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Expanding the Scope and Market of SIP Technologies:

A History of SIPs and CSIP Manufacturing, Construction, and Market Issues

A report by The Federation of American Scientists

The report begins with a background on the current options available to the industry, plant modifications to produce CSIP panels, and the current construction techniques of CSIP panels. This report includes an analysis of the current status of CSIP and non-wood facing SIP product in the Codes, a SIP constructability guide for builders and consumers, and an article describing the different testing options for products. The report is broken down to benefit the industry as a whole, manufacturers, architectural and engineering consumers, and end users. The report concludes with further research needs within the industry. The emphasis of this document is on CSIPs.

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FOREWORD

When this research first began, FAS leveraged the existing pool of certified CSIP companies to obtain information, test reports, and certifications. At that same time, we began investigating, deeply, the codes and code certification process for these new materials. We soon discovered that the existing industry had gross shortcomings in the code reports obtained to date. In that effort, we began discussing issues in the industry and inciting manufacturers of Fiber Cement Boards (primarily manufactured using the Hatcheck method) to start testing CSIPs with industry partners like the Structural Insulated Panel Association (SIPA).

The manufacturing of SIPs is not a scientific or precise endeavor and more research and development of standards and processes to move the industry towards a more standardized commodity is needed. However, there are respected strides in this area which the CSIP can leverage like the ANSI process that SIPA is undertaking and the accomplishment to get the International Residential Code (IRC) to recognize wood SIP walls. However, more work is needed and that work shouldn't be limited to wood facings.

The most significant contribution of this work is two-fold: envisioning how to grow the CSIPs industry, and determining how composite panels can approach more sophisticated markets.

In regards to the first contribution, the images and examples used in this document should help illustrate to the industry that there is intrinsic value in their products to grow new markets and these markets are fundamentally free of wood. And secondly, with the complex web of codes, manufacturer claims, and the role of the engineer, clear logic is needed to determine what systems are good candidates to be leveraged.

The purpose of this document is to be useful for the CSIP manufacturer to understand what is needed from their operations. It should also be a roadmap for the CSIP industry, which is slowly growing up, to compete not against wood but against commercial systems to see new markets and new market growth numbers. For many reasons, this document was written in a style to clearly explain the value of CSIPs in common English and using common terms.

SECTION 1: The Current Industry

This document is focused on a relatively new technology and a relatively small industry within the larger scope of the building community. In addition, by focusing on cementitious faced SIPs, this report is focusing on an even smaller segment of this already small industry. In order to properly focus this as a forward looking document, a review of the current SIP industry and its current practices is important.

This review will investigate the current industry, including material options, manufacturing processes, and current code and testing limitations. This review will serve to identify areas needed for market expansion and future development.

What are SIPs and CSIPs?

Commonly referred to as their acronym, SIPs, Structural Insulated Panels are high-performance composite building panels used in floors, walls, and roofs for residential and light commercial buildings. The panels are typically made by sandwiching a core of rigid foam plastic insulation between two structural skins. These panels are fabricated in a factory and shipped to a construction site, where they can be assembled quickly to form a tight, energy efficient building envelope.

SIPs are a simple composite sandwich panel. Sandwich panels are defined by the American Society for Testing and Materials as “The simplest structural sandwich is a three layered construction formed by bonding a thin layer (facing) to each side of a thick layer (core).”¹ The term “composite” is used to refer to any material in which two or more distinct materials are combined together, yet remain uniquely identifiable in the mix.

Many different variations (based on facing and core materials) are included in the blanket definition of Structural Insulated Panels. SIPs are currently made with a variety of structural skin materials, including oriented strand board (OSB), treated plywood, fiber-cement board (FCB), and metal. However, virtually any bondable material could be used as a facing. Core materials are typically Expanded Polystyrene (EPS), Extruded Polystyrene (XPS), or polyurethane, but other rigid insulation can be used as well. Facings and core materials are bonded by structural adhesives.

These variables allow for panels to be optimized to the very specific needs of any project. SIPs are typically available in thickness ranging from 4 ½ inches to 12 ¼ inches. Walls are commonly between 4 and 6 inches, and roof panels are generally thicker (often up to 12-inches, depending on climate conditions). SIP panels with FCB facings are typically cut to be 4 foot by 8 foot panels, but can be made

¹ ASTM C274 - 07 Standard Terminology of Structural Sandwich Constructions

as large as 9 ft. by 28 ft. with OSB facings. Custom sizes are also available, and many manufacturers offer curved SIPs for curved roof applications.²

This design flexibility, as well as the different combinations of core and facing materials, allow for unique performance properties for each project. These design capabilities, as well as the exceptional strength and energy saving potential, make structural insulated panels an important twenty-first century building material for high performance buildings.

It should be noted, however, that as a designed composite, SIPs are an assembled product. Therefore the subcomponents and assemblies must be tested, rather than evaluated theoretically.

A History of SIPs

SIPs were developed nearly 75 years ago when the Forest Products Laboratory (FPL), established by the U.S. Department of Agriculture, built the first SIP house in 1935 in Madison, Wisconsin. FPL engineers speculated that plywood and hardboard sheathing could take a portion of the structural load in wall applications. Their prototype SIPs were constructed using framing members within the panel combined with structural sheathing and insulation. These panels were used to construct test homes, which were continually tested and monitored for the next 31 years.³

Following the laboratory's experiment, Alden B. Dow – son of the founder of DOW Chemical Company and a student of Frank Lloyd Wright – created the first foam core SIP in 1952. By the 1960's, rigid foam insulating products were readily available, making for the production of SIPs as they are today.

In the early 1990's, advanced computer aided manufacturing (CAM) technology was developed. Using these systems, CAD drawings can be converted to the necessary code to allow automated cutting machines to fabricate SIPs to the specific design of a building. CAD-to-CAM technology has streamlined the SIP manufacturing process, bringing further labor savings to builders. This development coincided with the creation of the Structural Insulated Panel Association (SIPA) in 1990. SIPA was formed to provide support and visibility for those manufacturing and building with this emerging building technology, and to increase SIPs' market share through a partnership with the Engineered Wood Association (APA).

Taking advantage of the building industry's growing interest in energy efficiency, SIPA collaborated with the Partnership for Advanced Housing Technology (PATH) to "develop a set of prescriptive performance standards, which were submitted for inclusion in the International Code Council's Residential Code

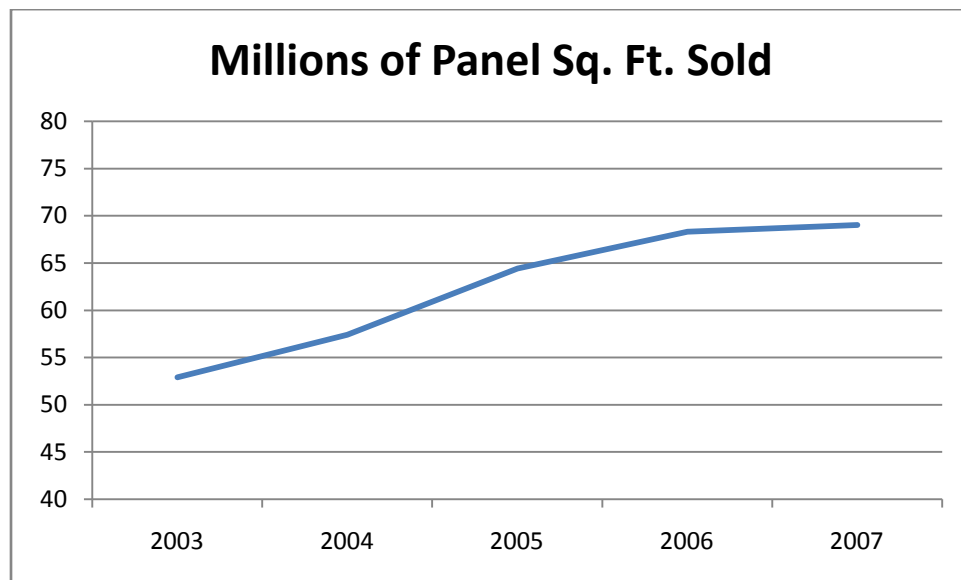
² "Structural Insulated Panels Product Guide". SIPA and APA. December 2007.

³ "The History of SIPs", <http://www.sips.org/>

(IRC).”⁴ Structural insulated panel wall systems were adopted into the IRC on May 22, 2007. The 2007 IRC Supplement and subsequent editions of the code include prescriptive standards for SIP wall construction in Section R614. For more information regarding the adoption of SIPs in building codes, as well as how this changes the design decision process.

The Current SIP Market

SIP usage has only been comprehensively tracked since 2003 through the industry trade association SIPA (Structural Insulated Panel Association).⁵ Currently there are roughly two dozen manufacturers and members in the association. This association represents some of the largest manufacturers in the industry but only a third to a half of the sandwich panel manufacturers in the US. Domestic SIP production has remained less than 70,000,000 sq. ft. of panels annually which can easily be converted, to roughly a \$350-525Mn market cap at market rates of \$5-7.50 per sq. ft. SIP’s annual growth has ranged from 4-12% annually, but the reliability of these numbers is questionable due to the small sample size and lack of standard reporting techniques.



The SIP market continues to be split evenly between residential and non-residential use. More importantly, SIPs can be broken down into panel types based on facings. Metal facings make up 50% of the market, followed by OSB on both sides (42%) and OSB on one side (6%). Plywood, fiber cement, and gypsum make up the remaining 2% of the market totaling 1.2M sq. ft. panels. Residential panel use is

⁴ Get Energy Smart.org “What Are SIPs?” <<http://www.getenergysmart.org/Files/Presentations/HY-R%20NYSERDA%20Presentation.ppt>> 8 Nov. 2006

⁵ This section relies largely on a 2006/2007 Survey of Production by SIPA.

typically limited to OSB where non-residential use is typically comprised of metal. Metal SIPs are also used extensively in the refrigeration industry and for patio enclosures.

Due to current code limitations, virtually all SIP buildings currently built are three stories or less.

Market Growth Potential

The CSIP industry currently faces many problems to growth, but carries significant potential for expansion within current markets, as well as to new markets.

There are currently many problems hampering the CSIP growth. There is currently a significant lack of awareness and technical knowledge from owners, builders, architects, engineers, and the general public. If these key members in the construction process aren't aware of CSIPs, they will not specify their use. Like any new building system, a builder's first SIP construction project will have problems. However, there is a fast learning curve to this, and the perception that SIPs are difficult to install must be avoided. This is compounded by a lack of case histories/studies, a lack of standardization and specifications within the industry, and a lack of knowledgeable installers. A disjointed and broad base of manufacturers further ingrains this problem.

SIPs are currently gaining a larger market share within the construction industry. This is good and bad for CSIPs. Due to the overwhelming trend within the SIP industry for OSB facings, a knowledge gap trending towards using OSB faced SIPs is emerging. Those who are using SIPs know how to use OSB SIPs, and the technical approach to this is becoming focused on one facing material. Despite these negative aspects, it is also spreading the knowledge and awareness of SIPs as a building technology independent of facing materials, making the recognition of and transition to cement-fiber facings easier within the building community.

In addition to a lack of knowledge and awareness, CSIPs face the need for industry development. The industry is currently small, and production capacity is small and slow to respond to market conditions. Also, the CSIP supply chain is in its infancy, with limited distribution channels, lacking a strong, national brand name. Growth will depend on finding more CSIP manufacturer start-ups to generate demand for the product, rather than waiting for the OSB faced SIP industry to recognize the new market value of CSIPs and expand to include the new material in production lines. The potential for product failure due to lack of technical background, a lack of continued service after sale, and the fact that a poor quality product could ruin the SIP industry's reputation are other potential problems for such a young industry.

Finally, testing, national standards, and inconsistencies in manufacturing facilities hold the industry from future growth. Significant areas regarding CSIP performance are lacking and must be completed. CSIP needs industry partnerships to leverage applications testing including more data on seismic, moisture, durability, and weatherization. This testing must also work towards informing a standardized process for

manufacturing and acceptance. CSIPs must develop and conform to consensus based reference standards (ANSI). This is important for a certified CSIP to spread and pick up new manufacturing locations. In addition, CSIPs must work for inclusion in the SIP Prescriptive Method for the IRC, and must work to extend a similar prescriptive method accepted into the IBC. CSIP must be a recognized substitute to SIP and not lacking code recognition/building size limitations. Without being accepted directly into the code, every CSIP project will require engineering to show compliance. Overcoming this step will make CSIPs much easier to be employed in a building project.

Despite these obstacles to market development and growth, SIPs offer many qualities that are becoming increasingly desirable, and there is tremendous opportunity for CSIPs in current and new construction markets. This is largely driven by the rapidly increasing energy and construction costs, and the ever-growing interest in “green” building. Due to their inherent energy-efficient performance and ease of construction, CSIPs are an attractive candidate for addressing these variables. When paired with other energy-efficient and green technologies, CSIPS provide the ability to impact building owner return on investment, asset turnover, opportunity cost, and leveraging the green building trend.

SIPs are characterized by their composite nature, which makes them versatile and desirable for both single- and multi-story construction. For both building types, CSIPs are an enabling technology which reduces substructure demands. CSIPs also offer an easily constructed, thermally efficient, cost-effective alternative building envelope. The wealth of materials and design options available in the SIP industry allows considerable flexibility for new SIP designs and uses.

CSIPs have significant development in order to fully embrace its potential. This research document provides a systematic compilation of the current industry, as well as a detailed description of its potential extensions. As such, this research serves as a benchmark evaluation of this potential, its potential applications, and future development.

Current Material Options in the SIP Industry

The three components of SIPs as composite sandwich panels are a structural facing, a rigid insulating core, and adhesive holding the pieces together. The variety of available materials allows panels to be tailored to each project and for component materials to complement each other, making the design of SIP panels both a material selection problem and a dimensional problem. For example, increasing the core thickness to obtain the proper design values can compensate for facing materials lacking rigidity. This flexibility allows materials to be chosen for reasons other than mechanical performance.

Material options are essentially boundless, and the rapid development of new technologies makes for new possibilities often. The following review includes the most common and readily available material options currently used in the SIP industry, and it highlights the material options focused upon in this research. With that in mind, it should not be considered complete or wholly inclusive.

Facing Materials

Ideally, SIP facings should have high stiffness (giving high flexural rigidity); high tensile and compressive strength; high impact resistance; quality surface finish; resistance to environmental impacts (chemical, UV, heat, etc.), and durability⁶

The following table reviews the most common facing materials in the current SIP market, examining their positive and negative performance attributes in regards to this list.

Common SIP Facing Materials		
Material	Pros	Cons
Oriented Strand Board	Inexpensive Readily available Recognized in current IRC code	Requires finishing on interior and exterior Swells with moisture
Cement Fiber	Will not rot, burn, or corrode. Acts as a finished interior and exterior More durable and last longer	Heavier than other options, and more difficult to handle Brittle, and prone to cracking during shipment More expensive than OSB
Metal	Inexpensive Readily available More durable and last longer	Requires finishing on interior and exterior
Others:	Magnesium Oxide board, fiber reinforced polymers	

Oriented Strand Board (OSB) facings are used for the vast majority of SIPs. OSB is an engineered wood product made from cross-oriented layers of thin, rectangular wooden strips compressed and bonded together with wax and resin adhesives. OSB has been extensively tested as a load bearing material, and is commonly available in large sizes. In addition, the Prescriptive Method Supplement to the International Residential Code (passed in 2007 and discussed in the next chapter) requires OSB facings for SIPs to be recognized in the code for 1 to 2 story residential buildings. In addition to OSB, SIPs are made with metal or cement fiber facings.

Metal SIP manufacturers often use aluminum as a skin material. This structural panel system is used in of both residential sites, such as carports or walkways, as well as industrial systems, such as the construction of cold storage facilities. Panel designers sometimes take advantage of their aluminum siding and connect panels metal to metal with pop rivets. Another option is a cam-lock system or a system in which internal gutters allow the panels to be reversed.

Cement Fiber Board faced SIPs (CSIPs), the focus of this research, constitute a smaller portion of the market than OSB, but carry many added benefits. CSIPs are typically manufactured of cellulose reinforced cement boards, for inside and outside skins. This is commonly referred to as fiber reinforced

⁶ Zenkert, D. "The Handbook of Sandwich Construction". Pg. 12.

cement, or simply fiber cement. For the sake of SIPs, fiber cement is determined by its compliance with several test methods and acceptance criteria. A table of required testing is included as “Required Evaluation of Cement Fiber Panels”.

Fiber-cement panels can have different finished looks, such as a wood grain, stucco, or smooth. With the smooth finish, stucco, vinyl siding, brick or stone can be installed.⁷ This removes the need for CSIP panels to be finished on the interior or exterior, making it the entire wall assembly and removing the need for several steps in the construction process. If CSIPs are used as the interior finish surface, cement fiber panels must perform specific testing for compliance must be demonstrated with the appropriate fire codes. For use as an exterior finish, cement fiber board must be tested for weather resistance, transverse and racking loading, and fire-resistance.

In addition to providing an interior and exterior finish, buildings constructed with CSIPs typically will last longer and require less maintenance than other types of SIPs panels. Cement fiber boards have a high resistance to moisture absorption, and will not support black mold growth. They are rot and vermin resistant, and are not significantly affected by water vapor. This, and other performance aspects, are verified).

Fiber-Cement Board used as skins does not rot, burn, or corrode. It has a higher fire rating than OSB faced SIPs, and in most residential applications no drywall would be necessary. This is determined by the fire-requirements of the applicable building code.

While there are many benefits to CSIPs, there are negative aspects as well. CSIPs are significantly heavier than OSB SIPs, weighing roughly 120 lbs. for a 4'x8' panel. This makes CSIPs more cumbersome during construction. In addition, due to free silica contained in most cement fiber, in field modifications (especially with rotary saws) should be avoided.

The final difficulty with CSIP panels is the relative infancy of the industry. There are currently very few manufacturers of CSIPs, and no large scale organizations, making prices higher for the consumer than need be, as well as making service less reliable and consistent.

⁷ <http://www.toolbase.org/Building-Systems/Whole-House-Systems/fiber-cement-faced-sips>

Required Evaluation of Cement Fiber Panels	
Interior Use	<ul style="list-style-type: none"> • ASTM C1325 - Standard Specification for Non-Asbestos Fiber-Mat Reinforced Cementitious Backer Units
Non-Structural Use	<ul style="list-style-type: none"> • ASTM C1325 with Section S1 and • ICC-ES AC376 – Acceptance Criteria for Reinforced Cementitious Sheets Used As Wall Sheathing and Floor Underlayment
Interior Finish	<ul style="list-style-type: none"> • ASTM E84 – Standard Test Method for Surface Burning Characteristics of Building Materials. <i>Refer to Section 2.2.8 for more information on this testing.</i>
Construction Types	<ul style="list-style-type: none"> • ASTM E 119 – Standard Test Methods for Fire Tests of Building Construction Materials • and comply with IBC Table 601.
Non-Combustible	<ul style="list-style-type: none"> • ASTM E136 – Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C
Vertical Use	<ul style="list-style-type: none"> • ICC-ES AC 376
Racking Strength	<ul style="list-style-type: none"> • ICC-ES AC 376 • Section 3.6/AC269 – Acceptance Criteria for Racking Shear Evaluation of Proprietary Sheathing Materials Used as Braced Wall Panels
Water Resistive Barrier	<ul style="list-style-type: none"> • Assembly Tests per ASTM E331 – Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference <i>under the conditions specified in IBC 1403.2</i>. • Tests on lateral resistance and nail head pull through shall be conducted with ASTM D1037 – Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials
Diaphragm Strength	<ul style="list-style-type: none"> • ICC-ES AC 376

Others: Magnesium Oxide board, fiber reinforced polymers, etc. Other facing materials are emerging in the industry, and the industry is readily trying to evaluate and adopt value added candidates. However, the rush to offer alternatives should sidestep the rigorous levels and layers of regulation and testing required certifying that a facing material is suitable for construction. Ultimately this will depend on carefully determining what tests are required to use the panels and what limitations the panels may have on the intended use (similar to developing required evaluation lists, like that above, for each new typologically different panel material). The industry must understand this requirement and respond to it as an industry through a consensus fashion.

Core Materials

The core is responsible for providing thermal insulation, counteracting shear and transverse forces, and resisting moisture penetration. The insulating core also reduces the panel's weight (compared to other prefabricated structural panel systems), making them easier to construct and better suited seismic regions.

The properties of primary interest for core materials are its density, shear modulus, shear stiffness, stiffness perpendicular to the faces, thermal insulation, and acoustic insulation.⁸ The following tables review the most common core materials in the current SIP market, examining their relevant performance requirements.

Minimum Properties for SIP Insulating Core Materials ⁹			
Insulation Material	Type I EPS	Type X XPS	Polyurethane
Min. Density, lb/ft ³	0.9	1.30	2.2
Thermal resistance of 1.00 in. thickness, minimum °F-ft ² h/Btu at mean temperature: 40°F	4.0	5.4	6.7
At mean temperature 75°F (23.9°C)	3.6	5.0	X
Compressive resistance at yield or 10% deformation, whichever occurs first (with Skins intact), minimum	10.0	15.0	19
Flexural strength, minimum, psi	25.0	40.0	30
Water vapor permeance of 1.00 in. thickness, max, perm (ng/Pa-s-m ²)	5.0	1.1	2.3
Water absorption by total immersion, maximum, volume %	4	0.3	4.3
Dimensional stability, (change in dimensions), maximum, %	2	2	2
Tensile strength, min. (ASTM D 1623), psi	X	X	35
Shear strength, min, (ASTM C 273), psi	X	X	25
<i>X = Please reference manufacturer's data</i>			

⁸ Zenkert, pg. 23.

⁹ This is compiled with a list of minimum values for each material, taken from ASTM C 578, ASTM D 1622, ASTM D 1621, ASTM C 203, ASTM D 1623, ASTM C 273, ASTM E96, ASTM C 27, and ASTM D2126.

Expanded Polystyrene (EPS) is the most common core material, used in 85% of all SIPs.¹⁰ EPS has a closed-cell, moisture-resistant structure composed of millions of tiny air-filled pockets. It generally does not release ozone-depleting chlorofluorocarbons (CFCs). The material is molded into large blocks and cut to the proper shapes for use in SIPs.

The IRC prescriptive method requires that SIPs use molded EPS as a core material. This EPS must meet the requirements of ASTM C 578 (referenced in “Minimum Properties for SIP Insulating Core Materials”) - a consensus document that was developed by producers of polystyrene foam, third party testing companies, regulatory agencies and insulation users in the North American region. It covers the types, physical properties, and dimensions of cellular polystyrene used as thermal insulation for temperatures from -65 to 165°F. Flame spread rating of SIP cores must be less than 75 and the smoke-development rating shall be less than 450, as tested in accordance with ASTM E 84. This does not mean all SIPs must use EPS, but if another material is used it must be shown by a professional engineer to be of equal or better performance.

Extruded Polystyrene (XPS) is similar to EPS, but is not used nearly as frequently within the SIP industry. XPS performs almost twice as well as EPS in regards to compressive strength, flexural strength, and shear resistance. However, these benefits come at a significant cost: sheets of XPS are far more expensive, can only be made 4 inches thick, and do not create a perfectly flat gluing surface. Because of this, XPS is used little in the SIP industry.

Polyurethane or polyisocyanurate (both commonly referred to as **urethane**) is also used by manufacturers as an insulating material. Liquid foam is injected between two skins under considerable pressure, which when hardened, produces a strong bond between the foam core and the skins. The foam core contains a blowing agent, some of which escapes over time, reducing the initial R-value of the SIP from about R-9 to R-7 per inch (2.5 cm) of thickness. Wall panels made of polyisocyanurate or polyurethane are typically 3.5 inches (89 mm) thick. Ceiling panels are up to 7.5 inches (190 mm) thick. These panels, although more expensive, are more fire and water vapor-diffusion resistant than EPS.¹¹

Adhesives

The final component of a SIP assembly is the adhesive that bonds the facing and core materials. Like facing and core materials, there are several options for this adhesive. This glue must:

- **Resist Forces:** The adhesive joint must be able to transfer the design loads (have the desired tensile and shear strength). They must resist buckling and racking forces.

¹⁰ Building With Structural Insulated Panels, Morley, Michael, Pg. 23

¹¹ From www.eere.energy.gov

- **Thermal stresses:** A frequent cause of de-bonding (and catastrophic failure of the panel) is due to thermal stress.
- **Moisture Penetration:** The adhesive must be able to withstand any sort of moisture penetration into the joint without de-lamination or bond failure.

Other variables of adhesive performance that must be considered include preparation requirements for application, required bonding pressure, adhesive viscosity, bond thickness, viscoelastic properties, and curing shrinkage.

Defining the common performance properties of available adhesives is difficult because each is a proprietary material. However, any adhesive used in the construction of a SIP panel must comply with ICC Acceptance Criteria AC05.

In the Plant: Explaining Factory Fabrication and Modifications to Run CSIPs

SIPs and CSIPs are prefabricated under factory controlled settings prior to use on a building site. The only code requirements of SIP fabrication is that the process must be conform to quality documentation in accordance with ICC Acceptance Criteria 10. Despite these variations from manufacturer to manufacturer, the process is relatively similar from one plant to another. However, as the focus of this document, CSIPs require plant optimization that most OSB companies are hesitant to address.

Prior to SIP fabrication, shop drawings are created for the panels, detailing exactly how each panel will fit into the overall building design. A count of the required panels, their dimensions, and special cuts (such as windows and doors) is created, and each panel is made specifically for its purpose within the building. These steps need optimization within the CSIP manufacturing to decrease the number of cuts and tooling in order to manage dust in plants.

Typically, fabricating EPS and XPS core SIPs begins by placing one facing out on the assembly area. The desired thickness of core material is run through a glue-spreading machine, where the appropriate amount of glue is spread on both sides of the core. The core section is then placed on top of the bottom facing, and a top facing is positioned. This assembly is moved into a press, which applies even pressure to the top and bottom facings. Specific adhesives require different pressure, curing time, temperature, and humidity, which are all controlled throughout the process.

After removing from the press, panels are set aside to cure for 24 hours. Once cured, they are moved to the fabrication section of the plant, where windows, doors, electrical chases, and other openings specific to the project are prepared per the shop drawings.

NOTE: The approach to urethane or isocyanurate panels is rather different. Panel facings are separated at the required distance by spacers and the mixed components of the foam core are injected between

the facings. As the foam expands and fills the void, the foam bonds the two facings together without the need for adhesive.

Once fabricated, SIP panels are shipped to a job site, where they are erected per the building design.

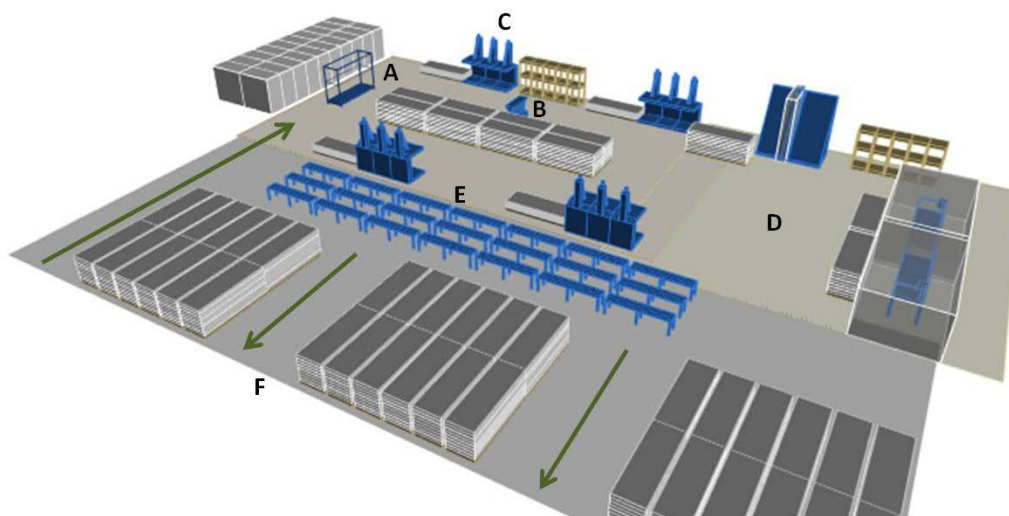
CSIP Plant Optimization

The manufacturing of CSIPs is typologically similar to Wood SIP manufacturing, yet the plant needs to address the following key issues and concerns:

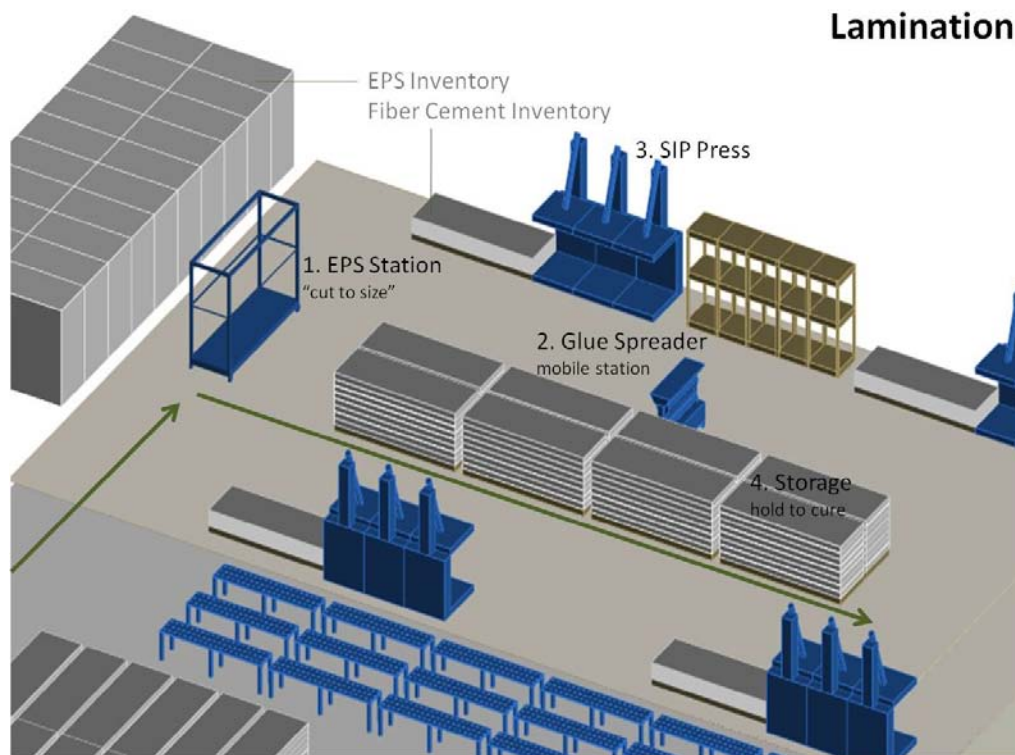
- Dust control – dust created by fiber cement contains free silica, which can result in silicosis if inhaled. Dust control for the fabrication and handling of FCB is critical;
- Smaller unit sizes – FCB comes in dimensions of 4x8, 4x10, 4x12 while OSB ranges as high as 8x24;
- Higher weights per unit size – FCB is denser than OSB; and
- Optimization of shop drawings to reduce fabrication.

Illustrated below is a 10,000SF SIP operation capable of producing roughly 1Mn Sft of panels per year (or roughly 250-300 single family affordable homes per year). The capital costs in equipment are in the (4) SIP presses (roughly \$25K each), the glue spreader (roughly \$5K), the equipment to properly cut EPS to the desired size (roughly \$5K), the vertical panel saw (roughly \$5K) and the CNC machines (roughly \$15K each). The total investment required is roughly \$150K.

Basic CSIP Manufacturing and Fabricating



This plant has three major zones: Lamination (where the panels are laminated highlighted by A,B,C), Basic Fabrication (where the panels are cut, highlighted by D), and Final Fabrication (where the panels are finished, labels, organized, and shipped, highlighted by E, F). These areas are outlined in the floor colors.



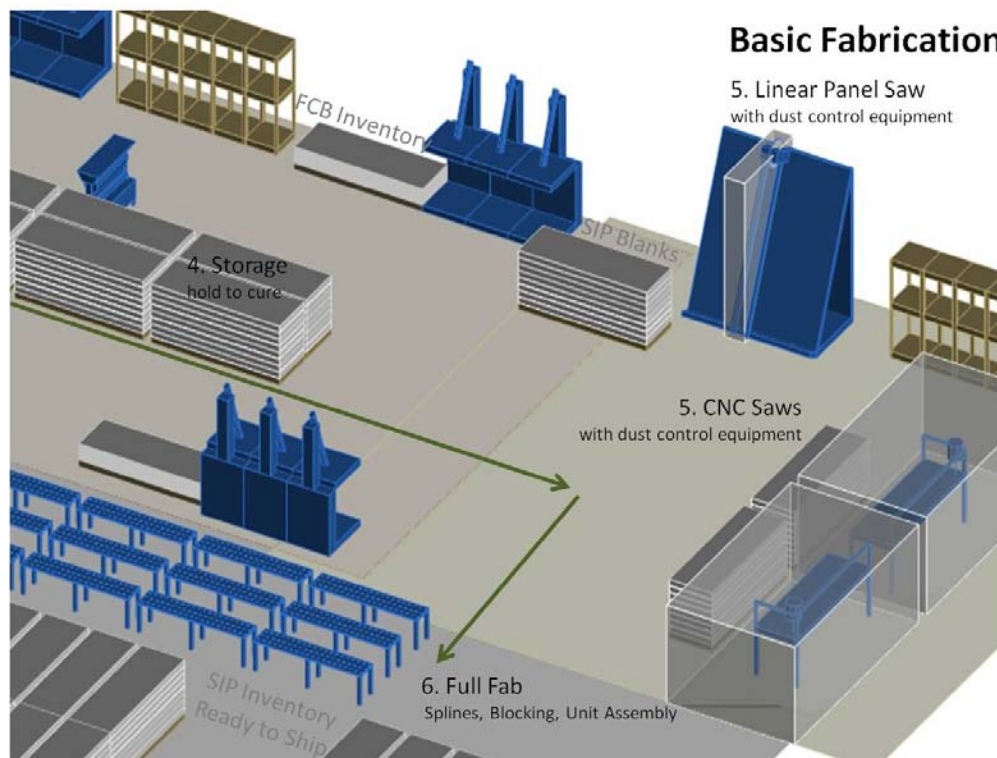
The process flow through the factory starts with the EPS station where large blocks of EPS are inventoried and are cut down to the desired panel size and thickness. Inventorying large blocks of foam is more cost effective than inventorying various sizes of foam. This station's primary tool is a hot wire station (1) which can rapidly tool the foam. From this station the foam is delivered to the individual panel presses (3).

The Panel Presses (3) are hydraulic presses which deliver a consistent amount of pressure to properly adhere the foam and the facing. Because the glue is exothermic and expansive, the press must offset this pressure. Large bundles of fiber cement board, which by themselves are extremely heavy, are pre-positioned at the head of the presses to reduce time and fatigue. Additionally, the mobile glue spreader (2) is prepositioned near the press and foam to decrease travel distances. The presses should contain built in pallets, so that the removing the CSIPs from the presses is a nominal task.



Typical SIP Press

The presses are loaded by laying one sheet of FCB on the press from the co-located bundles, spreading glue on the foam using the co-located glue spreader, placing the foam on top of the FCB and registering the final face of FCB on the foam. This sequence is repeated until the press is fully loaded. The hydraulic press is preloaded (to take up any slack) and the panels are re-registered to ensure they are uniform. The hydraulic press is set to the desired pressure and left from 2-3 hours or until the glue is fully cured. The crew then moves to the next press location. Four presses are shown above for a total rate of 100-120 panels a day (3 batches for 4 presses each). This process is a small batched process and is not continuous. After the presses are unloaded, the product may be held for 24hrs to fully cure (4). This is common in some operations.



The next station is Basic Fabrication where CSIP blanks (panels without any tooling) are cut to size or penetrations are cut out. These two tasks are the most critical in CSIP operations because they must be done with proper dust control. There are two primary cutting tools – 5. Linear Panel Saw and CNC Saws. The Linear Panel saw should be used when only one or two straight cuts are needed. A modified panel saw should be used with a blade capable of cutting a 6” panel. Next, for more complex cuts, a small CNC Saw should be used with a tool capable of cutting through a 6” panel. These CNC Saws are typically the lower end equipment (max of 4x12). Next the panels move to final or Full Fabrication where the splines are cut, the panels are checked and labeled, and assemblies are cut, caulked, and primed (if allowed for). The rate by which Basic Fabrication runs is 12 panels per hour. Because many project use blanks alone, this may or may not be the bottle-neck and is the primary reason shop drawing optimization (to reduce cuts) is necessary.

These panels flow, at this stage, on gravity conveyors to various stations.



Linear Panel Saw, CNC Saw, Gravity Conveyor

Staffing is based on the education of the work team. Lamination requires 2 operators and 1 shop hand; Basic Fabrication requires 2-3 operators and 1 shop hand. A general manager is needed for the plant. Shop drawings can be done in house or remotely, by consultants, or outsourced. Therefore, a total of 6 operators and 4 shop hands, 1 general manager is needed.

Current Use and Construction of Panels

Currently, CSIPs are limited to wall panel use in residential construction (governed by the IRC). Some companies detail roof panels, but there is a lack of comprehensive testing data on this use and use as a diaphragm. Because fiber cement facing panels are limited to small dimensions (i.e. 4x8, 4x10, and 4x12), all joints, connections, and penetrations must be properly managed, detailed, and constructed to provide adequate connection strength, proper moisture and water management, and reduced thermal shorts and bridges.

The following is a detailing guide which is typical in the industry. These details have been tested to all the relevant standards and have passed the weather barrier and thermal barrier tests. These details make some basic assumptions that,

- **Monolithic panels** makes up roughly 75% of typical residential envelopes with 90% of the panel being undisturbed (i.e. unbroken area);
- Therefore, the **splines and connection locations** (horizontal or vertical) to other substructures makes up remaining 10% (nailed connection area) with localized drainage planes; and,
- **Penetrations** make up roughly 25% of all envelopes and should be limited to full panels (i.e. penetrations do not span multiple panels) with localized drainage planes and redundant layers of flashing.

For manufacturers, this means that the layout panel shop drawings are based on window and door openings. These assumptions allow designers to assume that the splines, connections, and penetrations can be made with localized drainage planes – multiple layers of water management and pressure equalization to allow moisture to move freely outside of the panel core and adding additional layers to prevent water infiltration. Additionally, these detailing standards will encourage drying to the exterior and proper moisture management in any potential cavity. Basic standards include connections to substructures, splines, and all blocking in penetrations by the following standards. However, always consult your manufacturer for particular product specifications.

- **Edge:** 8d common nails, 6" o.c., ¼" from edges, 2" from corners;
- **Splines:** 5.5" 19/32 OSB, 8d common nails, 6" o.c. ¼" from edges, 2" from corners; and,
- **Finishing:** Prime entire envelope and openings with CMU block filler or equivalent to repair and patch any disturbed areas. Proceed with localized drainage planes and spaces around all penetrations.

The following section discussing wall panel installation uses the aforementioned standards unless otherwise noted.

Installation of Typical Wall Panels

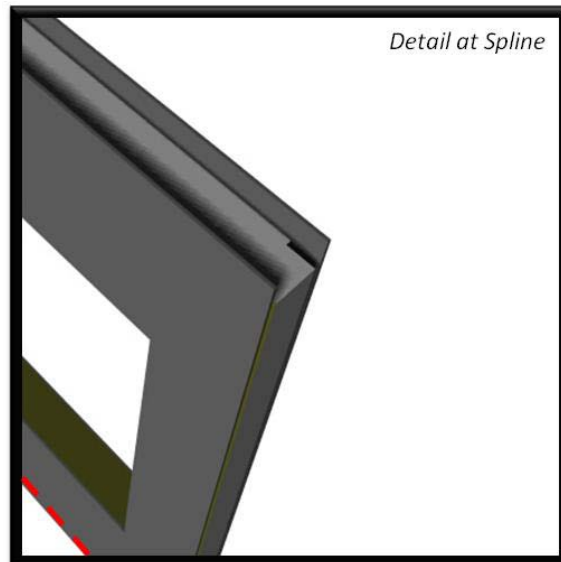
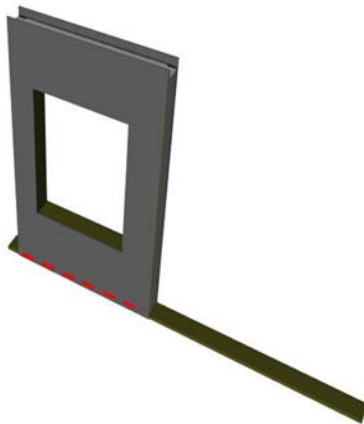
1. Installation of bottom plate: Connection to foundation system or horizontal plate: Bottom plate is installed with a capillary break between plate and foundation. The bottom plate must be fastened and properly sealed to prevent air infiltration. Where required by code, metal Z-flashing can be installed on the outer face of the top plate-SIP panel for proper water management.

1. Installation to bottom plate



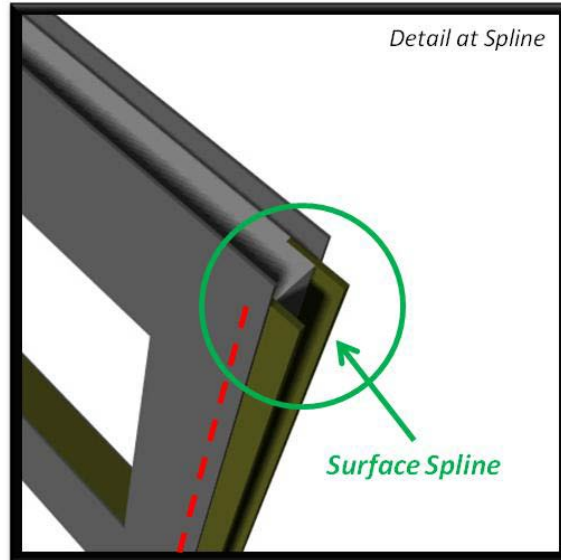
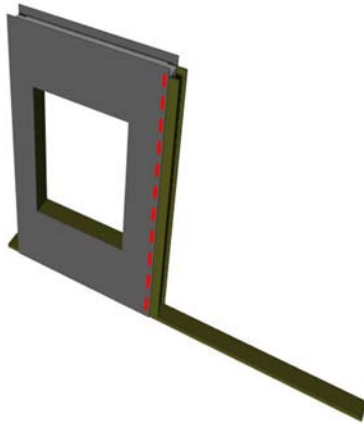
2. Installation of panel one: CSIP panel slips over bottom plate. Blocking installed in window penetrations at window opening. Note: window blocking installed at factory.

2. Installation of panel one



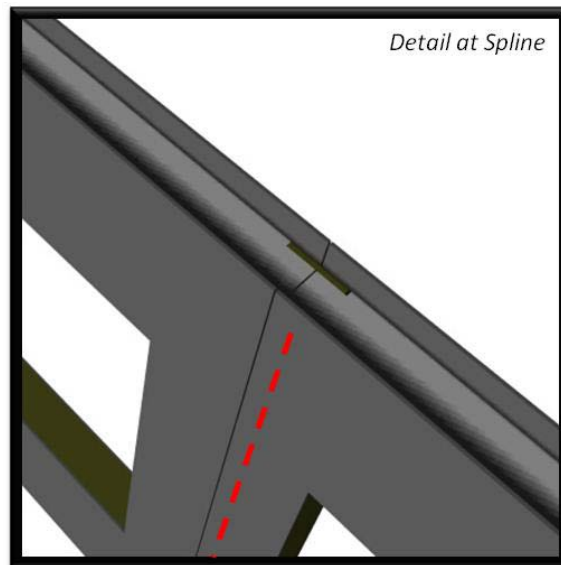
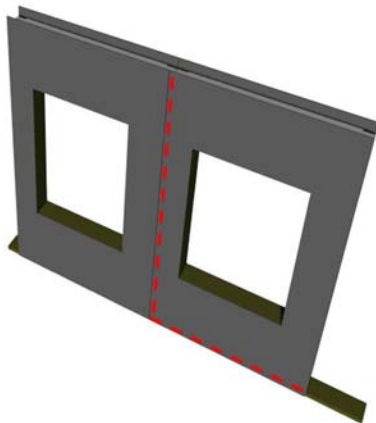
3. Installation of spline: Splines are comprised of 19/32 OSB or better splines, cut 5.5" wide to prevent telegraphing or "saw tothing" of panels. This detail recognizes the industry need to give generous spline widths and meet code minimums for fastening depth through the spline. More spline types are detailed later in this report.

3. Installation of splines



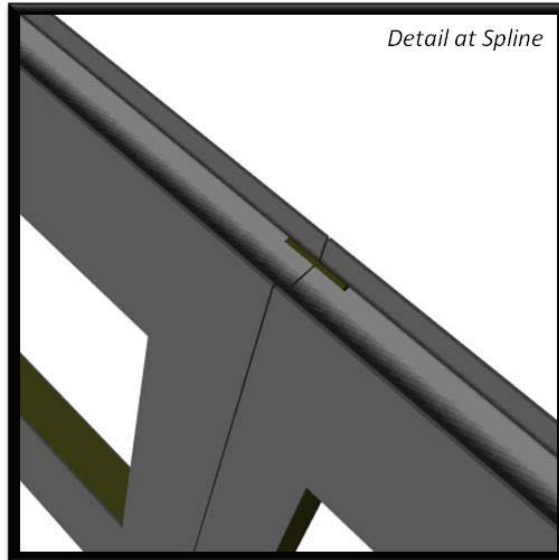
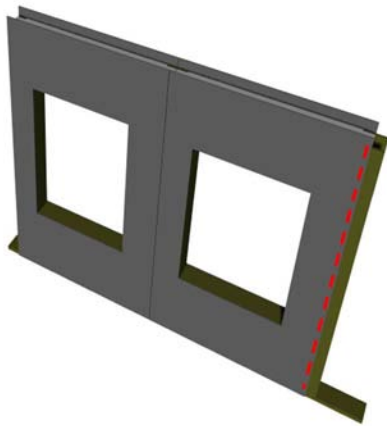
4. Installation of panel two: Refer to step 2.

4. Installation of panel two



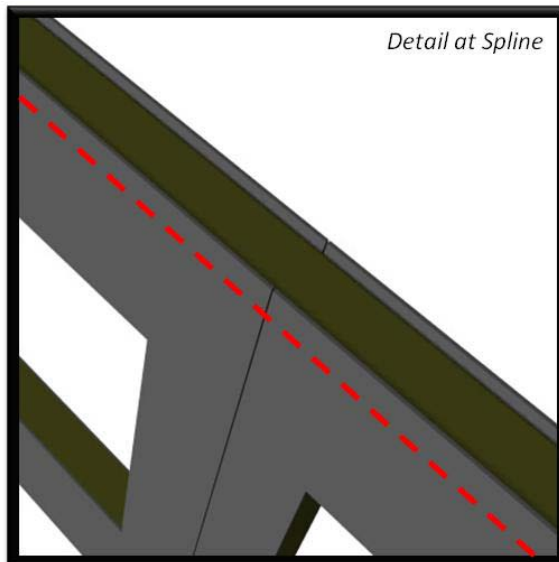
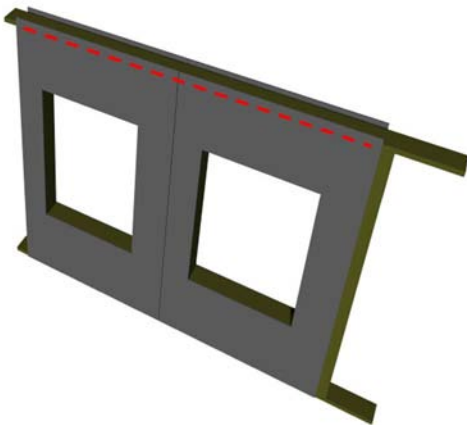
5. Installation of panel splines: Refer to step 3.

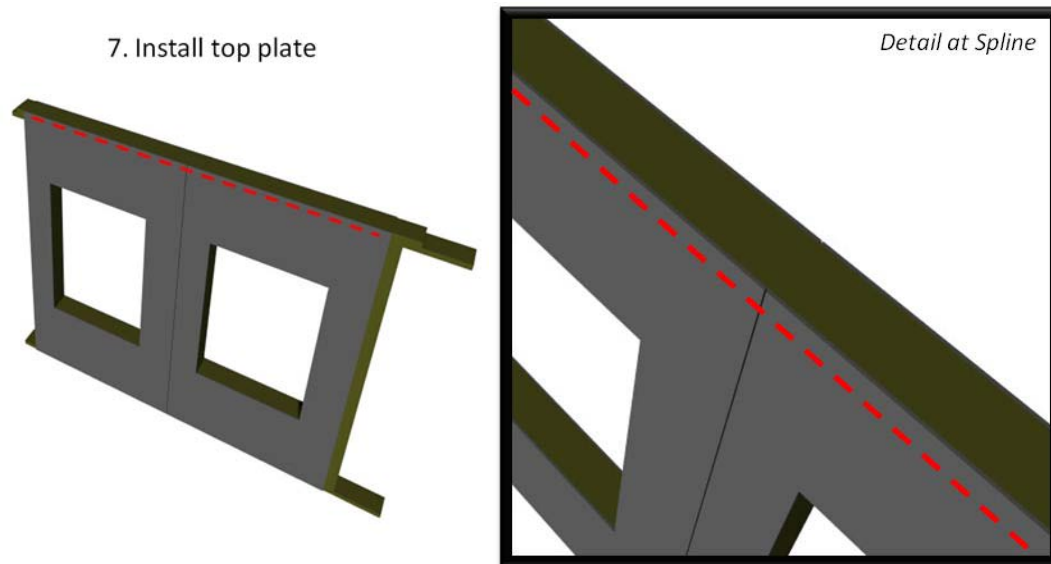
5. Installation of splines



6 & 7. Installation of band plate and top plate: installed with 2x6 #3 or better. Plates must be tied together horizontally with and to the panel, and must be tied together vertically.

6. Install band plate





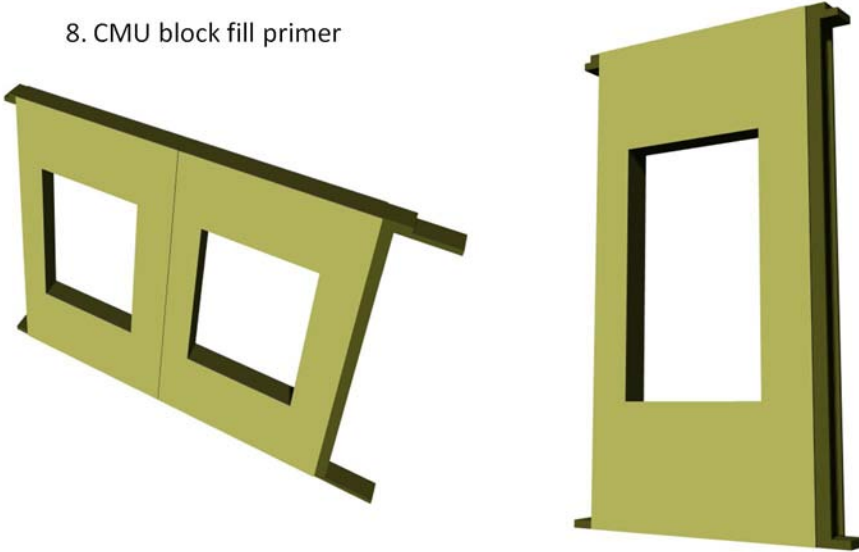
This concludes installing a basic panel. Subsequent panels tie directly into the installed panel to continue the wall plane.

Construction of Weather Barrier and Window/Other Penetrations

The construction of the weather barrier follows. These details are shown both as an individual panel and two combined panels.

8. CMU block fill primer: After all panels are set, the panels are primed to provide a continuous unbroken base finish using CMU block filler in all exposed surfaces and joints and potential surface defects and irregularities. The simple goal in this step is to specify a paint to fill imperfections, reduce water infiltration in pores, and seal all cracks and constructability issues. These paints should be specified with some latex qualities – i.e. elasticity to stretch and give.

8. CMU block fill primer

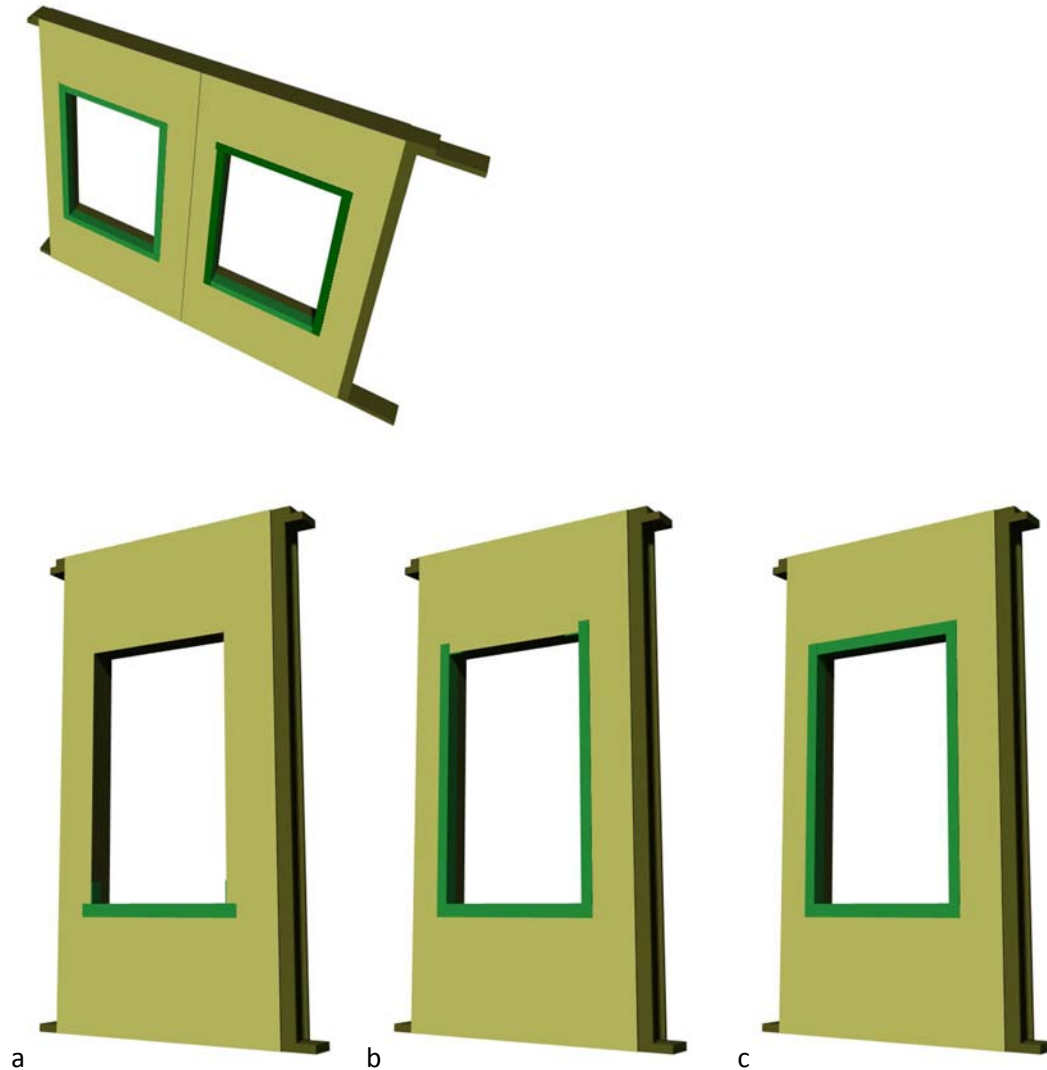


9a. Installation of pan flashing: Using self-adhering flexible flashing for pan flashing such as Dupont FlexWrap or StraightFlash to protect horizontal penetrations. This flashing must be cut ends to extend past window openings and fasten inner legs into jamb (minimum 1") by slitting the flashing so one leg turns up the jamb and the other leg continues straight on the wall. Pan flashing must fit tight into the opening. When using multiple pieces, pan flashing must overlap 3" min. Note: if mechanical fastening is required, fasten only at the exterior face.

9b. Installation of jamb flashing: Using self-adhering flexible flashing protect vertical penetrations by cutting the flashing ends to extend past window open and fasten inner legs into jamb/head (minimum 1") by slitting the flashing so one leg turns up the jamb and the other leg continues straight on the wall). The flashing must fit tight into the opening; therefore, when using multiple pieces, pan flashing must overlap 3" min. Note: if mechanical fastening is required, fasten only at the exterior face.

9c. Installation of head flashing: Using self-adhering flexible flashing protect horizontal penetrations by cutting flashing only fit into window to cover unprotected areas (i.e. use piece to overlap only in section unprotected by head). The flashing must fit tight into the opening. When using multiple pieces, pan flashing must overlap 3" min. Note: if mechanical fastening is required, fasten only at the exterior face.

9. Installation of flashing



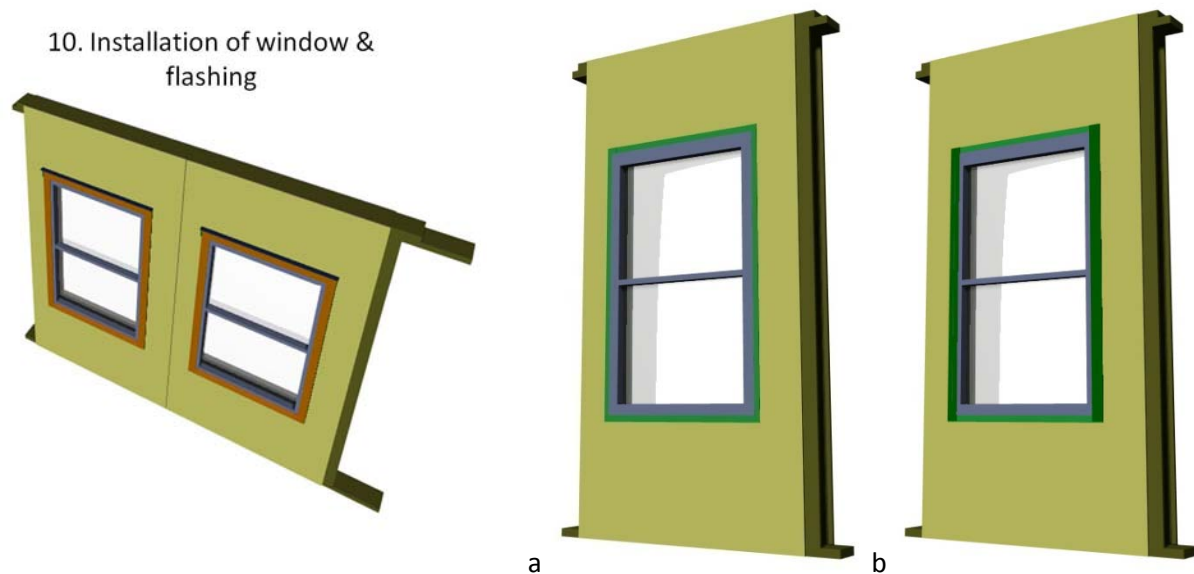
10a. Installation of window set: Only use windows with outer flange (i.e. nailing flange). Be sure to back caulk window by applying sealant at window jambs and head. Use sealant at sill where required. Then set window by installing the window level and plumb per manufacturer's specifications.

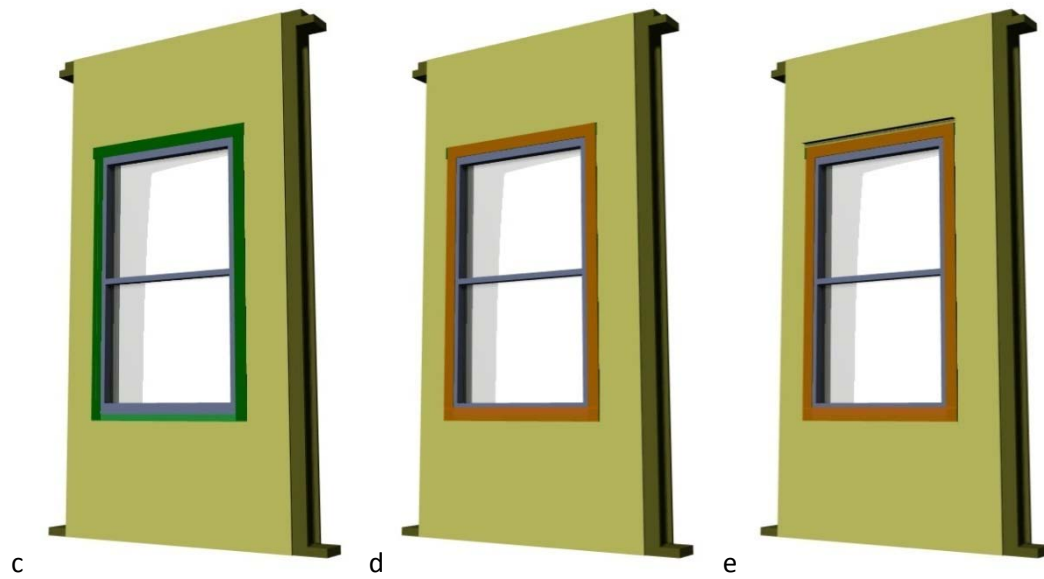
10b. Installation of jamb flashing: Using self-adhering flexible flashing protect vertical penetrations. Use continuous, unbroken piece (no mechanical fastening) and extend flashing above window a minimum of 1" and below the window a minimum of 3".

10c. Installation of head flashing: Protect horizontal penetrations using self-adhering flexible flashing. Use continuous, unbroken piece (no mechanical fastening) and extend flashing 2" past jamb flashing.

10d. Installation of localized drainage space: Using polypropylene mesh deflection and ventilation system (or equivalent product to capture a void), provide a space for drainage to occur between the flashing and the trim pieces. An ideal product would be an equivalent tape, which could be stapled over the drainage planes to promote positive drain action within this space. This creates a cavity space to help manage water flow and drying to the outer wall.

10e. Installation of metal flashing: Install metal cap flashing above topmost trim by caulking joint between the metal flashing and the fiber cement SIP. This is an important step because the drainage spaces and planes will allow any trapped water to move out of the assembly. However, the caulk will reduce the amount of water entering the space and should be considered best practices.

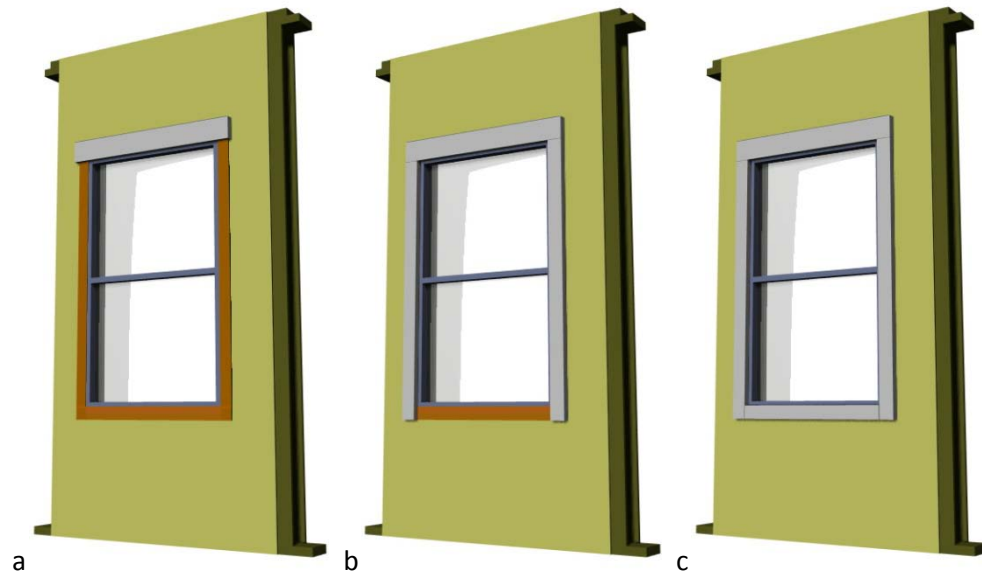




11. Installation of trim (a, b, c): Allow for positive drainage at all abutments and surface caulk all joints and other distortions. Follow manufacturer's specifications.

11. Installation of trim





SECTION 2: Code Issues

One of the most important aspects of the current CSIP industry is that of code requirements and limitations. There are two primary codes governing CSIP buildings: the International Residential Code, for residential buildings below three stories, and the International Building Code (IBC) for all other buildings. The majority of current CSIP buildings are governed by the IRC. CSIPs are not called out through a prescriptive method in the IRC, but the requirements are understood within the industry. CSIPs must be tested to demonstrate to show compliance with specific acceptance criteria. How this is done becomes an issue for manufacturers, which will be discussed in this section.

Like the IRC, CSIPs are not called out in the IBC, and compliance must be demonstrated as equivalent. However, the requirements in the IBC are much more stringent than those in the IRC. Because the majority of buildings do not fall within the scope of the IBC, its regulatory issues are less understood for CSIPs. However, if the CSIP industry is going to expand to larger markets and scopes of use, these issues must be understood and dealt with. In this report, the IBC is used because it is more stringent than the IRC. It should be noted that despite this baseline, however, that the local codes dictate the decisions and understanding of CSIP performance.

The code issues in regards to both codes should be seen in three ways:

- those that must be handled by the industry at large: limitations on the use and application of CSIPs to different buildings. How can CSIPs be used?
- those that must be handled by individual manufacturers: How does a manufacturer verify that a product complies with these codes?
- how a design professional approaches a product in light of these concerns.

Code Issues for the Industry

One of the current major limitations on CSIPs is code limitations. Currently, CSIPs are used in residential construction under three stories. While the applicable building code for a project is determined by the municipality providing the building permit, the majority of municipalities have adopted the I-Codes, a set of codes created by the International Code Council (ICC). The ICC has created distinct codes for One- and Two-story residential construction (IRC), larger commercial and industrial construction (IBC), energy conservation in buildings (IECC), and more.

For wider adoption within residential markets, the CSIP industry must work towards inclusion within the IRC. This should be done either by integrating itself into the SIP Prescriptive Method developed by SIPA and the APA, or by creating its own prescriptive method. This would be a major step for the industry, as

it would allow builders to specify CSIPs without relying upon an engineer to demonstrate compliance to the code.

For the industry to expand its scope of use into new markets, several issues within the scope of the IBC must be addressed. These include:

- Combustibility based on ASTM E136 - 04 Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C and ISO1182 Non-combustibility Test for Building Materials limit CSIPs to...
 - In the IBC, Type V construction (three story max per Table 503) and have limitations stipulated by the building code in Chapter 6, Types of Construction and Chapter 5, General Building Heights and Areas; or
 - In the IBC, Exterior wall coverings in Type I buildings per 603.1.10.
- Fire Rating based on ASTM E119 - 08a Standard Test Methods for Fire Tests of Building Construction allow CSIPs to...
 - Show conformance to IBC 2603.4 Thermal Barrier. Note: each vendor must show compliance as a thermal barrier.
- Weather Barrier based on ASTM E331-00 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference allow CSIPs to...
 - Show conformance to IBC 1403.2 as a weather barrier resistant to water intrusion and vapor permeance to allow drying while reducing vapor intrusion.
 - It should be noted that weather barriers are manufacturer/vendor specific. Typical details shown in this report have been known to pass the weather barrier requirements, but each vendor must show compliance as a weather barrier.
- Fiber Cement Siding under IBC 1405.15 Fiber Cement Siding as a Metal Veneer assembly (requiring the same fasteners, finishes, and other performance requirements of Metal Veneer assemblies.

Please note, that each manufacturer should supply data (through evaluation or certification reports) that their proper testing has been completed and verified demonstrating their system is compliant with the respective codes in the ICC.

Code Issues for Manufacturers

The primary code concern for individual manufacturers is how to demonstrate their product's compliance with applicable codes. There are two pieces to this: the development of acceptance criteria, outlining what constitutes an acceptable panel; and the process by which panels are evaluated to meet this acceptance criteria.

The values determining how CSIPs perform under these forces will be determined either by the prescriptive code, or by test results from defined testing identified in the applicable acceptance criteria. Under the auspices of ICC AC04, the International Code Council compiled acceptance criteria for SIPs in order to “provide a procedure for recognition of sandwich panels in ICC Evaluation Service.”¹² In addition to the principle tests described below in detail, the AC04 Standards also feature information on connections, openings, plumbing and electrical installation, and other common conditions.

With the acceptance criteria defined for CSIPs, a manufacturer must demonstrate the compliance of its product. There have been several approaches created to do this, and while they are often similar, they are not completely comparable. This section will explain two processes for manufacturers to demonstrate code compliance, as well as the costs and benefits of each. By making these distinctions clear, a product manufacturer will be able to optimize the process of product certification and significantly reduce the amount of time and money spent.

Code Compliance – Where the Pieces Fit

While final decisions of code compliance on all levels are left up to local code officials, several avenues have been created to aid this decision process. These options can be seen as two basic approaches: product evaluation, and product certification. Two subsidiary companies of the International Code Council (ICC)¹³ – the ICC-Evaluation Service (ICC-ES) and the International Accreditation Service (IAS) – each provide manufacturers with one of these methods to demonstrate to builders and code officials that their product meets applicable standards. As subsidiaries of the ICC, they both carry the weight of an industry recognized, impartial third party dedicated to ensuring building safety through building codes. The two provide a similar outcome, but the process and approach of each makes them very distinct and separate services.

¹² ICC Evaluation Service, Inc., “Acceptance Criteria for Sandwich Panels: AC04”, February 2004

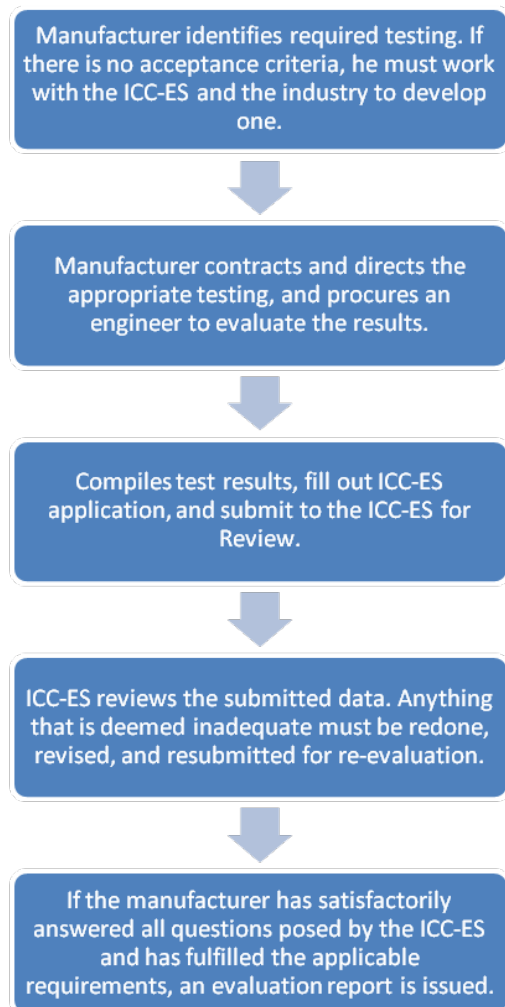
¹³ The ICC is a non-profit organization dedicated to consolidating building codes. It has created a series of comprehensive codes (the I-codes), most notably the International Building Code (IBC) and the International Residential Code (IRC). Most U.S. cities, counties, and states have adopted and ratified the I-Codes, modifying them to reflect local circumstances as needed. This allows code enforcement officials, architects, engineers, designers and contractors to work with a consistent set of requirements throughout the United States.

Product Evaluations and The ICC-ES Evaluation Report

As its name suggests, the ICC-ES is an example of a product evaluation service. Essentially, the organization verifies that specified testing has been done to show a building product, component, method, or material performs at a level compliant with applicable codes. If this is found to be the case, the ICC-ES issues a report to this affect, acting as a credible argument to agencies that enforce building regulations to help determine code compliance. This is valuable to a product manufacturer, as it allows for the easy implementation of their product within the scope of the I-Codes (codes used in the majority of the country that are developed by the ICC).

The process of obtaining an evaluation report begins long before a company submits an application to the ICC-ES. Prior to this point, a product manufacturer must select a testing laboratory, contract and direct the appropriate testing, and procure an engineer to evaluate the results. For new and innovative products where accepted testing criteria does not exist, the applicant must work with the ICC-ES Technical staff and the industry to establish one.¹⁴ These test results are then documented, compiled, and submitted to the ICC-ES. If the product is new or innovative, the burden of what to submit to the ICC-ES also falls on the company's hands.

Upon receipt of this information, the ICC-ES evaluates the data to check compliance with either the building code or the ICC-ES acceptance criteria provided. All data submitted by the manufacturer and each decision made by the applicant in the testing process is scrutinized. Anything that is deemed inadequate or incomplete must be redone, revised, and resubmitted for re-evaluation. Depending on the product, the manufacturers grasp on required testing procedures, and existing precedents for a product, this process can be especially long and circuitous. Once the applicant has satisfactorily answered all questions posed by the ICC-ES and has fulfilled other applicable requirements, an evaluation report is issued lasting for one year (and reissued at one or two year intervals).¹⁵



ICC-ES Product Approval Process

¹⁴ ICC-ES Criteria Development: http://www.icc-es.org/Criteria_Development/

¹⁵ More information on the ICC-ES approval process can be found online at <http://www.icc-es.org>

This end product is a positive step for a manufacturer, but there are sacrifices of time and effort made in this process. The length of the evaluation process depends heavily on such factors as the complexity of the product under consideration; whether an acceptance criteria needs to be developed and approved; and the applicant's promptness and thoroughness in submitting data. For new or innovative technologies, a lengthy wait is all but ensured. Even with these variables in a manufacturer's favor, there is likely a long turnaround that is both costly and draining for the manufacturer. According to the ICC-ES, the average time required to get a new ICC-ES report ranged from three months to 23 months during the organizations first two years. The average evaluation time for products ultimately found to meet code was 11 months.¹⁶

In addition to these holdups, this evaluation report merely provides a "snapshot" in time. It only shows that at the moment the testing was conducted, the product performed at a level that is acceptable by code. While this is a good thing to show, it is far from ideal. It does not assess ongoing quality standards, and does not verify that the product delivered will be comparable to the one tested. In addition, this approach does not allow a manufacturer to easily adapt his certification with changes to a product, code requirements, etc. All things considered, an important end goal is reached for a manufacturer by obtaining an ICC-ES report, but the path taken to get there is far from optimal.



IAS/ISO Guide 65 Certification

Product Certification, the IAS, and ISO Guide 65 Product Certification Agencies

The other route provided to manufacturers is product certification. One means of doing this is through a program conducted by the International Accreditation Service (IAS). Through a program initiated in early 2007, IAS accredits testing agencies as Product Certification Agencies (PCAs) under International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) Guide 65, General Requirements for Bodies Operating Product Certification Systems. With this accreditation, these PCAs

¹⁶ <http://www.icc-es.org/Help/about.shtml#reports>

are able to offer a much different avenue for manufacturers to demonstrate their products meet applicable codes on an ongoing basis.

This difference stems from the basic relationship between the evaluation agency and the manufacturer, especially in regards to who must demonstrate a product's compliance. While the ICC-ES requires that the manufacturer prove to an evaluation service that a product performs up to code, the ISO sponsored route places that burden on the certification agency. The PCA is directly responsible for all aspects of the evaluation process, from identifying and running the appropriate tests (i.e. following the I-code acceptance criteria) to documenting the results and delivering final product review and final product certification. The slow and bothersome back-and-forth process of identifying and filling in data gaps present in the ICC-ES approach is eliminated, significantly expediting the process and reducing the expense of obtaining a certification report (depending on lab turnaround time and schedules). This allows manufacturers to concentrate on their core competency rather than on product certification.

In addition to a more efficient delivery of an accepted initial certification, future certification measures are optimized by this process. By being so heavily involved in the entire process, the certification agency becomes intimately aware of the product's configuration, uses, and limitations. This allows the certification agency to respond quickly and competently to changes in the product, to changes in applicable codes, or to inquiries by the end user. Also, the PCA has the ability to pull a report, putting a company in bad standing and effectively cutting off their ability to sell a code compliant product if they deviate from the certification report, the in-plant quality control program, or take shortcuts that subvert the life safety goals outlined by the I-codes.¹⁷

Case Study: Florida

This important distinction between product evaluation and product certification is shown in the state of Florida's Building Code. The state of Florida's Building Code is independent from the IBC or IRC, and does not refer to the ICC-ES or the IAS, but still clarifies the different routes for product approval and treats each differently. Within the Florida code, a building product must receive local code approval to be used (statewide approval is an optional secondary measure). There are several acceptable methods for demonstrating this: a test report, an evaluation report from an evaluation entity (ICC-ES, Miami-Dade, etc.), an evaluation report from a Florida architect or engineer, or a certification mark or listing. If the evaluation report includes engineering analysis of any kind--which most do--then it must be sealed by a FL registered Engineer. Seen simply, these are essentially two methods: evaluation processes, and a certification process, each roughly comparable to the ICC-ES and the IES/ISO Guide 65 routes.

¹⁷ More information about IAS/ISO Guide 65 Product Certification can be found at http://www.iasonline.org/Product_Certification_Agencies/guide65.html

The first three methods are product evaluation approaches, in many ways comparable to the ICC-ES route. A product must be tested to specified conditions in a standardized way, and then the ICC-ES, a Florida architect, engineer, or testing agency must sign off on the product's compliance to code. To do this, however, the testing agency or evaluating architect or engineer must certify independence from the manufacturer. Also, products will only be accepted if manufactured under a properly audited quality assurance program. Any changes to approved products or installations must also be approved by a testing agency, architect or engineer. This is essentially this allows another independent party to take assume the role of the ICC-ES, and this evaluation becomes a piece of the argument for a product's local approval.

The fourth option is that of a certification agency. Like the ISO Guide 65 program run by IAS, this approach consolidates all the necessary components in one place. In this case, a certification agency evaluates products based on test results and/or rational analysis; conducts quality assurance; certifies compliance with standards; and lists and labels products. For all purposes, this is identical to the IAS Product Certification Agency, as an agency must follow the same set of guidelines (ISO Guide 65) to be approved in the state of Florida. This streamlines the process, as products bearing a listing or label from an approved agency require no further documentation to establish compliance with the code.¹⁸

While this may seem small, this approach to product certification in the Florida building codes demonstrates the important distinctions between both product approval options. It also shows the extra steps required to verify an evaluation process, further evidence of the different level of ease and simplicity inherent in each model.¹⁹

Impact Potential for Product Approval and New Market Entry

Seen simply, the two product approval processes are similar. In each case, a manufacturer receives an industry recognized and respected verification that his product performs up to code, allowing for easy local approval and use under the I-Codes. However, the balance of responsibility and the short and long term value of each process is significantly different. ICC-ES product evaluation requires more effort on the part of the manufacturer, takes longer to complete, but is currently more readily recognized throughout the industry. The IAS's PCA certification takes less effort on the part of the manufacturer to "figure things out," is typically completed faster, and the ongoing relationship between the testing facility and the manufacturer expedites future developments. However, IAS/ISO Guide 65 certification is a relatively new option, making it less recognizable throughout the industry (although no less legitimate). Regardless of a manufacturer's decision and circumstances, having multiple options allows

¹⁸ http://www.dca.state.fl.us/fbc/committees/product_approval/Local_Product_Approval0606.pdf

¹⁹ More information about Florida code approval can be found at:
http://www.dca.state.fl.us/fbc/committees/product_approval/2_product_approval.htm

for the optimization of the evaluation and certification process, and a means for potentially drastic savings in both time and money.

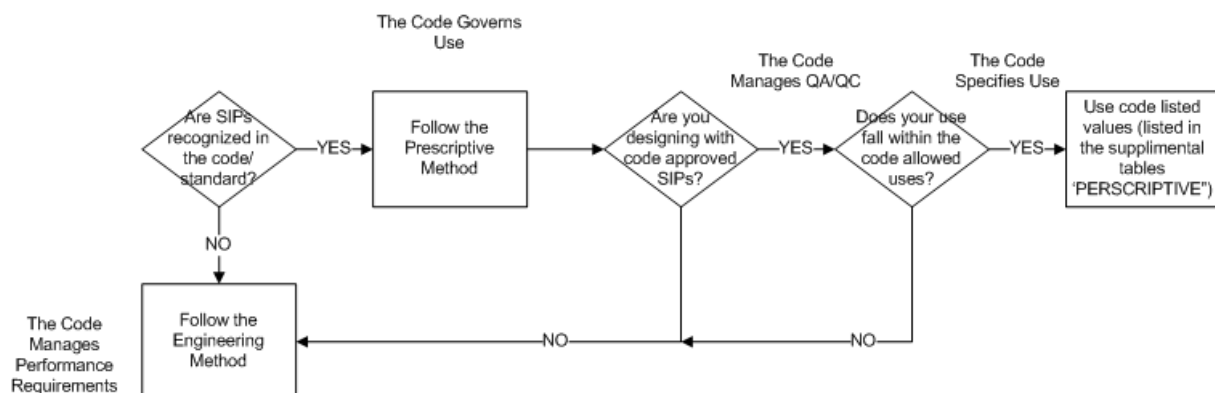
Code Issues for Design Professionals

The first issue that designers must consider in the design process is the selection of a candidate CSIP for application. Quite simply, the engineer must select a CSIP with a demonstrated track record in residential and commercial construction. It should be noted, that while the SIP industry is flourishing, few manufacturers produce CSIPs, but it is the goal of this document to highlight their value and unique issues to educate both existing manufacturers and architects, engineers, and consumers.

Panel system manufacturers must be evaluated to insure their products are compliant to the model codes, have an ongoing quality assurance and quality control program, and have tested design values for the system's performance. The first role of the design professional is to evaluate the available panels and choose a candidate by utilizing the decision tree to validate candidate panel systems. There are three methods to validate a CSIP system as a candidate system:

- A. Using code recognized systems (currently, CSIPs are not recognized specifically in the model codes),
- B. Using a certified, listed, or evaluated panel system (which has certification from a recognized product certification agency), or
- C. Using an uncertified system (which is discouraged; if manufacturers are selling uncertified system it is recommended that they work with a recognized product certification agency to certify their products).

Method 1 – using code recognized systems



- The designer must consider, ARE SIPS RECOGNIZED BY THE CODE? If the code specifically and discretely reference SIPS then the design professional can simply follow the PRESCRIPTIVE METHODS outlined in the code for use and application.

Currently only one code recognizes SIPS -- the IRC in a supplement -- and it is being carefully revised by SIPA. If a code recognizes SIPS then a designer must simply verify the product they are deploying is code approved or meets the code definition to answer the question IS THE PRODUCT BEING DEPLOYED A CODE RECOGNIZED SIP? (STEP 1a)

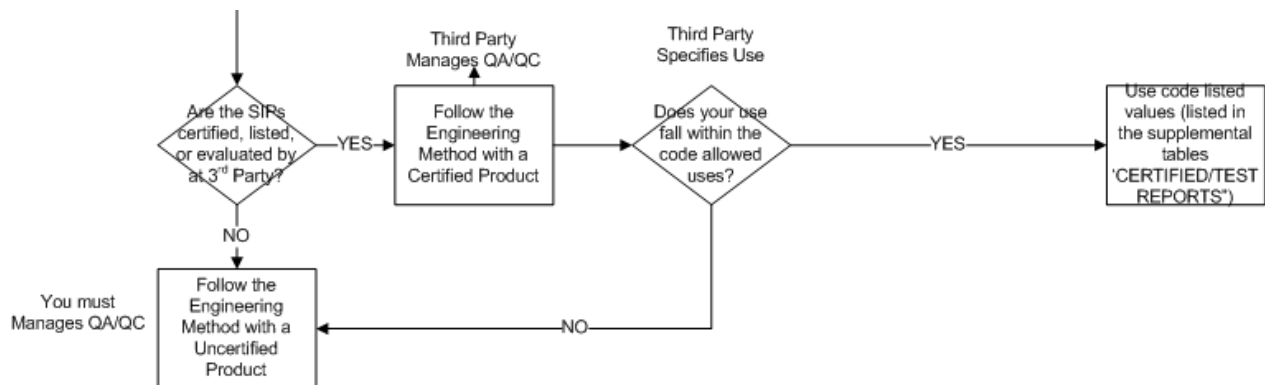
If the code does not address SIPS use METHOD 2.

- IS THE PRODUCT BEING DEPLOYED A CODE RECOGNIZED SIP? (STEP 1a) This step simply insures to the designer that the product that is being used falls under and within the code and is not another product which may be for another use. Currently, SIPA is in the process of helping the industry standardize a consensus standard and definition for a SIP and expectations in terms of quality and manufacturing. All of these activities are done through an open standards development process which is transparent and open to the public for participation and public comment.
- HOW DOES THE CODE LIMIT SIPS? (STEP 1b) Understanding the limitations of the system is as important as understanding the performance of the system.
- Use the listed values for the engineering analysis and design (STEP 1c). These values are listed in the supplemental tables, for example in the ICC addendum. The current status of SIPA's activities is to develop ANSI standards for the manufacturer to define SIPS and work within the ICC to get SIPS specifically and discretely into the code. All of these activities are done through an open standards development process which is transparent and open to the public for participation and public comment. For example, however, SIPA has focused on wall panel in residential to start this development within the IRC so the limitations now are currently to walls.

If the code specifically and discretely calls address SIPS, then the designer has less to worry about in terms of managing the product which he or she is trying to deploy because the code defines the QA/QC standards for the manufacturer to follow and report to, the code defines and specifies the use of the system in buildings, and ultimately the code stipulated the design values that are to be use. These benchmarks are ones in which the industry is moving towards, but unfortunately, they will take time. Additionally, the liability for the designer is narrowed to simply correctly applying the code to the design and specifying a code recognized system.

Method 2 – using a certified, listed, or evaluated panel system

If the code doesn't govern use, then the designer must follow the engineering methods, as the code solely manages the requirements that the panels must meet. Now the designer needs to determine if the panels are properly tested, manufactured, and have specified design values to be used in the application of the system to the code requirements. As you can see here, the liability is widening.



- The designer must consider, ARE the SIPs LISTED BY A CERTIFICATION OR EVALUATION AGENCY? (STEP 2a) Product certification and product evaluation are very similar things, and they provide a similar argument for code compliance. However, there are subtle (yet important) differences. Product certification and product evaluation are very similar things, and they provide a similar argument for code compliance. However, there are subtle (yet important) differences.

Product evaluation simply verifies that specified testing has been done to show a building product, component, method, or material performs at a level compliant with applicable codes. It reviews test reports to make sure the correct testing was performed, and then issues a third party statement to that fact. While product evaluation exists as a snap-shot of a product at one moment in time, product certification provides a more ongoing view into compliance.

Product certification agencies identify and run the required testing, evaluate the results, produce a certification report, and monitor quality control of production. These differences are largely in terms of the chain of custody between sampling, testing, and ongoing quality assurance.

If the panel company doesn't have a certification or evaluation report then the designer must follow the engineering method with an uncertified product as METHOD 3. If the product to be used is not certified or evaluated, the engineer should consider using a different system, as there is more management that he or she must do with the actual product and manufacturer. Although this work is not impossible, it is time consuming and it may expose the engineer to liabilities that he or she is not prepared for nor has a full understanding.

However, it is very common for panel manufacturers to have listings by a certification or evaluation agency. This issue has been specifically addressed over time and most modern company maintains a current listing. In fact, this certification requirement is a mandatory requirement for SIPA members.

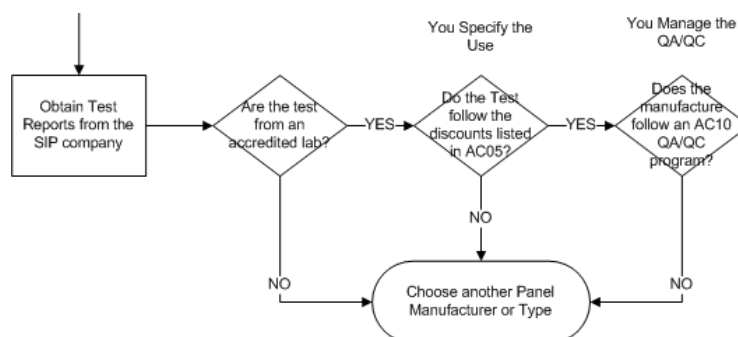
- IS THE USE WITHIN THE SCOPE OF USE OF THE PANEL CERTIFICATION? (STEP 2a) If the desired use is not listed or the intended design falls outside the scope of use, then the designer will have to proceed to METHOD 3. If the application falls within the certification's scope of use then the listed performance and design values in this certification or evaluation can be relied upon (STEP 2b).

Method 3 – using an uncertified system

If the code doesn't recognize SIPs and the product to be used doesn't have a certification or evaluation or the intended use falls outside the scope of the certification or listing, the engineer can evaluate the panel, the manufacturer, and determine the scope of use with the code and code referenced documents – this will require the designer to evaluate the sip company and the SIP system.

This is the most laborious method as it puts the requirement of quality assurance and quality control in the hands of the design professional. Before evaluations and certifications, this was the only option for application and many small companies still put these burdens on the design professionals. Additionally, this approach puts the burden on the design professional to understand everything they must consider, review, and feel comfortable being liable for in their application of the system to the use. This leads to engineers being conservative (rightfully so) and panel use being uncompetitive with traditional systems.

WARNING: whereas CSIPs can be applied to buildings following Method 3, this type of CSIP deployment is discouraged because it places more burden on the engineer and less on the manufacturer.



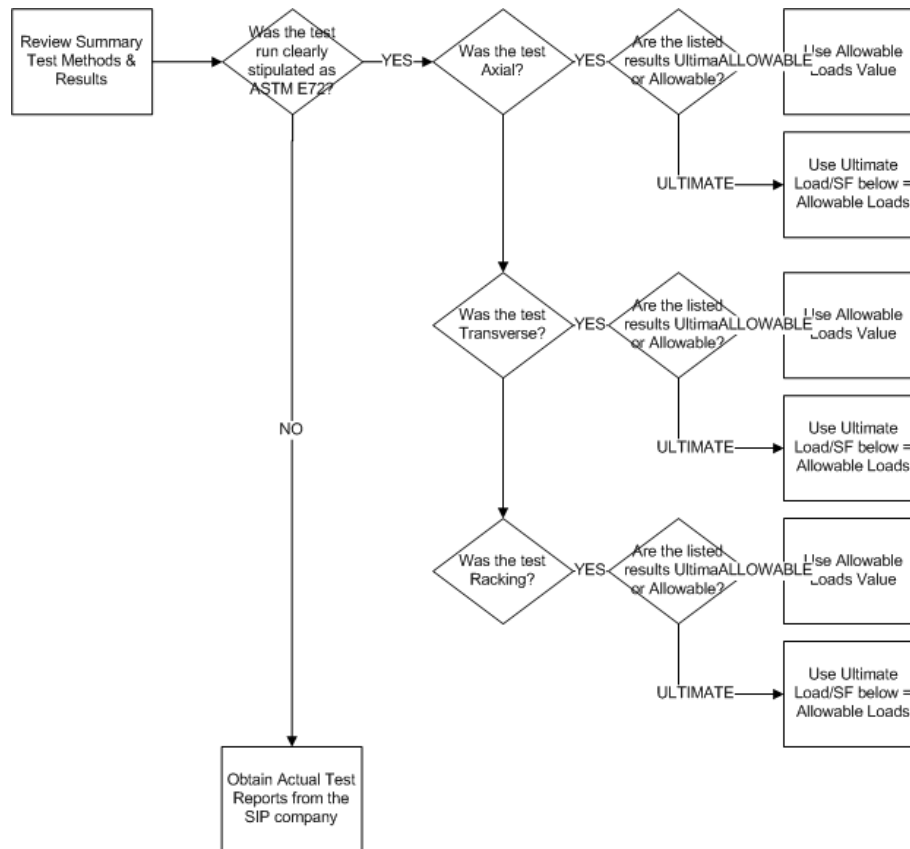
- The designer must consider, WAS THE PANEL TESTED BY A THIRD PARTY? (STEP 3a) If not, the engineer should best choose another system as there's no assurance that an independent third party has completed the necessary, required tests.
- The next step is for the designer to determine if the system is compliant with the industry consensus standards listing the test requirements, the safety factors, and other quality assurance/quality control needs (STEP 3b). This data can be obtained in the acceptance criteria for the code (AC04, AC05, AC10, etc)²⁰. Ultimately, these documents will also be supplemented by the ANSI standards that SIPA is helping develop. If in the engineer's review of these acceptance criteria to the test results are not sufficiently adequate then the engineer should best choose another system as there's no assurance that the results are consistent with best practices.

Note: The ICC defines three principle tests for sandwich panels: transverse load test, axial load test, and shear wall tests. Factor of safety (F.S.) as calculated by ICC are:

- F.S. = 2.0, ultimate load determined by bending failure for allowable live loads up to 20psf (958 Pa) and wind loads.
- F.S. = 2.5, ultimate load determined by bending failure for allowable snow loads.
- F.S. = 2.5, ultimate reaction at failure for all loading conditions.
- F.S. = 3.0, ultimate load at shear failure for all loading conditions.

Use the process diagram below to determine whether the listed values are ultimate loads or allowable loads. This step is critical as many testing labs unfamiliar with SIP testing and SIP standards list incorrect allowable loads.

²⁰ ICC Acceptance Criteria



- The designer should review the in plant QA/QC protocols to insure the panels tested are those that in fact still manufactured, consistently manufactured and inspected, and consistently tested to show conformance to the results being used to design the structure. The designer should insure all the parts and pieces are certified as independent components (like the facing materials, the EPS, and most importantly the glue which is governed by AC05).
- The designer should review the test results and resulting design values listed to AC04 to determine the appropriate safety factors are applied. Ultimately these design values will be the basis for the design.

This method assumes that there is a chain of custody between the results being utilized, the manufacturer's process, and the parts and pieces in the composite. As this is now the role of the engineer to verify and ultimately stipulate the use, the designer is entangled in the liability of manufacturing and utilizing the panels. If this cannot be determined, if the designer has reservations, or if there are any questions about the manufacturer that aren't adequately addressed, then the engineer should best choose another system as there's no assurance that the results are consistent with best practices.

Information to be Supplied to Code Officials

Code officials may or may not be educated on composite panels and SIPs/CSIPs. Therefore, the range of information to be supplied to the building official varies. Additionally, building officials are representatives of local government and may or may not recognize state or federal adopted codes and standards. However, following methods 1 and 2 above should yield an expedited building official review because either the code recognizes SIPs outright or the manufacturer has a current certification to the building code by a third party which is authorized and certified itself to produce reports following industry and code recognized standards. Method 3 may or may not yield successful results in code approval or the code official will rely solely on the professional of record's seal on the system and the design package for compliance to the code (which simply moves unlimited liability on the design professional for the design, construction, and systems within a building). For these reasons, it is highly recommended that Method 3 is not used and another candidate CSIP system is chosen.

Code Issues for the Design Professional

It is important for the design profession to double check the basis of the candidate system in the code being used. This basis can be checked for validation of CSIPs, restrictions on CSIPs, and ultimately limitations on the conditions of use of CSIPs.

Not all designs require testing. For small buildings it is rare to specify testing as long as performance data for the application, use, and details is available from the manufacturer along with panel certifications. For larger buildings and projects, testing is required to insure that all details and assumptions meet or exceed the performance requirements. Additionally, for large buildings it is recommended that the systems be certified for the specific use following the details being supplied.

Please note, that each manufacturer should supply data (through evaluation reports) or certification reports that their system is compliant with the respective codes in the ICC.

The basis for panels are validated and restricted by the following...

- A. Testing the CSIP Panel Assembly: typically, CSIP manufacturers have tested that their system are compliant to the following tests for the individual panels alone and panel to panel conditions).
 - i. Structural by ASTM E72 - 05 Standard Test Methods of Conducting Strength Tests of Panels for Building Construction
 - ii. Weather Barrier by ASTM E331-00 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference

- iii. Thermal Barrier equivalent to 15min exposures of gypsum by ASTM E119 - 08a Standard Test Methods for Fire Tests of Building Construction and Materials

B. Fire

- i. VALIDATION AND RESTRICTION: The basis for panels is validated and restricted by the code and each candidate panel system should provide evidence to show conformance to the following...
 - A. Combustibility based on ASTM E136 - 04 Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C and ISO1182 Non-combustibility Test for Building Materials.
 - a. *MANUFACTURERS should provide results of ASTM E136-04 or EPS data showing the relative melting points of the materials used. CSIPs are limited to the follow usage...*
 - b. *In Type V construction (three story max per Table 503) and have limitations stipulated by the building code in Chapter 6, Types of Construction and Chapter 5, General Building Heights and Areas. This document does not contemplate panels that are to be used in Type V construction; or*
 - c. *As exterior wall coverings in Type I buildings per 603.1.10.*
 - B. Fire Rating based on ASTM E119 - 08a Standard Test Methods for Fire Tests of Building Construction allow CSIPs to...
 - a. Show conformance to 2603.4 Thermal Barrier.
 - b. *MANUFACTURERS should provide results of ASTM E199 tests. If tests are not provided than the candidate system cannot be used as an interior finished good and additional layers of fire protection must be used.*
 - i. *MANUFACTURERS have no responsibility to provide information relevant to these issues. However, DESIGNERS must understand these and other code limitations to the use of all building materials in designs. Those items listed above are not exhaustive, but are primary issues which must be addressed in preplanning activities.*

Cautionary Note on CSIPs

Vapor retarders retards passage of both air and water vapor and perform similar tasks as combined water and air barriers. Vapor retarders are often mechanically fastened sheets, self-adhesive sheets, mastic, and spray coatings.

Vapor moisture management is less of an issue with closed wall panels like CSIPs if the facing materials are more permeable than the core material. This management principle will allow any water to dry out

of the core material (and more importantly the lamination line). Therefore, the designer should be concerned with the perm ratings of all facing materials and exterior finishes. As long as the perm rating of the facings is less than the core, condensation control may not be required.

However, using permeance as the means of vapor retardation for CSIP curtain wall units may only be effective in climates with an annual precipitation of less than 60 inches and in climates that have few degree heating days to allow for moisture extraction. The effects of this control measure and determining which climate zones are suitable for CSIPs is an area of future research for the industry.

Please consult the manufacturer for technical information and interpretations of vapor and condensation management.

SECTION 3: Construction Guide for Future Applications of CSIPs

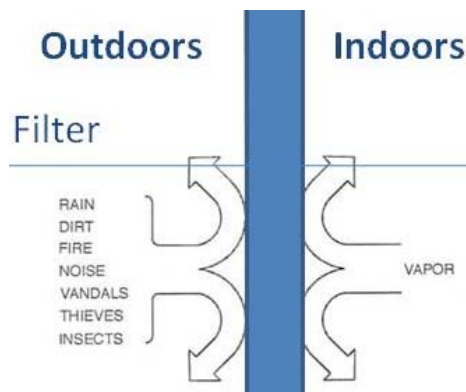
There are two equally important parts to optimizing CSIPs: proper design, and proper construction. Without one, the other is essentially irrelevant. This section will discuss the very basics of building envelopes, the basic design optimization requirements that inform constructability, and ways to ensure that constructability problems will be avoided to produce an optimized end product.

The Functions of Building Envelope and Wall Assemblies

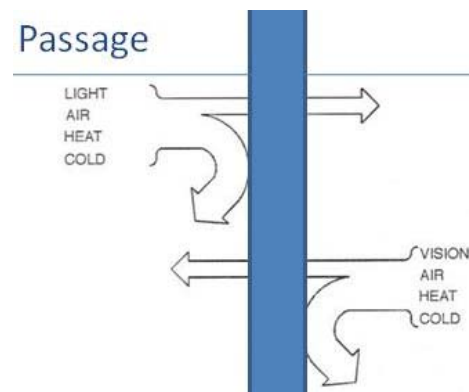
The functions of a wall primarily depend on the wall system used, which is largely a matter of the building size and the life-safety and code limitations. For construction governed by the IRC, CSIPs most often are used as load-bearing panels, dealing with gravity and lateral loads while providing the other functions of building envelope. However, for construction beyond the current scope of the IRC, CSIPs must act solely as the building envelope system.

The primary function of envelopes is to withstand the elements by controlling the ability of rain, dirt, fire, noise, and insects to pass through and enter the interior. The secondary function of envelopes is to control the passage between the interior and exterior. This control measure includes temperature (thermal transfer and losses), vent and light, and air infiltration. Additionally, the envelope controls the passage of interior vapors, humidity, and air to pass to the exterior. Envelopes act as weather barriers (to control the entrance of rain into the interior), vapor barriers (to control water vapor penetration into and out of the building and condensation), and air barriers (to control the movement of air, or unknown infiltration points, into and out of the building). A tertiary function of envelopes is to prevent access or entry into building through doors and windows (this function is not a focus of this report).

PRIMARY



SECONDARY



Buildings are dynamic in their response to the larger environment. Walls perform basic functions for building to help control and filter the interior and exterior environments...

1. Providing structural supports as bearing wall;
2. Providing structural support for wind loading as bearing wall and curtain walls;
3. Protective enclosure for the elements as waterproofing as weather barriers;
4. Allow for openings for vision and vent; and
5. Serves as a filter between indoor and outside for flow of heat, light, air moisture, dirt, sound, people, as air and moisture barriers.

Structural support is not a focus of this report; however, the control of water and the elements into the structure will be explained here as weather barriers and air barriers as ways to develop a buildings' thermal envelope. Thermal barriers, on the other hand, are a fire-safety requirement that has already been addressed in the industry code's section. The ICC fire rating is based on ASTM E119 - 08a Standard Test Methods for Fire Tests of Building Construction which allow CSIPs to show conformance to IBC 2603.4 Thermal Barrier (Note: each vendor must show compliance as a thermal barrier) and not require gypsum on the interior.

Weather Barriers: Understanding Waterproofing Control Measures

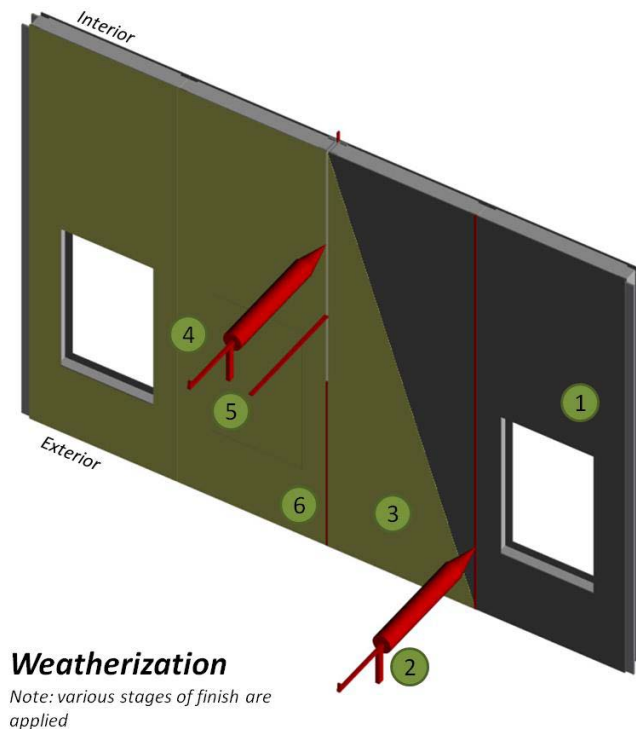
A weather barrier is neither an air barrier or vapor retarder, but is a liquid moisture resistant layer to protect the building from the elements. Weather barriers protect the construction from damage due to precipitation and wind driven rain. Weather barriers are "water-resistive barriers" from the ICC International Building Code (IBC 1404.2) which requires a minimum of one layer of No. 15 asphalt felt behind exterior wall veneer, unless other conditions are met or equivalency is demonstrated.

Waterproofing is best controlled through proper detailing of assemblies to insure that water has an unbroken barrier to escape any joint, infiltration area, or crack in the system. Water penetration resistance is a function of substructure construction, drainage details, water management control (weather stripping, gaskets, and sealants), and flashing/counter-flashing of all window, penetration, etc.

To understand the design issues, first we must discuss the mechanisms that move water into the building: gravity, kinetic energy, pressure gradients, surface tensions, and capillary action. Because CSIP wall units are built up from monolithic sandwich panels, there are more perimeter lengths that must be properly designed, detailed, and constructed to insure proper water management and water shed to the exterior of the building. This fact allows the designer to be cautious and conservative about water management details while focusing the main concern on water management between units and at unit corners.

Typically, the parts and pieces (including the individual panels) that make up larger wall units must be detailed to prevent water infiltration. However, leveraging these industry standards, designers will be

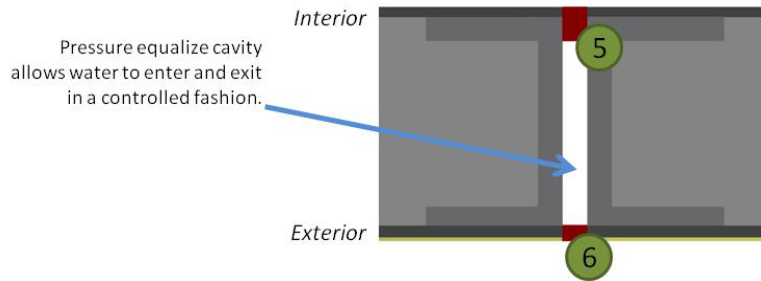
required to provide weatherization details by the following steps: Installation of the CSIP panels into wall units by installing the CSIP panels, applying the Latex Caulk at CSIP panel joints, and applying the Block Fill entire CSIP assembly. Next the Installation of multiple wall units together at designed pressure equalized cavities, as applicable, by applying caulk within the interior cavity between installed wall units, tooling the caulk in cavity to correctly apply to surfaces, and installing the gasket seal and provide weeps/pressure equalization points.



All joints and boundary conditions between wall units should be treated like pressure equalized cavities.

Pressure equalized cavities is a concept made common in pressure equalized rain screens. Pressure-equalized rain screens integrate a porous exterior cladding and compartmentalized air spaces with generous ventilation to an interior watertight airtight support wall. Pressure equalization controls the pressure differential across the cladding systems that are magnified by winds and control wind driven rain. This control measure effectively eliminates the remaining pressure force affecting rain screens that drive rain into the interior by using barriers to compartmentalize the air cavity as a pressure equalized cavity, thereby allowing rapid air pressure equalization and minimal moisture intrusion.

Adapting these details to wall units will involve the backmost interior surface to be sealed (illustrated below as (5)) to form a cavity between the inner and outer surface is allowed to vent while still allowing positive drainage to the exterior; the outer cavity is maintained by the installation of a gasket seal with weeps (illustrated below as (6)).



Tests for Weather Barriers are required based on ASTM E331-00 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference allow CSIPs to show conformance to 1403.2 as a weather barrier resistant to water intrusion and vapor permeance to allow drying while reducing vapor intrusion. Additional tests for weather barriers on whole curtain walls may be required including,

- i. ASTM E331-00 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference,
- ii. ASTM E547 - 00 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference, and
- iii. AAMA 501-4 Dynamic Rain Penetration Test (may be required).

Air Barriers: Understanding Infiltration Control Measures

Air Barriers retards air passage, may be vapor permeable (to allow condensation movement) but is liquid moisture resistant. Air barriers offered are typically mechanically fastened sheets (i.e. "housewraps") and spray or roller applied coatings (i.e. "fills" like block fill for CMU construction). An air barrier may also function as a water-resistive weather barrier.

Factors that affect building tightness are the interior seals, caulks and other treatment of interior finishes, trim, and interactions between the two which close gaps, cracks, and imperfections in the construction forming the air barrier. Typically air infiltration is a surface control measure which paint and caulk may control.

There is no easy way to calculate and design for building tightness prior to final finish because it ultimately relies on the specifications and quality of installation. The tightness is ultimately determined by the seals between the panels to panels, panels to building, and all the penetrations which can be evaluated after the building is constructed through similar testing methods as the blower door test. Building tightness hinges on the weather barrier test for the panel systems and basing the assumptions on physical tests, mock ups, and prototypes which use typical construction means and quality of that to be used in the final design. Additionally building tightness is determined by the seals and expansion and contraction of unit to unit interaction.

Penetrations through the envelope are key areas in which air infiltration is controlled. The proper use of flashing and counter-flashing can minimize air infiltration as well as the properly installing window units and preparing openings and penetration for controlled passage. The installation of windows into the panels are outside the scope of this document, as it is clearly manufacturer specific, but each penetration should be prepped with an elastomeric pan flashing, jamb flashing, and header flashing followed by the installation of the window with proper sealants and mechanical fastening to the blocking in the CSIP panel. These details may require windows with exterior flanges, but they promote proper drainage and evacuation of water to the exterior. Counter-flashing should be installed and as required, materials to create and maintain a drainage cavity should be installed between the counter-flashing and exterior window trim. These layers of redundancy and control allow localized drainage spaces and cavities to be built up around penetrations while relying on the flashing materials to channel excess water to the exterior. Any moisture saturated in the wall assembly can dry out given that the exterior and interior facing materials should be more permeable than the interior core material.

Tests for Air Barriers are required based on Air leakage, ASTM E283 - 04 Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen.

Optimizing the Thermal Envelope

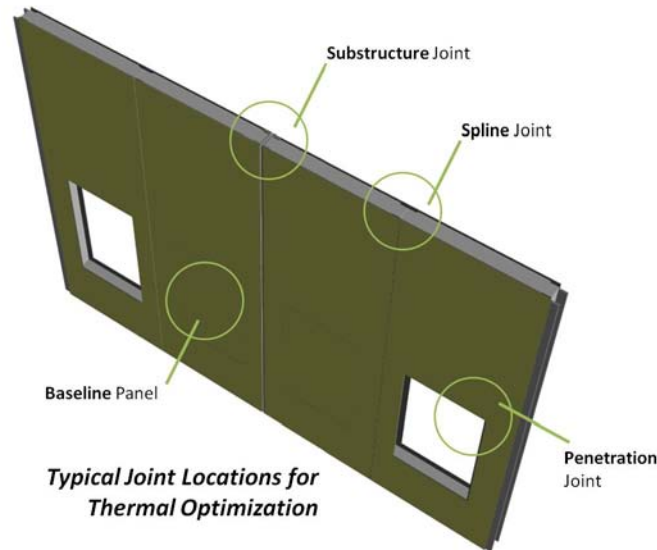
The energy saving potential of building with CSIPs is the most apparent sustainable advantage of utilizing CSIPs. A CSIP building envelope provides high levels of insulation and is extremely airtight. This means significantly lower operating costs for an owner, as well as a smaller contribution to the energy use and carbon emissions from your building. Energy Flow through building panels and wall assemblies are primarily driven through two mechanism:

- 1) Temperature driven heat transfer (through Conduction, Convection, and Radiative heat transfer are considered. Conduction is the heat traveling through a solid material, Convection is the transfer of heat by the movement of gases or liquids through a system, and Radiative heat transfer is the movement of heat energy through space without relying on conduction through the air or by movement of air), and
- 2) Infiltration.

Temperature driven heat transfer is the differential between the inside and outside temperature – heat is either lost or gained through the section, frame, and panels. This is indicated in terms of the U-factor or R-factor of the assembly ($U=1/R$). Infiltration of heat loss or gained through the air infiltration through cracks in the assembly. This negative effect is measure in terms of amount of air that passes through a unit area of the panel product under different pressure conditions. Infiltration is thus driven by wind-driven and temperature-driven pressure changes and fluctuations. Infiltration may also contribute to interior humidity.

The following areas must be optimized:

- Baseline Panel (CSIP panel Thickness),
- Substructure Joints (CSIP to Unit boundaries and Unit to Unit connections),
- Spline Joints (CSIP to CSIP Connections), and
- Penetration Joints (CSIP to Penetrating Unit Connections).



Determine A Baseline Panel Thickness

Baseline Thermal Performance is based on the insulation core's thickness. Not all CSIPs have the same thermal performance because of the materials used and the construction standards. CSIPs can be made thicker with more insulation, having a higher insulating value (R-value), and transferring less heat dependent on the spline conditions. However, it is not enough to judge their effective thermal performance by simply take note of this R-value. This assumes that a wall is entirely filled with insulating material, and makes for a poor and misleading comparison of building systems.

This improved performance of SIPs is confirmed in a study of whole-wall R-values conducted by the Oak Ridge National Lab. The study accounts heat loss through windows, doors, corners, and slab connections. The results demonstrate the benefits of SIPs – the lack of thermal shorts creates a higher whole-wall R-value than conventional wood framing construction.

The selection must be based on the insulation type from various vendors. There are three key insulation types – EPS foam, XPS foam, and Polyurethane. Their insulation values are primarily based on their relative density. This is a linear relationship throughout the assembly. Therefore, given the thermal conductivity of the insulation per inch (expressed as its U-value or R-Value ($R\text{-Value} = 1/U$ -

Value), designers can easily calculate the baseline required panel thickness required by code, the building owner, or by other needs. Listed below are the most common Insulation cores in the SIP industry. However, manufacturers should supply specific materials testing information on the cores.

EPS = 4.0 R/INCH

POLYURETHANE = 6.7 R/INCH

XPS = 5.4 R/INCH

WARNING: there are minimum standards for insulation in the respected insulation industries based primarily on density. Manufacturers have been known to advertise higher densities, and higher R-values, for insulation cores and then deliver panels with cores of substantially lower densities. It is very difficult to determine the insulation density after lamination and verify it on an ongoing basis. Therefore, it is highly recommended that designers use the minimum insulation values in there assumptions to protect from this issue.










Optimizing Splines, Connections, and the Boundary Conditions

Most building systems have small conductive elements that penetrate or go around the insulation to create thermal bridges – “short circuits” – through which heat can travel. Thermal bridges significantly lower the effective insulation value and create unanticipated temperature gradients that can lead to thermal stress, condensation, and other effects. Therefore, designers must be very critical of the connections and methodologies to make the connections (i.e. connection type vs. the effects on the thermal conductivity of the panel given the connection type).

Because SIPs are a system assembly, almost a kit of parts, it is easy to evaluate temperature driven heat transfer and infiltration simultaneously simply because all infiltration points are also points for direct temperature driven heat transfer are applied. These locations are confined to the perimeter or boundary of the panels. Therefore, we must consider constructability, weatherization, and thermal barriers as well as spline condition, type, etc. To accomplish this, FAS modeled the different panel connection types to determine the preferred designs. Thermal bridging is primary means for heat transfer in panels at panel to panel connections. There is a single mode to examine these locations in terms of thermal performance thanks to their sandwich cores which translates into a need to maintain insulation core and minimize heat transfer.

The following spline conditions were modeled in THERM and modeled as a physical assembly (showing the fiber cement siding (green), EPS (gray), and metal sections (purple)). Also, the infrared analysis showing heat transfer through the assembly and the gradations are illustrated. The Infrared sections help illustrate areas where heat flow is greater than the baseline. Ideally, gradual, defined, and uniform gradations are desired. For all assemblies the calculated R-value is given and the percent error in the solution.

Typological Connection Type & Relative Performance

		U-factor	R-factor	Error
	Blank panel (baseline) <i>Assumed baseline panel</i>	0.0400	25.00	0.00%
	Wood Surface Spline	0.0416	24.04	1.70%
	Metal Surface Spline <i>Preferred panel to panel connection.</i>	0.0430	23.26	4.50%
	Full Wood Spline	0.0580	17.24	1.20%
	Full Metal Spline	0.1752	5.71	7.95%
	Guarded Metal Tube	0.0862	11.60	6.53%
	Guarded Metal Solid <i>Preferred substructure panel connection.</i>	0.0870	11.49	6.56%
	Metal Offset Spline	0.1154	8.67	7.61%
	Guarded Metal Offset Spline <i>Preferred substructure panel connection.</i>	0.0709	14.10	8.99%

Note: assume 5.5" insulation core throughout.

These splines are for illustrative purposes only. After the structural design is complete, the designer should use THERM in critical conditions (i.e. panel to panel (plan), panel to building (plan and section) and other penetrations, connections, and boundaries to determine if the materials are optimized).

The performed thermal analysis are general in nature, and it is recommended that each project run specific evaluations for the Thermal analysis has varying section moduli and areas.

To avoid falling into these simple misconceptions, FAS has based thermal performance calculations on the finite-element analysis of a steady-state, two-dimensional heat transfer software. The software, called THERM, was developed by Lawrence Berkeley National Laboratory (LBNL) and is free to download and use. THERM uses a finite-element analysis. Once a cross section's geometry, material properties, and boundary conditions are defined in the program (all known quantities in a wall assembly), THERM meshes the cross section, performs the heat-transfer analysis, runs an error estimation, refines the mesh if necessary, and returns the converged solution²¹. These results show more than just the R-value of the insulating components. It allows the user to evaluate a building component's energy efficiency and local temperature patterns, demonstrating the effective thermal performance of the entire assembly. We recommend using THERM to evaluate any final design to insure "thermal shorts" are kept at a minimum.

²¹ More information on how THERM works can be found at FROM LBL WEBSITE.

THERM examines temperature driven heat transfer in a static 2-dimensional state. Thermal performance of spline can be modeled, studies, and optimized using THERM²². THERM is a static thermal modeling tool from Lawrence Berkeley National Laboratory using finite-element analysis to study heat-transfer. THERM is an easy method to optimizing joints. Engineers should engineer structural components then model joints and connections for both structure and heat flow

WARNING: There are some limitations to the current details in the industry. Wall details are primarily derived from residential construction and may need further modification for commercial use given construction/material handling. Wall details are adapted from standard practice and may not be optimum in terms of balancing the infiltration, heat transfer, and constructability. Overall, more research is needed in splines and optimum splines/connectors

How to Avoid Problems in SIP Construction

There are many advantages to SIP construction. SIPs offer excellent structural safety and air quality, soundproofing, and temperature control. They are also best known for their energy saving potential, reducing energy use and operating costs. Other advantages include environmental benefits from minimal on-site debris, rapid construction, better quality control, and an efficient use of material. SIPs are also especially versatile, as the panels can be used in both load-bearing and non-structural applications. Cement faced SIPs offer these SIP advantages and have less reliance on wood and the price fluctuations in the wood industry.

However, for these advantages to reflect on the final product of a building project they must be built correctly. Specific details should be followed to achieve proper building tightness, weatherproofing, and vapor barriers.²³ In addition, because CSIPs are a generally new building system for builders, attention should be paid to specific issues.

FAS has built several CSIP demonstration homes, and has encountered many of these problems and issues. This section synthesizes these lessons, explaining the major steps to execute a successful CSIP building project. Some of these steps might seem like common sense and some may be more unexpected, but each is crucial to the success or failure of the project.

To successfully construct a CSIP building, you must:

- i. Choose the right system for your project, needs, and location,
- ii. Choose the right manufacturer for the job,

²² 1: THERM 2.0: A BUILDING COMPONENT MODEL FOR STEADY-STATE TWO-DIMENSIONAL HEAT TRANSFER, Charlie Huizenga et al, May 1999; RATING AND LABELING OF ENERGY PERFORMANCE OF WINDOWS AS A TOOL FOR PROMOTING ENERGY EFFICIENCY PRACTICES IN BUILDINGS, Bipin Shah et al (unknown date)

²³ Common details have been outlined in this report, but should not be relied upon for project specifics. Manufacturer provided details, or those specified by an engineer should be used.

- iii. Choose a team and communicate from the beginning,
- iv. Take the correct approach when planning with the project delivery team, and
- v. Deploy the proper construction techniques – don't invent, and don't deviate from the plans in the field.

Each of these is important to a successful final product. We will elaborate on each, explaining our experiences and the mistakes made, the problems we've identified, and the best ways to avoid them.

STEP ONE: Choosing the Right System

The first step is to **pick the correct building system**. This is the fundamental building block for a successful project. It may seem like common sense, and in a lot of ways it is. In the same way that you wouldn't try to build an Igloo in Arizona, you wouldn't try to build an Adobe in the Arctic. And while this may seem like an obvious choice, making the correct decision can be significantly more complicated. To make the correct decision means understanding the intents of your project, the basic relationships between the integrated systems, and how the costs and benefits of each system fits into that complex system of needs.

To select a system, one must first **identify your project needs**. No two projects are the same, and each calls for a specific solution based on a complicated set of requirements. What circumstances are driving your project? Which priorities are the most important? There are many areas to focus on when answering these questions. To begin formulating these, take a look at the people, building, and environmental priorities listed in chapter one. Having considered those, identify the limiting factors of your project. This can include (but aren't limited to): climate, availability of materials, project size and budget, special safety needs (for example, being located in a seismic or hurricane zone), operational specific requirements, local code requirements, etc. Other issues, such as environmental concerns and minimizing energy use, should be priorities regardless of these other project requirements.

Once you have identified the driving forces behind your project priorities and requirements, you should look into how those fit within the **functional relationships of the systems in a building**. A building can be broken down into the building enclosure, sub systems and components, and its fit and finish. All of these pieces are interrelated, and changing an element can change the performance of a number of assemblies, potentially changing major characteristics of the building.

The building enclosure includes the roof assembly, the wall assembly (including paint, siding, sheathing, insulation, and drywall), and the foundation assembly. The foundation is largely selected by building size, as well as the soil type and topography of the site. This influences the wall assembly, which in turn helps determine the roof type. Inside the building enclosure is a set of sub-systems, made up of the electrical/power system, the heating/cooling/ventilation system (which includes ducts, air handlers, controls, and sealants), and the plumbing system. Each of these is dependent on the building enclosure, and the requirements of each help inform decisions about the building enclosure. The fit and finish of the building includes appliances, fixtures, and furnishings, providing the final character to the building.

Having investigated the functional relationships of a building in addition to your projects priorities and requirements, you can **identify which building system provides the best solution for your specific situation**. Each carries costs and benefits, and how each applies changes with differing circumstances. From our vantage point, the following is a partial, qualitative list of the ups and downs of each construction system...

	Wood Framed Walls	Steel Stud Framed Walls	SIPS	
+	Mature, adopted technology in residential construction, covered by prescriptive codes, no regulatory barriers, low cost	Lighter weight when panelized, mature, adopted technology in commercial construction, covered in prescriptive code, no regulatory barriers, low cost	Increased strength, increase energy efficiency, large wall panels are possible (i.e. 8x24), shortened construction duration, no need for skilled labor (panel installation is relatively easy), manufacturers are widespread in the US. Different facing options make the system adaptable.	Increased durability and energy efficiency; shortened construction duration, little or no wood, resistant to termites and mold, little or no need for skilled labor
-	OVE framing not widespread, a lot of wood used as a result, labor intensive, uses highly skilled/trained labor, poor energy performance, quality of materials and construction standards is rapidly decreasing, difficult to find commercial applications	OVE framing not widespread, a lot of steel used, labor intensive, uses highly skilled/trained labor, poor energy performance, difficult to find residential applications	Connections are residential in scope, heavily reliant on wood; price fluctuations as a result; application limited to structures under 3 stories, costly; must finish interior and exterior sides of panels for durability/fire protection	Application so far limited to structures under 3 stories high, dimensions of panels limited by cement board; brittle in transportation and constructability, few manufacturers, lack of sound structural data to date

Proceeding with the assumption that CSIPs are the correct building system for your project, you must then....

STEP TWO: Choose the right manufacturer for the job.

Now that you have chosen CSIPs as the right building system for your project, it is important to select the right manufacturer for the job. Due to the precise nature of their assembly, the manufacturer plays a very large role in a CSIP project. SIPs are like a gigantic, oversized puzzle, and pieces must fit together precisely. Just like if two puzzle pieces aren't cut precisely to match they won't fit together, if SIPs aren't manufactured and delivered to the site correctly, the project is doomed from the start.

With this in mind, the following is a list of suggestions for choosing the right manufacturer for anyone starting a building project with SIPs, either as a newcomer or an experienced professional. It is our recommendation that you:

1. Work with a company that has current code approval

This is a basic prerequisite. A current code approval will help ensure several things. First of all, it tells you that the manufactured product meets defined baseline limits for safety and performance. It also ensures that you will not encounter major problems in getting a building permit for your project. Even if local building officials are unfamiliar with advanced building systems such as SIPs, a manufacturer's current code approval will help move your project through code inspection. And finally, it is a level of assurance that the manufacturer chosen is "legit".

2. Work with a company that knows the limitations, discusses these limitations, and talks about things SIPs can't do,

Be suspicious of companies that think their products work everywhere and anywhere, and ask questions about where the products shouldn't be used. These questions will help you understand the weaknesses of the systems and the necessary steps you must take in planning and ultimately building with the system. If it sounds too good to be true, it just might be!

3. Work with a company that has detailed shop drawings and in-plant QC, and

After an architect designs the building project, he will give copies of drawings to the panel manufacturer. This manufacturer should then create a set of "shop drawings". Shop drawings are a more detailed version of the buildings construction documents, drawn to explain the fabrication of the panels to the manufacturer's production crew. This may seem redundant, but the increased level of detail is crucial to achieving the precision and accuracy needed to assemble a successful SIP house.

This was a major mistake in this demonstration project. Rather than fabricate the panels from a set of shop drawings, they were made from the architectural drawings. The level of detail was insufficient, and the final product suffered. Construction, which is quick and easy if the correct preparation is taken, was slow and arduous. Panels needed to be re-cut on the job site. This was problematic, as rotary saws used for this "throw" debris into the air, which is hazardous if inhaled.

Making additional cuts to panels also compromises the structural integrity of the panels, making the final product questionable.

- 4. Work with a company that has a list of Engineers that are familiar with their product and are licensed in the municipality you are building.**

STEP THREE: Choose a competent building team and communicate.

With any technology integration or adoption of technology, success usually depends on the user. If the team wants a project to be successful, they will be diligent and take the time to get things right, and they will make the project succeed. If the project's ultimate success isn't your main goal, you'll shortcut everything and make it fail. This strategy works with any new, team based venture. If the team is behind it, you'll be surprised how well and successful the system is. If one link is weak, then the whole team has already failed. It's this mindset that will help you rationalize, plan, and prepare for a successful project. It's this mentality that makes SIPs effective as a building solution, system, and green building component. In a lot of ways SIPs become the material in the project that make the team rally to meet all green building goals successful.

FAS believes that SIPs are a great foundation for green building for residential construction. Green Residential Buildings start with SIPs because it forces everyone on the team, all the subcontractors and staff, to re-examine how they've been building buildings to look at the specifications and notes to be sure that performance, material selection, and ultimately goals are being met.

STEP FOUR: Take the correct approach with the system-project-team.

One of the largest problems with SIPs is constructability issues at the job site – what to do, how to do it, and the changing of details from the prescriptive methods.

For SIPs to be successful we all have to plan properly. This means being responsive, getting ahead of problems, communicating effectively with all parties involved in the project, and coordinating all work well before it begins. This also means embracing the limitations of the technology – knowing where SIPs are effective and quite simply where they don't make sense. If you lean on the manufacturer alone, they tend to sell to increase their volumes only. Therefore, they say SIPs are good anywhere and everywhere, that it's just like stick frame construction only better, etc. The truth of the matter is it's a great insulation and envelope technology with high R-value, limited thermal shorts, and long-term sustained R-values. However, they are not a "magic bullet" for all parts of home construction, and shouldn't be used as such.

STEP FIVE: Deploy the proper construction techniques – don't invent...

SIP construction has the potential to be a very successful as a long-term, efficient building system so long as constructability issues are managed, panels are not misrepresented and limitations are discussed, and the core competencies of all parties are leveraged. Success means letting the panels perform like they have been tested and only using details that are tried and true. SIPs are a highly engineered solution, with each piece of its puzzle carefully and scientifically examined. Each connection has been tested to understand its performance, and the system has been engineered to optimize the performance of each piece. Trust this past research, put your work into getting the design and planning correct, and leave invention for the laboratory, not the job site.

These steps seem simple, and frankly, they are once we engage SIPs. And thankfully, this easy, straightforward approach is an important factor in making your next building project the success it should be. It is also the same key that will build the Green Building market – because Green building is not about materials selection, but about proper communication with all parties on goals to make sure the building performs to protect and respect the environment.

SECTION 4: Further Research

This research project has identified several outstanding issues and qualifications that the industry needs to address. These include:

1. The definition of a SIP is vast a various. There is not a industry specific definition of SIPs, therefore, all sandwich panels fall within this general category no matter if they are laminated, reinforced, or hybrids of traditional systems (i.e. including intermediate supports). The testing standards should recognize and address this deficiency and stipulate composites that fall within the definition of a SIP. These testing standards should also address limitations and reinforcements.
2. Openings and penetrations are not properly addressed within the analysis of SIPs. The testing standards should address penetrations in the wall by setting ranges of unsupported penetration spans.
3. Connections throughout the industry have been driven by constructability issues and not engineering analysis and optimization. Sufficient research needs to be directed into the research of new connection systems, evaluation of connections, and general accepted connection standards. Connections will be the limiting factor of shear and combined loading which may benefit the structural performance of buildings.
4. Diaphragm assemblies need more thorough testing in the industry. Combined shear and tension acting on the panels is assumed to be carried at the connection. The testing standards should include some acknowledgement of diaphragm testing procedures and creep.
5. Knowledge of adhesives and long term durability must be evaluated against the durability of the subsequent constituent materials. Are the adhesives perfectly rigid like the facing materials to only be attached to a flexible core, or are the adhesives flexible? Is the durability of the system limited to the lowest durability of the constituent materials?
6. Fire resistance needs more education within in the industry. SIPs may be fire rated, but they are not non-combustible. The fire resistance of a polystyrene core is always going to be the limiting factor, thus new insulations must be deployed if SIPs are to ever be considered for uses in bearing wall construction of multistory buildings. The SIP industry needs more education of architects and engineers on the fire resistance aspects of the products for them to be accepted for non-residential uses.
7. The industry needs standards for manufacturing, testing, material handling (including maintaining the chain of custody and compliance) and industry accepted quality assurance and control.
8. Further research is needed to understand the effects of passive moisture control measures such as pressure equalized cavities as weather barriers. This research should include the suitability of this approach by climate zone.