Cementitious Structural Insulated Panels: Demonstrations of Advanced Technologies

Case Studies and Recommendations

By Joseph Hagerman, Brian Doherty, and Todd Gerarden

The Federation of American Scientists
1725 DeSales St, NW 6th Floor
Washington, DC 20036
www.fas.org

Abstract

This report provides monitoring and analysis comparing construction activities, construction costs, construction timeframe, and energy efficiency of panelized houses in the Gulfcoast and Turkey. Construction and energy analysis (completed where applicable) will provide more data on the performance of the CSIP building system, and will inform recommendations for future projects in the Gulf Coast and Internationally.

Table of Contents

About the Federation of American Scientists

The **Federation of American Scientists** (FAS) is a nonprofit organization founded in 1945 by members of the Manhattan Project, who were concerned about the implications of the atomic bomb for the future of humankind. Endorsed by 68 Nobel Laureates in chemistry, economics, medicine and physics, FAS addresses a broad spectrum of issues in carrying out its mission to promote humanitarian uses of science and technology.

About the Building Technologies Program

FAS's Building Technologies Program works to mitigate climate change and advance social justice and environmental responsibility through the building industry. Buildings are the leading consumer of electricity and energy in our country, and energy production and use are responsible for 85 percent of human greenhouse gasses. With this in mind, the main focus of FAS's work is to improve energy efficiency without sacrificing affordability and life safety. While current research trends are moving towards expensive technologies, such as solar power and phase changing materials, FAS believes energy consumption and access to efficient technologies should not be socially or economically stratified. With this in mind, FAS has chosen to focus on developing static conservation technologies that are affordable, efficient, and obtainable by all socio-economic classes. To guide these efforts, FAS has defined the following areas to direct current and future research:

1. **Policy** – working to create guidelines, evaluation systems, and incentives to improve energy efficiency standards and to reduce the environmental impact of the built environment on a national scale.
2. **New Technologies** – the development of new technologies that improve the energy efficiency and reduce the environmental impact of the built environment, as well as providing for their practical implementation.
3. **Training** – developing training programs to teach building inspectors about energy efficiency standards, energy audits, and advanced building systems. This helps ensure energy incentives can be properly measured and implemented, and advanced building systems can be properly evaluated by building inspectors.
4. **Affordable Housing** – Applying energy efficient, environmentally responsible technologies to affordable housing projects. This is done through demonstration projects, working with affordable housing groups, and developing appropriate building systems at a price comparable to traditional systems.
5. **Emergency Housing** – providing economically viable, energy efficient, environmentally responsible housing stock for emergency relief in a temporary and intermediate timeframe.
6. **Demonstrations** – Constructing demonstration buildings to show the real-life potential of these technologies and advanced building systems on a local scale. FAS partners with charitable organizations, such as Habitat for Humanity, to build energy efficient, affordable housing, while simultaneously allowing for real-time monitoring of new building systems.

FAS works to create strategically optimized solutions within these categories through academic, professional, and industry partnerships to have a real and positive effect on the global impact of our built environment.

Project Introduction.

FAS began this task to investigate the properties of Cementitious Structural Insulated Panels through two real-time demonstration projects. The first project was to build two homes through a partnership between FAS and Habitat for Humanity in Mobile, Alabama. The second project was a house built outside Istanbul, Turkey with ILHAS Holding A.S., a leading construction company in Turkey. Both projects, started in 2006 by the Federation of American Scientists, were to be analyzed for construction time and cost, as well as energy performance.

FAS has formatted this document by examining each project individually, explaining the performance variables of CSIPs that can be best leveraged for each project, and a narrative description of the project planning and description. Following this, the process of each is analyzed, and important lessons are highlighted. The report concludes with general recommendations, as well as recommendations specific to future Habitat construction, and for future International projects.

At the beginning of this project, and the relationship between the Federation of American Scientists and its partners, is an appreciation for advanced building technologies, and more specifically, Structural Insulated Panels. To begin this narrative, we must first answer the following question: "what are structural insulated panels?"

What are SIPs:

Commonly referred to as their acronym, SIPs, Structural Insulated Panels are high performance 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, efficient building envelope. Cementitious Structural Insulated Panels (CSIPs) are one type of SIPs, using cement-fiber board as the structural facing material.

Typically, SIPs are fabricated from CAD drawings of a specific building. These drawings are converted to CNC fabrication machines, and panels are cut to the specific and exact dimensions required by the project. "Chases", or channels for electrical wiring are cut or formed into the foam core, and the core is recessed around the edges to accept connection splines or dimensional lumber. 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). Panels are typically cut to be 4 foot by 8 foot panels, but can be made as large as 9 ft. by 28 ft. Custom sizes are also available, and many manufacturers also offer curved SIPs for curved roof applications.[1]

[1] "Structural Insulated Panels Product Guide". SIPA and APA. December 2007.

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

A Brief History of SIPs

SIPs were developed nearly 75 years ago when the Forest Products Laboratory, established by the U.S. Department of Agriculture, built the first SIP house in 1935 in Madison, WI. FPL engineers speculated that plywood and hardboard sheathing could take a portion of the structural load in wall applications. Their prototype structural insulated panels (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.[2]

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 1990, the Structural Insulated Panel Association (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). This coincided with the development of advanced computer aided manufacturing (CAM) technology. Using these systems, computerized architectural drawings (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.

The SIP Impact:

Today SIPs offer an affordable high tech solution for residential and low rise nonresidential buildings. Advances in computer aided design and manufacturing allow SIPs to be produced with amazing accuracy to deliver flat, straight, and true walls.

Even though SIPs have been on the market for a long time, they only make up approximately 2% of the residential construction market.[3] Although SIPs have been slow to leave their mark on the construction industry, there is an increase in overall awareness due to growing interest in energy-efficiency. Taking advantage of this growing interest, SIPA collaborated with the Partnership for Advanced Housing

---

[2] "The History of SIPs", http://www.sips.org/content/about/index.cfm?PageId=37 , 6/18/08

[3] E-Build: The Professional's Guide to Building Products, "Construction Products Overview: Structural Insulated Panels," <http://www.ebuild.com/guide/resources/product-news.asp?ID=353470&catCode=15> 8 Nov. 2006

Technology (PATH) to "develop a set of prescriptive performance standards, which were submitted for inclusion in the International Code Council's Residential Code (IRC)."[4] Structural insulated panel wall systems were adopted into the International Residential Code (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.

Cement Fiber Board faced SIPs, referred to as CSIPs and the focus of this research, are 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. Buildings constructed with CSIPs typically will last longer and require less maintenance than other types of SIPs panels. Fiber-Cement Board used as skins will 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. Cement fiber boards will not support black mold growth, and has a high resistance to moisture absorption. They are rot and vermin resistant, and are not significantly affected by water vapor. 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.[5]

While there are many benefits to CSIPs, there are negative aspects as well. CSIPs are significantly heavier than OSB SIPs, weighing 120lbs for a 4'x8' panel. This makes CSIPs more difficult to deal with during construction. In addition, due to free silica contained in most cement fiber, in field modifications (especially with rotary saws) should be avoided. In addition, limitations in the prescriptive method of the International Residential Code calling out OSB as the facing material require every CSIP building to be engineered to show equivalence to the code. 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. While it is difficult to quantify improvements in this area, this will change with time as the industry grows and completes more projects, and should not be viewed as a long-term problem with the technology or the industry.

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

[5] http://www.toolbase.org/Building-Systems/Whole-House-Systems/fiber-cement-faced-sips

Cementitious Structural Insulated Panels & Habitat for Humanity

Abstract

In June of 2006, the Federation of American Scientists (FAS) collaborated with Habitat for Humanity in Mobile County, Alabama on a project exploring alternative construction techniques in Habitat developments. The goal of the collaboration was to produce two 1056-1200 sq ft demonstration homes out of Cementitious Structural Insulated Panels (CSIPs) in a larger Habitat subdivision in Mobile, Alabama. SIP panels offer an opportunity for high energy efficiency both because of the insulating properties of the expanded polystyrene and because the panels do not require studs or other structures that form 'thermal short circuits' through the walls and roofs. CSIPs that are pre-cut in the factory ensure that virtually no scrap is produced on site. The two homes have been finished, and two families have moved in.

Project Narrative

Mobile County Habitat for Humanity and FAS:

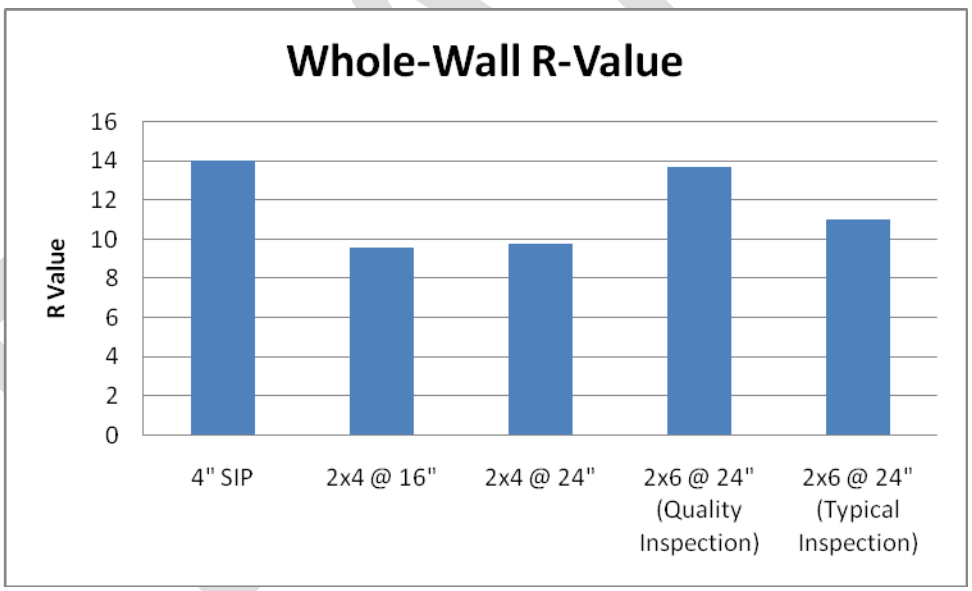
The partnership between the Federation of American Scientists and Habitat for Humanity planned to construct two CSIP homes in Mobile County, Alabama. The goal of the collaboration was to produce two 1056-1200 sq ft CSIP demonstration homes in a larger Habitat subdivision in Mobile, Alabama. The project would complete monitoring and analysis comparing construction activities, construction costs, construction timeframe, and energy efficiency of the panelized houses with regular Habitat stick-built houses.

Additionally, the homes were to be documented for Habitat so that best lessons learned can be determined for future CSIP/SIP application to the Habitat Home building process. The project helped FAS gather more data on the performance of the CSIP building system, but also helped guide decisions by Habitat for Humanity International to consider alternative construction and green materials across the US and internationally.

Project Planning:

The first step in project planning was the selection of Cementitious Structural Insulated Panels for the homes. FAS felt that the advantages of CSIPs could be leveraged to address the requirements of Habitat for Humanity very well. Some of these major characteristics of SIPs/CSIPs are:

- **Thermal Performance:** Insulation is crucial to the structural make-up of a SIP, and it follows that the end product carries high quality thermal performance. Panel connections are designed to eliminate thermal bridging, a common problem in stick frame construction. What results is a building envelope with a higher total wall insulation value. While there are many benefits of this, a key factor for Habitat is the reduced energy use and energy costs, an often heavy burden for families in Habitat provided housing.

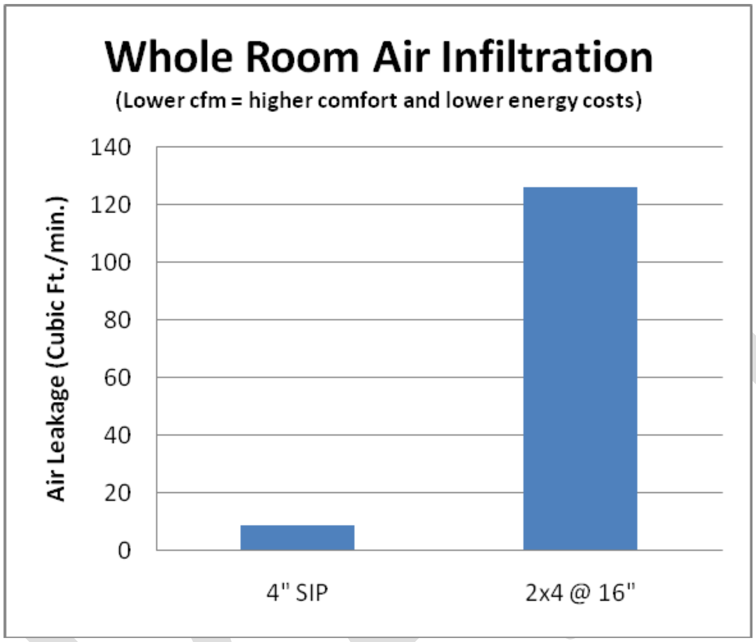


- **Ease of Construction**: CSIPs fit together like puzzle pieces, making their construction simple and straightforward. In addition, the cement fiber board facings do not require further finishing, removing several steps from construction. This is a significant benefit for Habitat for Humanity, who relies upon heavily inexperienced volunteer labor.

- **Construction Time:** It is difficult to quantify increases in construction time, as this differs significantly between projects. However, because SIPs constitute an entire wall assembly and are shipped to a job site ready to be placed on a foundation, construction is simple and quick.

This is a significant benefit for Habitat, as volunteer crews are usually operating on a weekly basis.

- **Increased comfort:** Heating and cooling is more evenly distributed in a SIP home. As shown in the following diagram, SIP walls have a more consistent temperature, free of the spikes found with frame wall construction. This is a difficult quality to measure, but has a significant impact on occupant comfort.



- **Decreased Job Site Waste:** By using prefabricated panels in construction, significant waste is avoided on the construction site. It also makes for an easier to maintain job site – especially helpful when working with untrained and inexperienced volunteers.

After deciding upon CSIPs for the construction system, FAS selected a CSIP vendor in nearby Florence, Alabama. Working with the vendor, FAS and Habitat created a set of plans, optimizing a traditional Habitat design for panelized construction. This included planning for two different foundation types: a slab system and a pier system.

The initial construction kick-off date for construction, originally set for September 26th, was postponed consecutively, as Habitat for Humanity encountered problems finding and sheltering volunteers for the construction of a 100-house subdivision that also included the two CSIP houses. The surge of volunteers to the Gulf Region in the aftermath of Katrina caused misallocation of labor that either resulted in shortages or abundance, depending on the location.

In parallel to Habitat's problems of securing volunteers, the CSIP manufacturer reported a shortage of raw materials needed to produce and deliver panels for construction. By late October, FAS and Habitat for Humanity reconsidered the kick-off date and mutually agreed on mid-November, which was once again delayed due to Habitat for Humanity International's plans to hold 500th house celebrations in Mobile. Fearing that Habitat International would steal the spotlight from the CSIP project, the project kick-off was rescheduled for December 5, 2006.

Construction:

Construction of the two homes began in December of 2006. The following narrative, based on field notes taken by FAS's Building Technologies Program Manager Joe Hagerman, describes the construction process and the problems encountered. Lessons learned from this process will be synthesized as conclusions and recommendations in the following section.

Nothing out of the ordinary was observed during delivery and staging of the panels. The panels are considerably heaver than wood sips and smaller (wood SIPs often come in 8'x24' panels). Habitat supervisors indicated that the panels arrived on site very late in the night when delivery was scheduled for early afternoon. This speaks to the overall quality of services provided by the manufacturer.

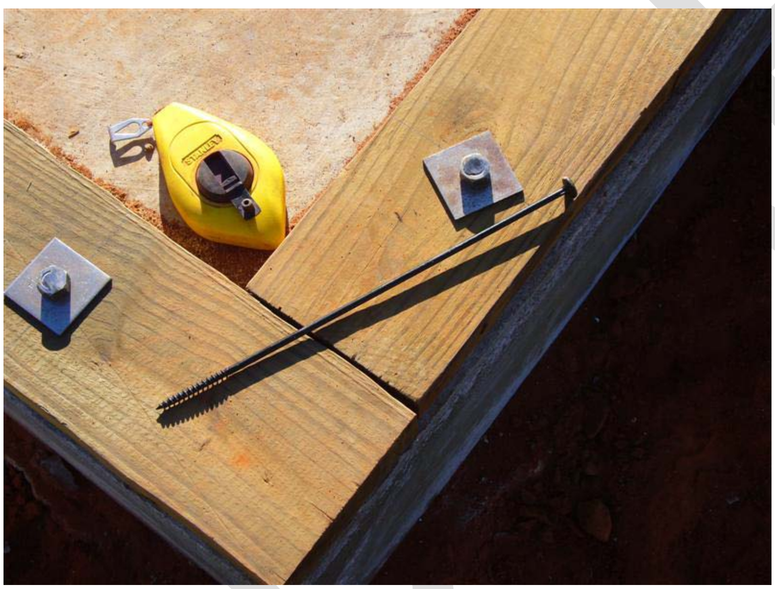
The pier, or stem wall, house had the floor system already installed when I arrived on site. Note: the panel splines are made only on the topmost surface (the manufacturer stated that the bottom splines are "optional") and fasteners are only made on the topmost side. There are no intermediate members running through the panels. All the panels are simply resting, on their edges, to the beams spanning between the piers. A secondary member is needed tying the panels into the beams and making the beam rigid. A general note, more wood and proper fasteners are needed in the floor system. Connections between the floor system and the piers/stem wall need further consideration. Generally the floor system details are poor. The manufacturer instructed the Habitat supervisors to deviate from the engineering specifications set forth in the drawing set. Habitat had originally intended to put dimensional lumber in the floor panels.

A better view of the floor system of the house on piers; note no intermediate members are tying the panels together.

Volunteers are tying the bottom plate (here a treated 2x6) to the piers at the treated plate resting on the piers. To accomplish this they are driving 12” panel screws through the 8” splines at an angle. They cannot drive them straight because the screws will hit the concrete foundation. These screws are tying both the bottom plate of the wall and the floor system to the foundation plate not the concrete piers. This detail was modified by the manufacturer and clearly deviates from the engineering drawing set.

Bottom plates at the corners are touching, therefore requiring the panel corners to be cut or notched out. This causes the panel facings not to rest directly on the slab. This asymmetry on loading the panels could cause cracking and other construction irregularities. This detail is not approved by the larger SIP industry – instead they require the plates to be separated by the width of the panel facing.

Notching of panels is inconsistent with industry practices and may create stress fractures at the joint. Because this is an end panel, there is dimensional lumber at the end and the stress fractures should be contained, but this can easily be avoided with plate modifications.



Pictured is a comparison of the anchor bolts, every 4’ o.c. and the panel screws that are being used to hold down the floor system. This is not a direct comparison as the screws are placed on an angle so that the 12” length won’t hit the concrete 10” below. It is unknown whether these screws have been designed for this type of installation. It is also unknown what the pull through, and pull out strength of these connections is. Note, the larger threaded rods are being spread over a washer to hold the bottom plate. This is another deviation from the engineering drawing that the manufacturer implemented.

The floor system must be notched to work around anchor bolts. Also, note the drywall screws are the only tie of the pier top plate and the floor system until a panel screw is recommended by the manufacture. This detail needs a proper connection to insure that the system is tied together and the floor system is tied into the beam and piers. This detail is lacking.

The first panel being set by The manufacturer and Habitat. Note, the 2x located at the joint falls short of the top plate. Also, note that the crew is pushing the near corner in first, which may cause cracking on the panel. This may be necessary because the treated bottom plates were installed without cutting them to the size of the panel (i.e. 5.5”). Treated lumber swells and must be sized so that the panels fit easily onto the bottom plate track. This panel was not damaged during the first set, but was damaged after it had to be removed and the panels around it were removed. The installing/uninstalling of panels contributed to a poor quality of the installation – all due to a poorly fabricated package.

The second panel in the corner is set. It must be leveled to insure that the wall plane is square. Typically this work is done from the far corner out towards the front of the house, instead of starting at the front of the house.

Brian, Habitat's construction supervisor, notices that the roof pitch was incorrectly fabricated on the panels. At this point, we notice also, that the beam pockets are also missing.

Progress on day two cannot be judged by the progress being made in installing the panels, because as the team was installing the panels, we noticed that the panels were not fabricated correctly and panels were being uninstalled, repaired, and re-set. Progress is typically started on one corner (the far corner) and works out in two directions. In Mobile, there was no structure to the installation and no shop drawings to help coordinate the panels being set. Because a lot of the panels were installed then uninstalled, the finish quality is poor, yet this is also compounded by poor quality from the factory and poorly aligned and set interior panels.

The manufacturer personnel making modifications and cuts to the panels. Using a circular saw, the panels kick up a lot of dust and no one on the jobsite was wearing a respiratory. Habitat volunteers and staff did not cut any panels. Most companies use circular saws in the field because they are common place, but most use panel routers in the factory to get clean cuts and to easily collect the dust (Routers don't "throw" debris like circular saws).

The concentrated load transferred at this panel location requires dimensional lumber (as a column) to be integrated into the panel. This type of connection is traditionally made at the panel spline (the point where two panels connect) but because the manufacturer left it out, it had to be field cut and placed in a location that is not preferred.

Here volunteers are going panel joint to panel joint to screw the splines into place. However, we noted that a lot of splines did not pull to the face of the panel because of excessive cuts in the foam – pockets too deep and too large – and because the panel splicing material is also cementitious. Screws holding into cement fiber board do not hold as well as screws in wood. It should be recommended that the splicing material is either wood or metal. To accomplish this, a super spline (SIP used as a spline) should be produced with metal or wood facings.

A crane was used to lift the CSIP panels onto the roof – an unconsidered additional cost. Habitat elected to have the panel manufacturer install the roof panels so volunteers wouldn't be at risk.

The two CSIP homes were enclosed – just in time for a March 21, 2007 ribbon cutting ceremony held in Mobile to mark the 500th house erected in the Gulf Coast by Habitat for Humanity International. This allowed Habitat to begin working on the interior of the homes.

Here the building is shown roughly 60% complete.

Despite the considerable and unexpected construction difficulties faced, Habitat's construction crews finished the two homes in the Spring of 2008.

On April 10th of 2008, a dedication and key ceremony was held for the two homes. At this time the homes were turned over to the two families for occupancy.

FAS's Senior Director for Corporate, Foundation and Public Outreach Jeff Aron was on hand for the dedication.

Project Analysis

One of the goals of the project was to complete monitoring and analysis comparing construction activities, construction costs, construction timeframe, and energy efficiency of the panelized houses with regular Habitat stick-built houses.

Construction:

As described in the previous section, there were many major issues with the construction of the two homes. Unfortunately, these complications have resulted in delays, less than perfect construction, and significantly higher than anticipated costs.

One of the major issues from this project was the selection of a reliable vendor. Unfortunately the vendor failed to meet the deadline for the delivery of panels, as only the first installment had arrived by the first day of construction. In addition, approximately 20 percent of all panels endured small amounts of damage during transportation, and not all panels were cut precisely. This meant they did not have a perfect fit and were mismatched, making the lego-like construction far more difficult. All of these issues slowed construction and required extra work by Habitat staff.

This also extended the time-table of construction. The shell of a typical SIP home can be enclosed within 3 days; the two Mobile houses took weeks longer than originally planned, which caused problems with volunteer schedules. This extended the total construction deadline by 4 months.

While CSIPs – and SIPs in general – are relatively straightforward and less labor-intensive to build compared to traditional construction, the Habitat project demonstrated the need to have a sufficient number of trained personnel on site to guide volunteers, many of whom were unfamiliar with formal construction processes and of course unfamiliar with SIPs. FAS Building Technology Project Manager Joseph Hagerman's presence on the site was a valuable asset for managing the manufacturer quality that was received on site; both FAS and Habitat for Humanity were disappointed with the overall quality of the product supplied from the vendor

While these results are unfortunate and can skew the perception of CSIPs, they do demonstrate the importance of many constructability issues. FAS has made recommendations, both specific and general, for avoiding these issues in future construction projects. These can be found in the Conclusions and Recommendations section of this report.

Energy Performance

METHODOLOGY

In order to determine the effectiveness and appropriateness of SIP construction techniques for Mobile Habitat for Humanity, the energy consumption of this SIP house was modeled in parallel with that of a traditional stick-built home. These houses have the same dimensions but are not identical; instead they follow industry practice for each product. These differences will be discussed in more detail below. EnergyGauge USA served as the tool for this analysis. This software uses DOE-2 hourly building energy simulation software. It then couples DOE-2 outputs with local energy costs to estimate annual electricity expenditures. In addition, this tool estimates emissions due to energy use, produces HERS ratings, and confirms IECC compliance. The following analysis considered only the effects of different wall systems on heating and cooling, as other end uses would not vary significantly between two identical homes with identical inhabitants. In addition, this analysis applies only to Mobile County Habitat for Humanity, as different climates and building practices would change the applicability of this information.

Two primary characteristics were used to differentiate between the SIP and traditional houses using EnergyGauge USA. First, the SIP components were modeled by changing the R-value and framing fraction of wooden framed walls. These changes in insulation levels resulted in corresponding changes in energy consumption. Although EnergyGauge does not include SIPs in its library, this approximation is appropriate. Other energy modeling programs include some basic SIPs, but these programs lack many of the features included in EnergyGauge (HERS ratings, IECC compliance, etc.). Modeling SIPs by changing R-values and framing fractions is common to many energy modeling programs. The second varying characteristic is that the SIP house was modeled with a vaulted ceiling while the traditional house was modeled with an unconditioned, vented attic. The effects of this drastic change in conditioned volume will be discussed later.

Each construction type was modeled twice, once according to code and once below code. The object of this test was to investigate and gain a quantifiable understanding of the effects of quality control in both SIPs and traditional construction. The models of houses “to code” represent theoretical results from the house design. The houses modeled below code represent realistic expectations due to errors in manufacturing and construction. Therefore, the “SIP not Code” house most closely resembles the house constructed during this project. The insulation grade, framing fraction, and infiltration were varied to differentiate between the two instances of each house. These additional models proved the importance of effective construction techniques: conditioning the houses built below code would cost approximately ten percent more each year than the houses built to code.

The Habitat Hybrid model is a house of SIP walls and a framed roof with an unconditioned attic. In addition, an online insulation tool (discussed later) was used to determine the most cost-effective level of insulation for the climate in Mobile. These two points are discussed later in our recommendations, but the Habitat Hybrid analysis results are included in the aggregate data for ease of comparison.

The Energy Star model is an extension of the Habitat Hybrid. This theoretical house was modeled to reach an HERS rating lower than 85 in order to qualify as an Energy Star residence. In order to do this, the Habitat Hybrid was augmented by 6” SIP walls, R-50 insulation in the ceiling, and a radiant barrier system. By dealing with structural characteristics, this design does not interrupt the existing supply chain for windows, doors, and other components by requiring advanced products for these applications. This model is also included in the aggregate data below.

RESULTS

Annual Energy Consumption and Expenditures

	THEORETICAL				**REALISTIC**				**FUTURE PROJECTS**			
	SIP to Code		**Wood to Code**		**SIP not Code**		**Wood not Code**		**Habitat Hybrid**		**Energy Star**	
	kWh	Cost	kWh	Cost	kWh	Cost	kWh	Cost	kWh	Cost	kWh	Cost
Cooling	2125	$170	1735	$139	2271	$182	1846	$148	1864	$149	1665	$133
Fan	396	$32	323	$26	419	$34	340	$27	343	$27	305	$24
Heating	672	$54	788	$63	844	$68	959	$77	892	$71	559	$45
Fan/Pump	108	$9	130	$10	137	$11	159	$13	147	$12	92	$7
Total	3301	$265	2976	$238	3671	$295	3304	$265	3246	$259	2621	$209
Per Volume	0.246	$0.020	0.325	$0.026	0.273	$0.022	0.361	$0.029	0.355	$0.028	0.286	$0.023

Annual Emissions[6]

	THEORETICAL		**REALISTIC**		**FUTURE PROJECTS**	
	SIP to Code	**Wood to Code**	**SIP not Code**	**Wood not Code**	**Habitat Hybrid**	**Energy Star**
SO2 (lbs/ft^3)	0.003	0.005	0.003	0.005	0.005	0.004
NOX (lbs/ft^3)	0.001	0.002	0.001	0.002	0.002	0.001
CO2 (tons/ft^3)	0.0003	0.0005	0.0004	0.0005	0.0005	0.0005

[6] Figures also include emissions due to lighting and miscellaneous end uses.

HERS Ratings

THEORETICAL		REALISTIC		FUTURE PROJECTS	
SIP to Code	**Wood to Code**	**SIP not Code**	**Wood not Code**	**Habitat Hybrid**	**Energy Star**
90	97	91	98	88	81

IECC Compliance

	THEORETICAL		REALISTIC		FUTURE PROJECTS	
	Sip to Code	**Wood to Code**	**SIP not Code**	**Wood not Code**	**Habitat Hybrid**	**Energy Star**
IECC Comp	YES	NO	YES	NO	YES	YES
eRatio[7]	0.93	1.03	0.95	1.04	0.93	0.82

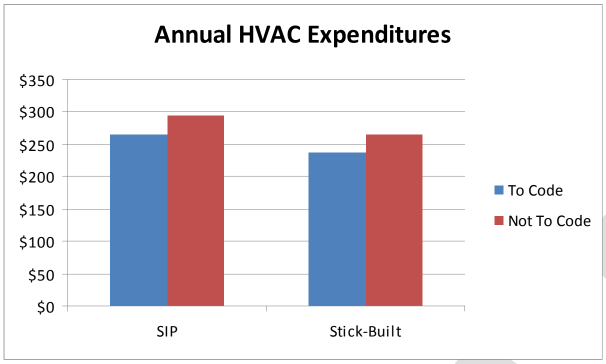
ANALYSIS

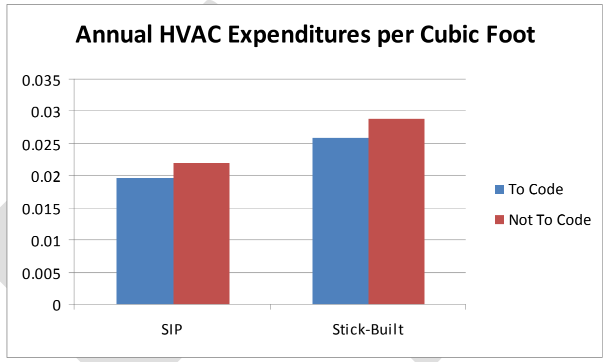
Energy Consumption and Expenditures:

Under a strict comparison, EnergyGauge USA concluded the home built using traditional construction techniques consumes less energy and costs less to condition over the course of one year. The well-built SIP house performed comparably to the poorly built wood frame house. Throughout several modeling iterations, the SIP homes consistently demanded more energy to cool. Meanwhile, traditional construction techniques resulted in higher heating loads. In Mobile, annual cooling degree days dominate the demand for energy. Therefore, the results of this analysis cannot be applied to any climate; similar construction techniques in colder climates could yield completely different results.

[7] The eRatio is a figure produced by EnergyGauge to quantify the score of a home for IECC compliance (as opposed to a simple pass/fail). Each house must achieve a 1.0 to pass the IECC compliance test. As with HERS ratings, lower eRatios are awarded to more efficient homes.

The outcomes of this analysis are not completely transparent. After close examination of inputs and outputs, we concluded that ceiling and roof construction complicated this analysis, obscuring the results. The SIP house was modeled with vaulted ceilings; the traditional wood frame house was modeled with an unconditioned attic. In order to account for this difference in construction, energy use and expenditures were scaled by cubic foot of conditioned volume. The results of each method are displayed graphically below:





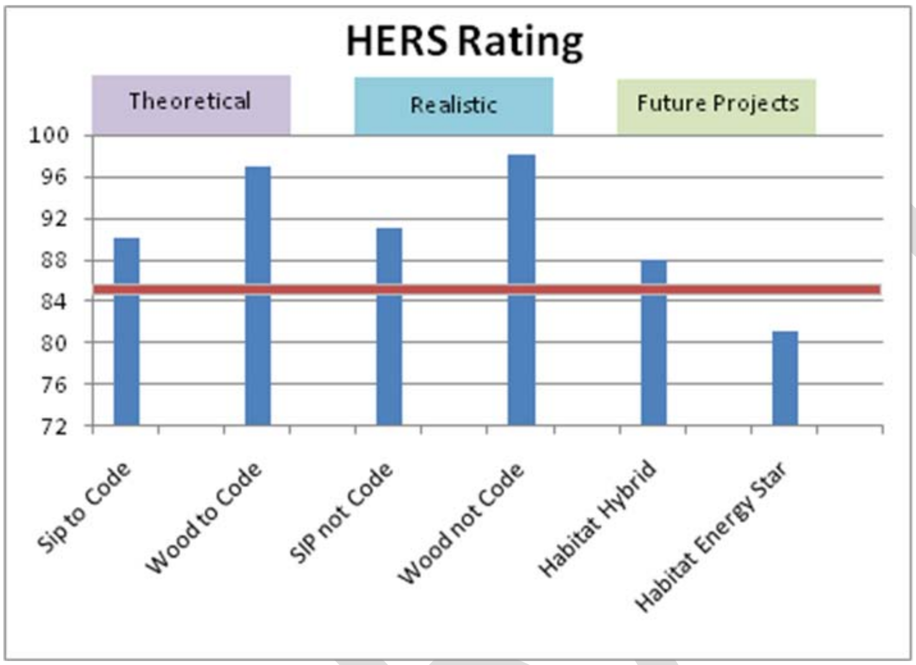
As these figures depict, the effects of unconditioned attic space can be significant. The approximate conditioned volume of the SIP house is 13,442 cubic feet; the traditional house, 9,152 cubic feet (a difference of almost fifty percent). As a result, the volumetric cost of heating and cooling favors SIP construction by a difference of nearly thirty percent. The Habitat Hybrid and Energy Star concepts attempt to resolve this issue through a combination of SIPs and traditional construction.

Emissions:

The emissions for these homes correlate directly with the energy use and expenditures summarized above, although these estimates also include emissions from lighting and miscellaneous use. Because each model home uses the same fuel (electricity), these results do not reveal any new points for consideration. However, it is still important to analyze and understand annual emissions, particularly when dealing with houses consuming different fuel types or using electricity from different power plants (although electricity source is not included in the analysis by EnergyGauge USA).

2006 HERS Index:

EnergyGauge USA produced favorable HERS ratings for the SIP houses. In fact, the difference in ratings between the two wood homes and the two SIP homes far exceeded the effect of proper construction. The HERS ratings varied by just over one percent due to code compliance. Meanwhile, the two types of construction differed by almost ten percent. These results, although seemingly contrary to the annual energy consumption analysis, confirm the effect of conditioned volume. While the SIP homes must use more energy to condition a greater volume, they are more efficient than traditional construction. The two alternative houses for future consideration scored exceptionally well under this test. The graph below compares the results of this HERS test with a red line representing the benchmark for Energy Star homes; these homes must score under 85 to qualify for the Energy Star label.



IECC 2006 Section 404 Compliance:

The tests of International Energy Conservation Code compliance reconfirmed the effect of conditioned volume. Surprisingly, the two stick-built homes failed the compliance test altogether. Again, even the poorly constructed SIP home outperformed the well-built traditional construction techniques.

FACTORS AFFECTING RESULTS

EnergyGauge USA automatically estimates appropriate HVAC hardware during each simulation. Therefore, the capacities of the heating and cooling systems in each house varied significantly. While this is appropriate for house design and modeling, it is not necessarily realistic. Analyzing each house with a fixed HVAC system may produce different results, but it could also unfairly favor a particular home.

This analysis only considered electricity as a fuel source for all end uses. Therefore, the discussion of emissions and comparisons of costs do not reveal any important trends hidden by the electricity usage estimates. However, fuel source would be an important aspect to consider in future analyses, particularly because of the difference in emissions from each fuel source.

Other components of the houses could have affected the results. These include windows, doors, lighting, and appliances. While all of these were fixed across the different models, these factors could also be changed to design a cheaper and more efficient home.

Costs

FAS does not believe the cost of this project is representative of CSIPs as a technology. While this is unfortunate, it has provided a valuable lesson for the importance of specific variables, including constructability. This analysis will describe the project as it happened, and use these shortcomings to inform recommendations to avoid future problems.

The typical cost of a Habitat house is approximately $40,000-50,000 while the costs for the two demonstration projects were approximately $75,000. The major areas of extra cost are due to the defective panels and the panels requiring extra field modification by the manufacturer. However, electrical subcontractor costs (because of additional work), additional material and labor for finishing the houses, and additional fees to operate the jobsite were also incurred. Because the entire house was made of cementitious panels the costs were compounded due to the defects, which lead to overruns, overages, and cost inefficiencies.

Additionally, the increase price in the panels because the entire house was constructed out of CSIPs increased the overages. The final budget for the houses was $75,000 each. There was little or no difference in cost due to the traditional foundation or the slab. The overages and additional materials were shared on each house to an exact number is hard to determine. These additional costs made the project 50-100% more than a typically constructed habitat house.

These results should not be seen as representative for the following five reasons:

1. The house had to be constructed and unconstructed due to the panel defects. This ultimately costs excessive amount of time because the panel supplier had to correct the panels not Habitat or volunteers. Additionally these in the field modifications to the panels resulted in subsequent costs for habitat to absorb to insure the house was well constructed, well finished, and ultimately durable for the long term.

2. The modifications to the panels required extensive repair on the interior and exterior that was not in the original architectural details and additionally sealing and insulating which could have been avoided. These types of problems can be avoided by following the constructability issues presented earlier in this report. Ultimately, constructability resulted in additional costs and time for volunteers.
3. The vaulted space required additional finishing and detailing that is atypical of habitat construction. While this design takes advantage of the properties of the SIPs, it takes additional work for Habitat and ultimately requires more energy to operate given the increase in volume.
4. The electrical subcontractors were unfamiliar with sips, and the panels were manufactured with atypical raceways which were difficult to wire and finish. The additional work to habitat is approximately at $10,000 alone.
5. Habitat's construction advantages, lots of labor requiring often little supervision, was not properly leveraged using panels throughout the building, using panels with defects, and using panels that were heavy and in need of modification.

Despite the unexpected and unrepresentative results, the experience provided FAS with many important lessons for future design projects. These recommendations will be included in the Conclusions and Recommendations section of this report.

Cementitious Structural Insulated Panels & Istanbul, Turkey

Abstract

Turkey has many populated areas located near large geological fault lines and is struggling to find a way to build safe housing and commercial structures at an affordable price. Any technology adopted by Turkish construction firms will affect the entire region since Turkish firms are major providers of construction services in Central Asia. FAS worked with IHLAS, one of a largest construction firm in Turkey, to build several demonstration homes in Turkey using the Cementitious Structural Insulated Panel system. The collaboration will also work in the future to ensure that the panel system complies with Turkish building codes. Also, FAS worked to help deliver information to the partners to evaluate if plants for fabricating the panels can be built quickly in Turkey.

Project Narrative.

The Federation of American Scientists, Washington, D.C., USA, and IHLAS Holding A.S., Istanbul, Turkey, initiated activity in 2006 on advanced building technologies that are earthquake-resistant, energy-efficient and affordable.

Seismic and energy goals are especially important in Turkey, as well as the United States, leading to the joint activity. The major joint undertaking is the construction of a demonstration house—the Lale villa, in the Güzelşehir development on the Sea of Marmara. A critical element in the preparation of the final designs of buildings using SIPs is that they meet the Turkey earthquake-resistant building standards. In future projects this will require coordination between the U.S. earthquake-engineering research and standards activity and the similar activity in Turkey, such as the work at ITU and METU, to get SIP panels fully tested and certified to all Turkish codes.

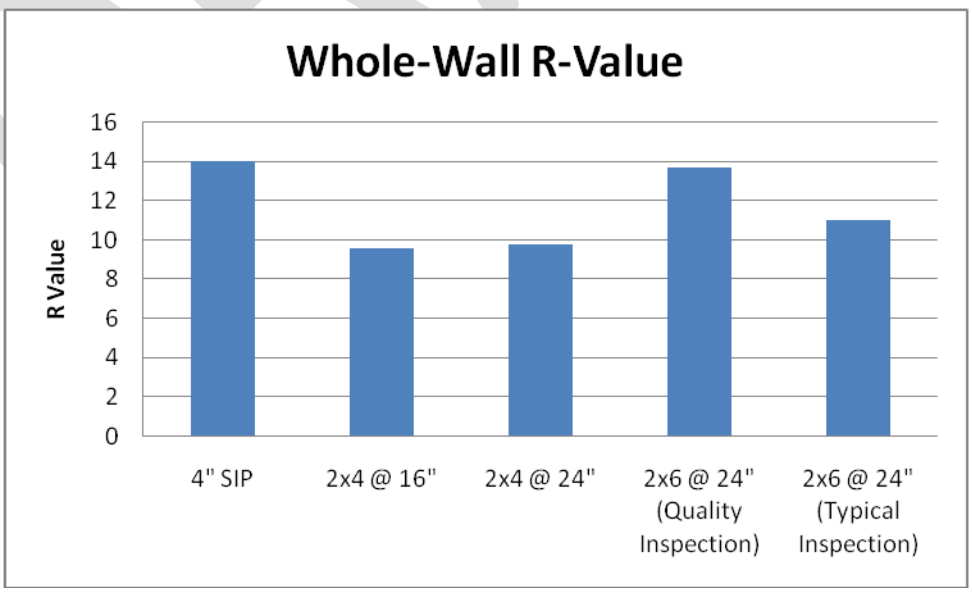
The ultimate goal of this demonstration is the international transfer of advanced building technologies. The FAS work on advanced composite materials and their applications has promising international applications, particularly in seismic active areas that currently rely primarily on masonry construction. The international technology transfer also provides important social, economic, and political benefits.

Project Planning:

The first step in project planning was the selection of Cementitious Structural Insulated Panels for the homes. FAS felt that the advantages of CSIPs could be leveraged to address the requirements of International development very well. Some of these major characteristics of SIPs/CSIPs are:

- **Seismic Robustness:** SIPs inherently can carry seismic loads and offer responses that differ from traditional concrete construction. The SIP industry is currently evaluating SIPs and CSIPs for its seismic response factor, robustness, and connection optimization. Some of this research is funded by FAS and is recognized to be critical at long term success as a product and to address code concerns. FAS sponsored research conducted by Professor Khalid Mosalem of the University of California Berkeley should prove to overcome this roadblock. Mosalem is employing the use of pseudo-dynamic analysis to study the system performance of SIPs under seismic loading. While this research is still not completed (and the seismic resisting value of SIPs is not fully known), CSIPs are a potentially valuable technology in seismic regions.

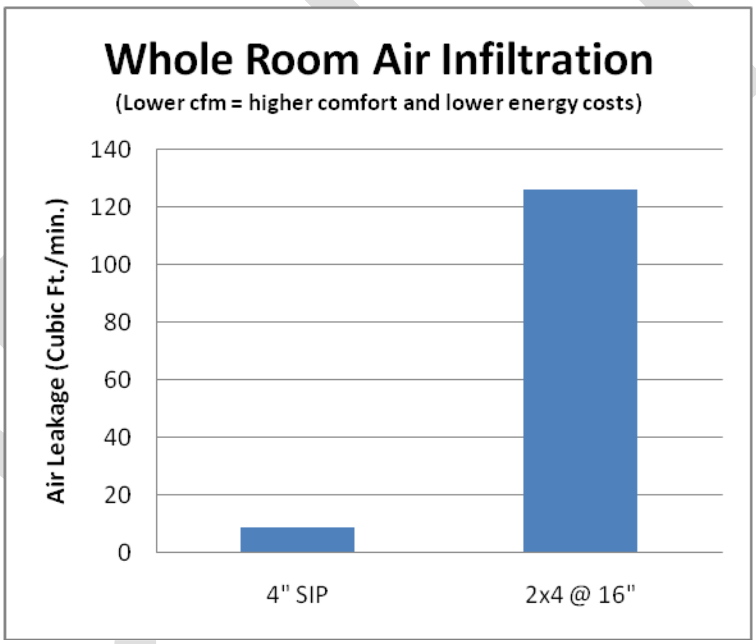
- **Thermal Performance:** Insulation is crucial to the structural make-up of a SIP, and it follows that the end product carries high quality thermal performance. Panel connections are designed to eliminate thermal bridging, a common problem in stick frame construction. What results is a building envelope with a higher total wall insulation value. While there are many benefits of this, a key factor for Habitat is the reduced energy use and energy costs, an often heavy burden for families in Habitat provided housing.



- **Ease of Construction:** CSIPs fit together like puzzle pieces, making their construction simple and straightforward. In addition, the cement fiber board facings do not require further finishing, removing several steps from construction. This is a significant benefit for Habitat for Humanity, who relies upon heavily inexperienced volunteer labor.

- **Construction Time:** It is difficult to quantify increases in construction time, as this differs significantly between projects. However, because SIPs constitute an entire wall assembly and are shipped to a job site ready to be placed on a foundation, construction is simple and quick. This is a significant benefit for Habitat, as volunteer crews are usually operating on a weekly basis.

- **Increased comfort:** Heating and cooling is more evenly distributed in a SIP home. As shown in the following diagram, SIP walls have a more consistent temperature, free of the spikes found with frame wall construction. This is a difficult quality to measure, but has a significant impact on occupant comfort.



- **Decreased Job Site Waste:** By using prefabricated panels in construction, significant waste is avoided on the construction site. It also makes for an easier to maintain job site – especially helpful when working with untrained and inexperienced volunteers.

After deciding upon CSIPs for the construction system, FAS selected a CSIP vendor. Working with the vendor, FAS and IHLAS created a set of plans, optimizing a traditional IHLAS design for panelized construction. Panels were fabricated in Florence, Alabama, and then packaged and shipped to Turkey for construction.

Construction:

The construction consisted of three key events which had to be overcome to complete the project: 1) Damage to the panels from exporting, 2) delays and re-engineering due to making use of the shipped panels, 3) modifications to insure the final design was seismically safe. These three areas are the focus of this report.

Damage Due to Panel Export

At the location on the dock of the loaded flat racks, a surveyor determined whether the cargo was ready for shipping. Based upon the restacking, the shipping company accepted the panels for shipment and the vessel. The purpose of the inspection was to determine if the restacking had caused damage to the panels and whether the restacking was done in such a way as to prevent damage during the shipment from the US to Istanbul.

The restacking had caused significant damage to many of the panels according to visual inspection. The panels, most frequently 4’ by 10’ or 12’, were loaded in stacks, two abreast, in three rows the length of the flat racks, and making six stacks on each flat rack.

Two major changes were made in the restacking. The expanded polystyrene (EPS) blocks on which the stacks of panels were initially loaded had been replaced by 4x4” wooden blocks. A second fiberglass strap had been placed over the tops of the stacks and cinched down to double the tension on the top of the stacks.

As a result of these changes, there was a significant increase in tension on the cementitious panels. The exposed side of each of the stacks of panels was examined, noting any damage that would be likely to destroy or greatly reduce their structural integrity and serviceability. The most serious breakage was to the cement panel facings on the top edge of panels on the top of the stack adjacent to the second strap and on the cement facing on the bottom of the panels near where the 4x4” wooden blocks had replaced the EPS foam blocs. The close proximity between the breaks in the cement board facings and the added straps and 4x4” wooden blocs indicated that the changes during the restacking were the cause of the breakage.

The damage differed somewhat from flat rack to flat rack. In addition to these severely damaged panels, many additional panels had minor damage, such as small breaks in the cement board or minor pieces cut from the ESP foam. This can be compensated for on-site with additional foamed insulation, glue or mortar and minor repairs.

In addition to the damaged panels, the manner in which the panels were restacked appeared to make some of them vulnerable to additional damage during shipment. On five of the stacks of panels, the straps over the top panel came down over the edge of a cement board facings without supporting 2x4s" to absorb the tension of the tightened straps. The motion during shipping and handling will make these cement board facings vulnerable to breakage. The horizontal plane of the panels on the bottom of the stacks showed some distortion as the pressure by the 4x4" blocks caused a compression of the panels and some expansion in the areas between the blocks. This could worsen during shipping and could make the panels unusable.

It is estimated that about 30 percent of the panels were severely damaged in shipment. Much of the damage appeared to have been made by the straps that went over the top of the stacks of panels. In addition, the panels were the only product that was still on the flat racks. None of the splines, fasteners, equipment or glue that were shipped with the panels were in the shipment that arrived in Istanbul.

Ongoing Construction Difficulties

Our Turkish partners had serious problems in the construction of the demonstration "Lale" villa, but persevered and learned along the way. The demonstration developed slowly because of problems with the panels, the engineering drawings, and the weather.

The foundation and first floor of the panels were completed in three weeks. According to the Turks, there were a number of problems with the panels and engineering drawings, in addition to the broken panels. Chases were not cut in the correct locations. There was not a tight fit between the panels to facilitate a consistently good connection to the splines. Some of the window and door openings were not precise enough. The screws to secure the second floor panels weren't long enough and it took some time to find longer screws. The Turks reported that about 30% of panels were damaged during shipping.

In addition, the Turks were worried that the extra set of panels shipped (for testing) may not reach the Istanbul Technical University due to the panel deficit in the house. Afterwards, the steel beams arrived and work began on the second floor. The head of the construction company, didn't believe the panels themselves are strong enough to support the second floor and the roof, so steel columns are being added to provide additional support. There were some questions as to why the roof panels had to be so thick and heavy, adding to the need for the steel supporting columns.

Many of these problems relate to quality control. Any shipments from the U.S. need to be protected from damage. This can be achieved by the creative use of closed containers, as well as local fabrication. Turkey manufactures some alternative facing materials that have greater strength.

Modifications to Insure Seismic Safety

During a trip to Turkey, Henry Kelly, Joseph Hagerman and John Millhone had the opportunity to visit the construction site, where the shell of the house was almost complete. Due to the large number of damaged panels, Turks had opted in for a conventional roof with steel beams and wood panels. The damaged panels also forced Turks to consider alternative ways to improve panels' structural elements, which resulted in a large steel frame built to hold the panels up.

The timing of the FAS trip to Turkey was very fortunate as Joseph Hagerman got a chance to view the house prior to its completion. Upon observing the construction methods Turks employed to reinforce the two-story, 3000-square-foot house, Mr. Hagerman made suggestions to modify places where SIPs' structural advantages could be optimized. Suggestions to enhance the home's structural stability included:

- Stiffen the Floor Diaphragm and Tie the Floor Diaphragm into the Steel Framing,
- Re-skin Cut Walls,
- Tie the top plate of the first floor, the second floor system, and the second floor bottom plate with metal strapping or plates, and
- At the Corners of the exterior walls, tie the exterior wall diaphragms together.

Both John Millhone and Joseph Hagerman agree that constructability issues mimic those endured in other case studies, and that technology transfer remains a challenge despite Turks' efforts to familiarize themselves with a brand new concept in construction.

The following pictures, taken during by Joseph Hagerman during this visit, illustrate these constructability issues.

Rendering of Lale House.

Near complete shell. This shell was completed with mix-and-match panels because of the panel shipment problems. As such, the local engineers had to reinvent how the shell was to be constructed and had to “figure it out themselves” as how to integrate CSIPs into their traditional construction practices.

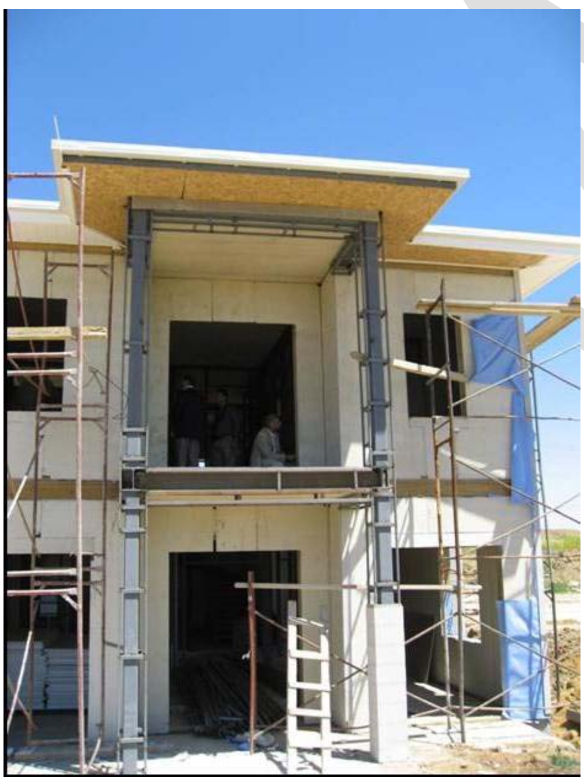
This detail shows CSIP panels resting within the web of floor trusses, thus spanning the distance between the floor trusses to act as floor joists. However, the CSIPs are simply resting in the web and do not form a continous diagphram. FAS identified a method to correct this by tying the floor diaphram together by redecking the second floor.

This detail shows what quality of panels the Turks had to work with. Almost all the panels where broken, thus requiring the local engineers to mix and match panels to re-engineer the building without any experience with SIPs. This problem led to construction inefficiency and delays. In some areas, FAS recommended reskinning these panels.

Here, steel c-channels were used to construct the interior walls. Originally, these walls were to be CSIPs, but the broken panels lead to many of these to be used on the exterior shell and interior, local framing used to frame the interior building.

The Turks cut panels to fit plumbing and electrical because chases were left out or improperly fabricated. This problem is a result of poor QA/QC in the fabricator due to vendor problems. These types of problems led to construction inefficiency and delays.

This detail also shows what quality of panels the Turks had to work with. In some instances (such as this), FAS recommended reskinningpanels.



Here, the Turks used metal columns, yet broke the columns at the second floor rather than continuing the columns to the top. Therefore, there is very little material tying the two floor systems together. FAS identified this problem and recommended tying the wall systems together and floors together through exterior metal ties.

FAS inspected the panels to be used in testing and found many were too damaged to lead to product approval in Turkey. It is recommended that proper tech transfer be developed by leveraging the countries assets rather than importing new products into the country. If anything, the US should be exporting the equipment, QA/QC measures, testing services, and know-how.

As shown here, almost all the panels where broken due to improper shipment.This problem is a result of poor QA/QC by the fabricator.

Project Analysis

One of the goals of the project was to complete monitoring and analysis comparing construction activities, construction costs, construction timeframe, and energy efficiency of the panelized houses internationally.

The introduction of advanced SIP panels in Turkey and, potentially, in other countries in the region, will require a considerable investment of time, attention, and financial resources. This task will begin the assessment of the potential market for the buildings that could incorporate the SIP technology. Because of shipping costs and to ensure quality control, a SIP manufacturing plant would need to be constructed in Turkey. In addition, an education and marketing campaign would need to be launched to inform prospective buyers of the earthquake-resistance and energy-efficiency advantages of the buildings.

The SIP plants in the United States range from those that are quite simple, such as the ThermaSAVE plants, to more modern plants. To make an informed decision on a Turkey plant, it will be important to become familiar with the full range of the existing U.S. plants and obtain the recommendation of an experienced industrial engineer on a plant design that would meet the requirements of the Turkey business plan. The most critical component of the panels is the facing material. Turkey has manufacturers of cement board facings which appear to be of good quality. Arrangements should be made to include a SIP panel using the Turkey cement board facings in these tests.

Construction

As described in the previous section, there were many major issues with the construction of the home. Unfortunately, these complications have resulted in delays, less than perfect construction, and significantly higher than anticipated costs.

Some constructability issues began long before the panels arrived on the job site. Some of these issues can be avoided if the unique characteristics of the SIP panels should be considered from the beginning of the engineering and architectural design process. While the panels can be cut to fit a wide variety of designs, this adds significantly to their cost, construction complexity, and construction time. Engineering and architectural members of our team prepare a list of the potential modifications to SIP-designed building, starting with the most basic changes and proceeding to those that are optional and more expensive. This approach would provide the information needed to make trade-offs between costs and features.

Change	Benefits	Cost
The structural strength of SIPs should be incorporated into the design so they aren't treated simply as curtain walls	Lowers cost of structural elements	Lowers cost
Steel supports should be added, as necessary	Provides structural strength	
SIP panels should fully enclose the living area	Energy savings. Increased comfort	Lower costs
SIP panels are not necessary for the roofs or interior walls.	Improves ease of construction	Lowers costs
An attic fan and air vents reduce heat build up in the attic	Reduces air conditioning load	Lowers costs
Add energy and temperature monitoring package	Identifies energy savings, problems	
Balconies are a high priority in Turkey	Increases house value	Added costs
Steel support columns should extend from the foundation to the roof, with a break	Structural strength	
Plumbing and wiring should minimize penetration of SIPs	Eliminates energy losses	
Heating and cooling equipment can be reduced in size because of improved thermal efficiency	Equipment sized to load	Lowers costs
Insulation of foundation exterior may lower heating costs		
High reflective roof tiles	Reduces air conditioning load	Lowers costs
Add solar energy system to Lale Villa	Demonstrates renewable energy	
Meets "Green Building" standards	Demonstrates high efficiencies	Some costs

Table 1: Proposed Modifications to the Future Turkey/International Demonstrations

However, simply optimizing projects for CSIPs to make construction easier does not solve all constructability problems. One of the major issues from this project was the selection of a reliable vendor. Unfortunately the vendor failed to export the panels safely, failed to provide engineering drawings that the Turks could use, and failed to provide technical support on the ground. All of these deficiencies lead to compounding problems. Proper shop drawings must be done, and panels must be cut exactly to project requirements. Care must also be taken during shipment, and panels should be made locally if possible to reduce shipment requirements.

These pre-construction issues caused significant delays on the job site. However, the project also demonstrated the need to have a sufficient number of trained personnel on site to guide workers, all of whom were unfamiliar with SIPs. In future demonstrations, more emphasis must be placed on training construction crews and engineers rather than actual construction because it is more important that the international engineers, project managers, and construction personnel are trained using panels, else we leave the technology "up to them to figure out." Therefore, proper technology transfer is the biggest issue to focus on in international projects.

FAS has made recommendations, both specific and general, for avoiding these issues in future construction projects. These can be found in the Conclusions and Recommendations section of this report.

Energy Performance

While Energy Performance is a key issue in the reasons to use CSIPs, this project's energy performance and efficiencies are unrealistic if technology transfer is successful. Because FAS didn't directly manage construction on the ground, there is no assurance as to the construction details including spline, joints, etc, and air tightness. In addition, alterations made on the job site, such as increased steel framing, significantly alter the energy performance of the home. For these reasons, the energy performance will not be estimated.

Costs

While Costs are a key issue in the reasons to use CSIPs, this project's cost are unrealistic if technology transfer is successful. The improper shipping led to excessive damages and re-engineering and modification that were atypical. This led to higher costs for other materials (used to compensate), extra construction time for modifications, re-engineering costs, etc. Unfortunately, it is not possible to remove these variables from the total cost of the house, making any analysis reflect less on CSIPs as a technology and instead on the well-documented constructability issues. While these problems have been studied to avoid cost-creating problems in future projects (with recommendations made in the conclusions and recommendations section of this report), a strict cost analysis will not be reported in this document.

Conclusions and Recommendations

While both construction projects were delayed and difficult due to factors outside the partnership's control, the results and lessons learned were successful at demonstrating that SIPs are:

- a competitive product (if the vendor is chosen correctly),
- new technology can be easily integrated into their housing model (if all the relationships are in place during the initial project planning), and
- energy savings is essential in a tightening economy to insure affordable houses are affordable to purchase, operate, and maintain.

Despite various problems and setbacks that are all too common in demonstration/construction projects, FAS feels that both projects have been truly invaluable in establishing a growing partnership with Habitat for Humanity and with International builders that has allowed FAS to observe and record data on the construction of alternative building systems. The research project was instrumental in understanding constructability issues faced in the use of CSIPS in particular and in Gulf Coast reconstruction efforts in general. After analyzing the cost, energy, and construction data, FAS has generated a large list of recommendations for future projects. These recommendations include general and basic approaches to any CSIP construction project that will help avoid many of the basic problems encountered, as well as specific recommendations to optimize CSIP construction for the Habitat model and for future international projects.

To Avoid Problems in CSIP Construction:

Construction problems compound themselves, and can significantly impact the cost of a building and its ultimate performance. When undergoing any CSIP project, there are several basic lessons to follow to avoid these pitfalls. 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:

1. **Choose the right system for your project, needs, and location,**
2. **Choose the right manufacturer for the job,**
3. **Choose a team and communicate from the beginning,**
4. **Take the correct approach when planning with the project delivery team, and**
5. **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.

The first step in choosing the correct system is to 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	
			Wood Facings	Cement Facings
Advantages	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
Dis-advantages	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 is 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

A building isn't built with only one specific material, so we can't expect each of the three criteria explained earlier to apply when evaluating the merits of SIPs. That said, considering them within this holistic framework of priorities gives a better understanding of their unique nature, as well as their contribution to a building's overall design and performance.

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.

This demonstration project was done in conjunction with Habitat for Humanity, and one of the project goals is to influence their future construction projects to embrace advanced building systems such as SIPs and CSIPs. With that in mind, specific constraints and priorities are in place. Houses are to be safe, decent, and affordable. They are to be of a simple design, to be constructed at as low a cost as possible, should be erected quickly, and should not require overly skilled labor (as Habitat employs mostly volunteers for short term stints).

First of all, SIP construction creates a good, **safe, comfortable** building. SIP panels have been tested to code-regulated structural standards based on the performance of the assembly and the durability performance of the parts. This testing focuses on transverse loading, racking-shear loading, and axial loading (all performed according to ASTM E72 standards). In addition to meeting these baseline standards, SIP panels have proven to perform well in simulated seismic and hurricane conditions, making them a good building system for disaster-prone areas.

SIPs also support **exceptional indoor air quality**. The degree of building tightness capable in SIP construction better enables mechanical ventilation to filter allergens and dehumidify air. This helps prevent mold problems, as mold and dust mites cannot survive in low humidity environments. Also, the solid core insulation of SIPs is free of the voids, compressions, or thermal bypasses often associated with mold growth in wood frame, fiberglass insulated construction.

In addition to making for high standards of indoor air quality, this tight building envelope allows for **easy temperature control and soundproofing**. While initial testing shows positive performance of SIPs in areas of fire safety and moisture control, more substantive testing must be done. For example, while many SIP producers have passed the 15 minute residential fire test under the auspices of UBC 26-3 rating, more vigorous fire codes for commercial or multi-family housing may oblige SIP manufacturers to design systems that can withstand hour-long tests. Also, moisture performance in SIPs has been rather difficult to document as current moisture tests do not necessarily measure permeability or absorption rate effectively for SIP assemblies and connections. Further research is also necessary to fully understand the cost of SIP construction. While we know that SIPs are more energy-efficient than traditional stick-built homes and cheaper to operate in the long run, there is insufficient data on capital and life-cycle costs. Even with these unproven areas, SIPs provide well for Building Science's People Priorities.

Beyond these people priorities, the most apparent advantage of SIPs is their incredible **energy efficiency** as a building system. A SIP building envelope provides high levels of insulation and is extremely airtight. Wood framing in traditional stick built construction acts as a thermal bridge, transferring heat through the wall and lowering its overall insulation value. These thermal bridges are virtually nonexistent in SIP construction, making for a more efficient building shell. This reduces the amount of energy used to heat and cool a home by up to 50 percent. Seen on a small scale this means **significantly lower operating costs** for a home owner. However, this is also important seen within the big picture. Energy used to power homes and commercial buildings is responsible for a large portion of greenhouse gasses emitted into the atmosphere, and by using SIPs to reduce the amount of energy used in buildings, architects, builders, homeowners, and YOU can contribute to a cleaner environment for the future.

SIPs also make **efficient use of resources**. The insulation used in SIPs is a lightweight rigid foam plastic composed of 98% air, and requires only a small amount of petroleum to produce. The foam insulation used in panel cores is made using a non-CFC blowing agent that does not threaten the earth's ozone layer. In fact, the average SIP home saves nineteen times the energy it took to make the EPS insulation in the first year of installation. C**onstruction waste is also reduced** by the use of SIPs in a building project. SIPs are prefabricated in a factory, cut to the exact shape and size needed for the project. This minimizes the amount of excess material that gets sent to a landfill, which is often up to 30% of material sent to a construction site and amounts to over 130 million tons annually. Also, many manufacturers recycle factory scrap to make other foam products, further maximizing the life of each piece and minimizing construction waste.

Finally, SIP construction (if done correctly) can be a very quick process. The building envelope of a SIP home can be put up in a matter of 2-3 days, which is ideal for Habitat for Humanity, who uses volunteers on a weekly basis. In addition, if they are properly cut in the factory, SIPs fit together like puzzle pieces. This makes construction simple – it is intuitive how to put panels together correctly, and unskilled volunteers can provide the majority of the labor.

All of these attributes make SIPs and CSIPs an ideal building system for many residential building projects, and more specifically, for those done by Habitat for Humanity. 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:

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".

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!

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.

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. Its 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.

While Habitat for Humanity is embracing SIPs and other advanced techniques on an organizational level, it is important that this construction knowledge gets passed down to Habitat's construction managers over-seeing site production. Having knowledgeable, strong leadership that is capable of working with SIPs will help Habitat's teams communicate and build effectively.

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 key 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.

After reviewing our past mistakes we recommend that the industry develop…

- a more robust and "building science driven" construction detailing standards to properly seal the build and insure that no vapor drive into the assemblies is possible which may otherwise compromise the long term integrity of the building,
- a more systematic approach to the generation of the shop drawings, their review, and the fabrication of the panels from these drawings,
- a more sophisticated and sound connection standard which will decrease the onsite labor and increase the overall quality of the house, and
- panelized stick build interior walls with CSIP exterior walls and a Wood SIP roof to maximize construction efficiencies.

Recommendations for the Gulfcoast & Habitat for Humanity

In addition to these general rules of avoiding problems in CSIP construction, this project has provided the following recommendations as to how to further optimize CSIPs for the Habitat model

Alternative Construction:
Ultimately, the factors influencing energy performance and lifecycle costs extend beyond construction and volume issues. Therefore, the following recommendations were designed for Mobile Habitat for Humanity's future projects considering wall construction alternatives.

Energy modeling and analysis made clear the importance of minimizing conditioned space and avoiding vaulted ceilings to lower energy consumption and costs. In order to minimize energy consumption, Mobile Habitat for Humanity should consider combining SIP and traditional construction techniques, forming the Habitat Hybrid modeled in this analysis. We recommend using SIPs to lay the floor and walls while building a traditional roof with trusses anchored to the SIP walls. Insulation could then be installed in the attic, leaving it unconditioned with ventilation. This technique would capture the best of both construction types: improved insulation and ease of installation from SIPs with minimal conditioned space from trusses.

The results of the Habitat Hybrid simulation confirm some of these expectations. For example, the annual energy bill of the Habitat Hybrid decreased by over two percent compared to the SIP house. The change in HERS rating also proved favorable. To qualify for the Energy Star label in Mobile, Alabama, a home must obtain an HERS rating of 85 or lower. In order to achieve the Energy Star label, the Habitat Hybrid could be improved by thicker walls (6" SIPs), R-50 insulation in the attic, and a radiant barrier roof, decreasing the energy demand for air conditioning. This house, the Energy Star described earlier and analyzed above, scored an HERS rating of 81 in our analysis, well under the limit of 85 for Energy Star homes. With the recommended changes, it may be possible to attain this product branding, increasing the financial and environmental value of the house and community.

In addition to its excellent HERS rating, analysis of the Energy Star home showed that it consumed the least electricity annually, resulting in lower utility bills. In addition, it passed the IECC compliance test by the greatest margin (given by the eRatio). We recommend that Mobile Habitat for Humanity investigate the potential of employing the techniques found in the Energy Star house in future construction due to the favorable results of this analysis.

Insulation Tool:
Oak Ridge National Laboratory developed a tool to determine the most cost-effective level of insulation for homes in different climates. This tool was used to model the Habitat Hybrid house. We recommend

that Mobile Habitat for Humanity use this tool to determine proper construction specifications. It requests basic information on construction and appliance characteristics, returning values for attic, cathedral ceiling (if applicable), wall, and floor insulation.

Construction Practices:
It is evident that construction quality affects energy efficiency and lifecycle costs. As these models illustrated, low quality construction can cost homeowners up to ten percent more every year on their energy bills. It is possible that SIP construction offers less risk of inefficiency due to lower construction quality. In order to fulfill its mission and propagate affordable housing, Mobile Habitat for Humanity should evaluate the effects of construction quality in both SIP and traditional construction.

In addition to these recommendations to improve energy performance, there are several steps to be taken to make the project more cost-effective. Recommendations derived from cost analysis of the houses are:

- CSIP walls should be used in the exterior of the building only.
- CSIP walls should be optimized for the floor plan so they need NO field modification
- Panelized interior walls (made from dimensional lumber) should be used in the interior.
- CSIPs and SIPs should not be used in the ceiling or roofs. Dimensional trusses should be used in for the roof, attic, and ceiling.
- CSIPs should be obtained from SIP manufacturers who have a known local track record in the community to be served, additionally; it is preferable that the SIP manufacturer be a member of SIPA. SIPA members are known for their quality, service, etc.
- Habitat should follow the constructability guide included in this report with best lessons learned.
- The manufacturer of the CSIP should hold a short training and educational seminar for the volunteers prior to starting any work.
- The manufactured of the CSIP should work with Habitat and its subcontractors before starting any planning/work, cutting any panels at the factory, and in the field construction. A manufacturers rep should be on site at all times during CSIP erection.

The Future:
In order to fulfill the project goals and to demonstrate what SIPs (or CSIPS) are truly capable of, Habitat for Humanity and FAS are planning to build a third house. FAS has taken steps to prevent the mistakes made during the construction of the first two homes by producing shop drawings to optimize architectural blueprints for SIPs. FAS will expand its research by using the third house as another data point for energy consumption and continue to partner with Habitat for Humanity.

While finalized cost data has been generated from the construction of the two homes, further energy analysis is planned. FAS will monitor the actual energy use of the homes for the next year to establish a real-time baseline of how the homes perform. In addition, a Home Energy Rating (HERS) will be performed for both houses.

Impacts and Conclusion from the Gulf Coast Activities

Attention to SIPs is at the forefront of the gulf coast reconstruction, thanks to the partnership between Habitat for Humanity and FAS. The strong working relationship the two groups have formed has resulted in increased awareness in the gulf coast of alternative means of construction – durable, storm resistant housing that is energy efficient and cost effective. Even though the project faced numerous challenges, as any technology demonstration project does, FAS and Habitat successfully promoted the advancement of technology in affordable housing.

This demonstration project helped move the FAS Building Technologies Project toward a different and more productive path by providing the opportunity to test technical and theoretical research in practice. FAS worked with Habitat for Humanity that ultimately helped to move the FAS research forward by pinpointing possible areas for improvement (i.e. shop-drawings, vendors, oversight, etc).

The project was also pivotal in demonstrating the importance of translating theoretical research into practical data, as FAS had been researching alternative construction methods without evaluating differing technologies on construction sites. Through this project, FAS has had the opportunity to observe constructability issues and how they affect the course of the construction. FAS is grateful for the opportunity to work with Habitat on future projects to apply the lessons learned from the research made possible by this grant.

Ultimately, this project also had tangible impacts as two families were provided new, innovative, and efficient homes to raise families and the future of Mobile, County.

Recommendations for Future International Projects

In addition to these general rules of avoiding problems in CSIP construction, this project has provided the following recommendations as to how to further push CSIPs into new international markets. The main recommendation of this report centers on proper technology transfer. The Lale House project consisted of three key events which had to be overcome to complete the project:

- Damage to the panels from exporting,
- Delays and re-engineering due to making use of the shipped panels, and
- Modifications to insure the final design was seismically safe.

These issues have been addressed in earlier sections. However, they could be avoided in future projects by taking several steps towards proper technology transfer. **The introduction of advanced SIP panels in Turkey and other countries in the region will require a considerable investment of time, attention, and financial resources. This will include significant education initiatives and testing to demonstrate the advantages of the technology, the proper approach to fabricating and using the technology, and code acceptance of the technology. This will also require the leveraging of local resources.**

The first, and perhaps most critical issue, for future SIP projects internationally, is education. The builders building the Lale House did not know how to integrate CSIPs, and did not trust their structural properties. If this is to be avoided, an education and marketing campaign would need to be launched to inform builders and buyers of the earthquake-resistance and energy-efficiency advantages of the buildings. As a result the CSIP walls are simple curtain walls on a steel frame.

The following groups must be trained…

- Public officials to support new technologies and their adoption,
- The inspectors for code compliance and quality assurance (this may be a subset of the general contractor).
- The home buyers to build interest in CSIP construction,
- The general contractors and home builders who will build with CSIPs, and

Public officials must be trained to support the adoption of CSIPs into local building codes, and inspectors for code compliance must be trained to recognize their proper construction. There are many steps that must happen for this education, including proper testing of materials and proper quality control and quality assurance. FAS highly suggests that any product used abroad follow the established quality control and quality assurance procedures set in place in America. This includes creating acceptance criteria for panels, and third party verification that a plant's quality control manual will meet these standards. Additionally, the testing regime of this composite can be conducted locally per the local codes, or if no codes exist, can follow the testing protocols in the US. In Turkey, for example, this may occur by leveraging tests at the Istanbul Technical University or Middle East Technical University.

For more information on the developed systems for this verification currently in place in America, see FAS's paper titled "Product Certification and Evaluation: A Comparison of Approaches to Building Product Approval" (Appendix A) and the attached information regarding panel testing (Appendix B).

In addition to educating those in charge of code regulation, it is crucial to train local contractors and builders on how to properly build with CSIPs. We shouldn't ask locals to invent how to build with new technologies or how to inspect for proper construction. It is evident that construction quality affects energy efficiency and lifecycle costs. Low quality construction can cost homeowners up to ten percent more every year on their energy bills. It is possible that SIP construction offers less risk of inefficiency due to lower construction quality if properly inspected. In order to fulfill its mission and propagate affordable housing, International Builders should evaluate the effects of construction quality and train local work forces to properly install products and inspect after installation has occurred. This will entail using industry accepted details and standards.

Following proper construction details are crucial to ensure building tightness and the full energy efficient gains of SIP technology. For proper adoption of CSIP technology abroad, currently accepted construction practices should be adopted. The Structural Insulated Panel Association (SIPA) has published a book of accepted construction practices, titled "Builder's Guide to Structural Insulated Panels", which can act as a guide. In addition, FAS has included a guideline for common construction and weatherization details as APPENDIX C.

In addition to these recommendations to improve energy performance, there are several steps to be taken to make the project more cost-effective. Recommendations derived from cost analysis of the houses are:

- CSIP walls should be used in the exterior of the building only.
- CSIP walls should be optimized for the floor plan so they need NO field modification.
- Panelized interior walls (made from dimensional lumber or lightweight steel studs) should be used in the interior.
- Some combination of trusses and CSIPs should be used for the roofs (even potentially metal roof SIPs).
- CSIPs should be obtained from SIP manufacturers who have a known local track record in the community to be served, additionally.
- Users should follow the constructability guide included in this report with best lessons learned.
- The manufacturer of the CSIP should hold a short training and educational seminar for all workers involved in the project prior to starting any work.
- The manufactured of the CSIP should work with all subcontractors before starting any planning/work, cutting any panels at the factory, and in the field construction. A manufacturer's rep should be on site at all times during CSIP erection.

CSIP homes should only be built with quality engineered drawings. The Lale house required re-engineering due to poor engineered drawings for the panels (in addition to severely broke panels), sacrificing construction time and end quality. Avoiding these pitfalls is crucial to easily adopting new technologies, and can be avoided by having proper engineered drawings.

In addition to proper education, proper technology transfer requires the leveraging of local resources. CSIPs should not be imported from the US to International locations, but rather, CSIPs should be manufactured locally with local supplies of EPS and Cement board to further increase the educational and awareness capacity of the projects.

The SIP plants in the United States range from quite simple to more modern. To make an informed decision on a Turkey plant, it will be important to become familiar with the full range of the existing U.S. plants and obtain the recommendation of an experienced industrial engineer on a plant design that would meet the requirements of the Turkey business plan. Additionally, the establishment of a CSIP plant should be optimized following US plants as a model. If equipment is needed, US equipment should be imported (including CNC equipment, presses, and glue spreaders). Please see APPENDIX D for the "Optimization of a CSIP Plant."

Effort should also be placed on acquiring locally produced materials (facings, core insulation, and adhesives). The most critical component of the panels is the facing material. In this particular example, Turkey has manufacturers of cement board facings which appear to be of good quality. Arrangements should be made to include a SIP panel using the Turkey cement board facings in any certification tests.

Impacts and Conclusion from International Activities

The Lale House demonstration project has provided FAS with an opportunity to understand the opportunities and difficulties with CSIP construction abroad. FAS continues to support the transfer of advanced structural insulated panels systems to Turkey in cooperation with the IHLAS Holding A.S., a leading Turkish construction company.

In early August 2008, FAS met with Erdogan Bayraktar, President, Housing Development Administration (HDA), Republic of Turkey to discuss future CSIP project and collaboration. This was significant follow-on work with SIPs and CSIPs in Turkey and the neighboring countries. FAS has supported a multi-year program designed to develop energy-efficient, hazard-resistant, cost-effective technologies and building designs. Compared with conventional masonry constructions, SIPs can provide superior insulation and are light in weight, provide both structural wall and curtain wall features, and simplified assembly. The work has underscored the importance of quality control in the manufacture of the panels, in incorporating their unique features in building designs, and in on-site construction. FAS expressed interest in sharing the results of this work with the HDA. It was discussed that there is a high priority given to expanding the construction of energy-efficient, safe, and affordable housing. The meeting provided a productive exchange in terms of moving forward to adopt CSIPs.

FAS identified tasks for Turkey to adopt CSIPs. It includes five tasks:

1) Completion of the Lale Villa (complete),
2) Review of the changes and advances in SIP options,

3) Assessment of the market for buildings using SIPs,
4) Architectural and engineering plans for the use of SIPs in new buildings, and
5) Preparation of a business plan to introduce SIPs into the Turkey regional market.

Task 1 will document these lessons and how they are being addressed. Task 2 will broaden the selection of available SIPs. Task 3 will show the size of different SIP markets. Task 4 will combine this information in the preparation of the engineering and architectural plans for a new building, or buildings, using SIP panels.

The SIP panels used in the Lale Villa were manufactured in the US. They have cementitious (cement board) facings which have performed well in a shake table test and resist moisture, mold and mildew. The FAS recently has expanded its program to evaluate different types of SIP panels with different performance characteristics and different potential applications in order to optimize the building's envelope.

The differences in SIP panels include:

- Facings. The most common facing is oriented strand board (OSB) -- +95% of the market. Other facings include metal, magnesia board, and other planar building materials. The facings differ in their weight, fire protection, structural strength, brittleness, and connections to other SIPs and a building's structural framework. In a seismic region, the panel's brittleness and strength at the connections may be the most important factors to consider.
- Insulation. The panels are a "sandwich" with insulating material—of different thicknesses, depending primarily on performance objectives—between the facings. The most frequent insulating material – due to cost and performance -- is expanded polystyrene (EPS), but other material may have preferable fire, durability and other characteristics desirable in some applications.
- Structural Glue. The glue holds the facings to the insulation. A variety of different glues are available with different performance features and time and pressure setting requirements which could affect the manufacturing cost. The glue, however, plays a significant role in the assembly.
- Seismic performance. The performance of the all existing CSIPs is documented primarily from legacy tests—tests that were performed prior to the more recent earthquake-resistant standards and not independently tested. Currently, an FAS- and U.S. Department of Energy-supported project is evaluating a wide variety of advanced panels in a test program at the University of California, Berkeley, CA, USA. Dr. Mosalam is leading that research project.
- Lengths and widths. The application of SIPs often has been limited by the size of the available facings, particularly the cementitious SIPs. The most common U.S. SIPs are 4 feet x 8 feet. In Turkey, this may be 1 meter x 3 meters. A greater choice of dimensions would increase the cost-effective application of SIP panels in different architectural designs and reduce the need for interior supports.
- Costs. The choice of facings, insulation, glue and available sizes, described above, will affect the cost of the panels and their cost-effectiveness in different applications. However, the size of the company greatly influences price – the larger SIP manufacturers get volume pricing that result in lower first costs, better quality products and better service.

The growing appreciation for the diversity of the performance and costs for different types of SIP panels is moving away from the "one-size-fits-all" perspective. The future is likely to provide a menu of different SIP panels that are combined in a wall assembly or structure to create the various different interior environments desired in a building.

The review of the SIP options will consider those that are available currently or can be available in the near future as well as those under research and development that have the potential for improved performance and lower costs within the next two to five years. Because of shipping costs, the introduction of the use of SIPs in Turkey probably will require the construction of a SIP manufacturing plant in Turkey. SIP manufacturers in the region or China may be able to ship panels to Turkey and sell them at a reasonable price. During this task, the potential for importing panels from China and other possible sources should be determined and added to the mix of options being considered. The performance and quality control of any panels, whether imported or manufactured in Turkey, should be evaluated. When considering the construction of the plant, the availability in Turkey of different facings, insulation, etc. and their job creation and economic benefits should be considered. The flexibility to transition from the initial manufacture of panels using current- or near-term technology to the manufacture of panels using advanced technologies—as they become available—also should be considered. No matter what option is followed, fabrication in Turkey is mandatory. There is no good reason to import fully fabricated panels at risk of damage when labor costs in Turkey are low.

Market assessments require the professional talent of experts trained and experienced in this field especially from local resources. The information will be combined to prepare plans for the potential construction of new buildings using SIPs. SIP panels have attractive features as a building product, but there are a number of things to be done differently there based upon what is known about local strengths.

Perhaps the most significant lesson from the Lale Villa is that the unique characteristics of the SIP panels should be considered from the beginning of the engineering and architectural design process. While the panels can be cut to fit a wide variety of designs, this adds significantly to their cost, construction complexity, and construction time.

The suggested approach is that the engineering and architectural members of our team prepare a list of the potential modifications to SIP-designed building, starting with the most basic changes and proceeding to those that are optional and more expensive. This approach would provide the information needed to make trade-offs between costs and features. The experience with Lale Villa illustrates this most easily.

In the design of a different type of building, such as a high-rise, multi-family apartment building, while there would be fewer design details, a table could explore the design variations and their benefits and costs. The table would be useful in selecting a final design.

A critical element in the preparation of the final designs of buildings using SIPs is that they meet—and we are able to show that they meet—the Turkey earthquake-resistant building standards. This will require coordination between the U.S. earthquake-engineering research and standards activity and the similar activity in Turkey, such as the work at ITU and METU.

The product of Task 4 will be the design of one, or more, building types that incorporate the lessons learned from the completion of the Lale Villa, that include an optimal mix of available SIP panels, and that target a significant market for new buildings in Turkey.

The introduction of SIPs into the Turkish building market would require a significant investment. Because of shipping costs and to ensure quality control, a SIP manufacturing plant would need to be constructed in Turkey. In addition, an education and marketing campaign would need to be launched to inform prospective buyers of the earthquake-resistance and energy-efficiency advantages of the buildings. The business plan would bring this information together in a form useful to the decision makers.

The prior tasks are useful primarily in providing information on the market side of the equation. They pull together experience, science and technical information that can be used to document the performance advantages of the buildings. They've designed buildings for the most promising markets. The designs can be used to estimate many of the construction costs, which is necessary to assess their market appeal.

FAS is confident in the ability of CSIPs to provide quality energy efficient construction abroad. FAS will continue to research these opportunities and educate international players about proper construction practices and approaches, as well as proper code development and testing.

Appendix A - Product Certification and Evaluation

Behind the built environment lies a complicated series of legal regulations, created to specify the minimum acceptable level of safety for constructed assemblies and products as they relate to the construction and occupancy of buildings and structures. This is where product evaluation and certification lies, as every building component specified must be shown to meet the applicable building codes and to perform as equivalent to the prescriptive method outlined. This paper will explain two processes for manufacturers to demonstrate this 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

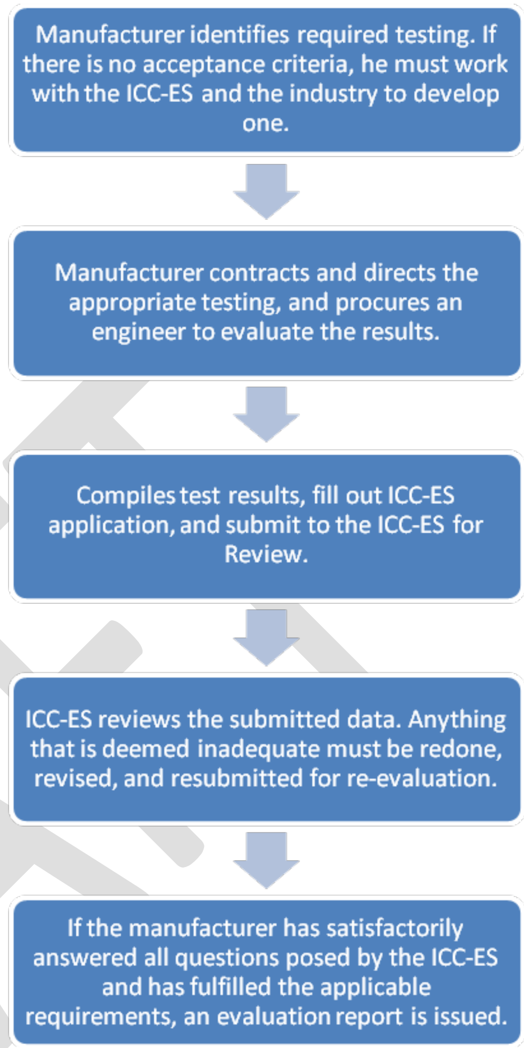
While final decisions of code compliance on all levels are left up to local code officials, several avenues have been created to aid this decision process. These options can be seen as two basic approaches: product evaluation, and product certification. Two subsidiary companies of the International Code Council (ICC)[8] – 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.

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).

[8] 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.

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.[9] 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.



ICC-ES Product Approval Process

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).[10]

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

[9] ICC-ES Criteria Development: http://www.icc-es.org/Criteria_Development/
[10] More information on the ICC-ES approval process can be found online at http://www.icc-es.org

the organizations first two years. The average evaluation time for products ultimately found to meet code was 11 months.[11]

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.

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 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

IAS/ISO Guide 65 Certification

[11] http://www.icc-es.org/Help/about.shtml#reports

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.[12]

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.

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

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

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.[13]

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.[14]

Impact Potential

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

[13] http://www.dca.state.fl.us/fbc/committees/product_approval/Local_Product_Approval0606.pdf
[14] More information about Florida code approval can be found at: http://www.dca.state.fl.us/fbc/committees/product_approval/2_product_approval.htm

Appendix B - Panel Testing

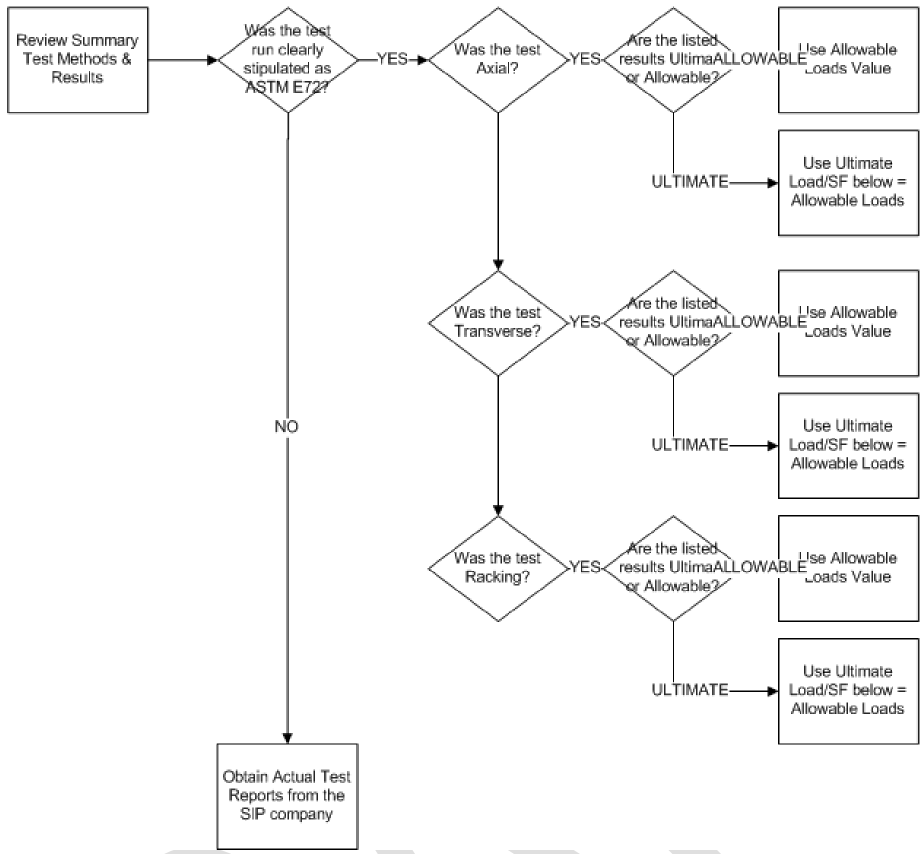
The next step is for the designer to determine if the system is compliant with the industry consensus standards listing the test requirements, the safety factors, and other quality assurance/quality control needs (STEP 3b). This data can be obtained in the acceptance criteria for the code (AC04, AC05, AC10, etc)[15]. 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 (discussed in section 2.1.1). 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.

[15] 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.

Transverse Loads

A transverse load is a load applied perpendicularly to the plane of the longitudinal axis of a structure. How a panel deals with transverse loads is crucial for its performance in walls (dealing with wind loads), roofs (snow loads), or floors (the live and dead loads associated with occupancy).

Due to the relationship between transverse loads and shear stress, sandwich panels have advantageous characteristics for carrying these loads. In a similar fashion to the case of bending moments, the internal shear stress (τ) in a simply supported beam is inversely related to the moment of inertia:

$$\tau \equiv \frac{\mathrm{V} \cdot \mathrm{Q}}{I_A \cdot t}$$

In contrast to the case of normal stress due to bending moments (where faces experience the greatest stress), the core of the panel experiences the greatest shear stress due to transverse loads (Figure 1).

TESTING:

To measure the performance of CSIPs in dealing with transverse loads, structural tests have been specified by the American Society for Testing and Materials (ASTM) and specified by the International Code Council (ICC) in the standard building codes ratified by most municipalities.

The Transverse Load Test measures deflection when a load is applied perpendicular to the panel surface. For panels with brittle materials as facings, ICC requires that "with a 5-pound-per-square-foot (239Pa) horizontal loading imposed, the interior wall panel deflections shall not exceed" L/240 for use under the following code standards: Boca National Building Code (BNBC), State Building Code (SBC), Uniform Building Code (UBC), where 'L' is the length of the panel.

The ICC requires loads to be imposed in increments to failure, with deflections measured at each load. Deflection is monitored at "mid-span within 3 inches (76mm) of each edge and at the center of the panel's width." ICC criteria for transverse load tests call for "panels tested over a double span are to have the same three deflection readings taken at the expected maximum deflection point based on analysis."

Transverse load testing is conducted in accordance with Sections 4.2 and 4.3 of ASTM E72 standards, where a panel is placed horizontally on two steel beams that function as framing members. Two equal loads are applied by two hydraulic cylinders each placed at a distance of one quarter of the span from the supports, toward the middle of the span. ICC requires "a preload of approximately 10% of the anticipated ultimate load to be applied to 'set' the panel in the test apparatus" and the deflection to be recorded (see Figure 1 below). The panel is then loaded in increments to failure with deflection readings taken with each load at mid-span, within 3 inches of each edge, and at the center of the panel width. Deflection for the span is calculated by averaging the deflections obtained from each of the two micrometers.

RESULTS:

The following are sample test results from CSIP manufacturers demonstrating typical design test results and design values. It is important to note, however, that any values listed in this report should not be used in the engineering or design of a SIP building. Products differ with varied manufacturing techniques and quality control procedures, and only values from a certified report from a trusted third party organization (the ICC-ES, IAS Guide 65 Product Certification Program, etc.) should be used in the engineering of a SIP construction project.

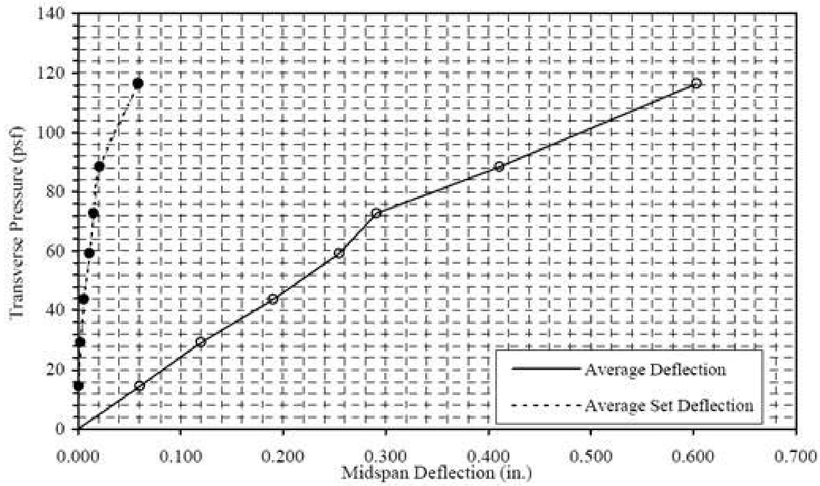


Figure A1: Load vs. Deflection Plot

The approximate design values for the transverse loading of CSIPs (with a safety factor of 3) is around 60 pounds per square foot (psf). However, actual design values should only be taken from manufacturer product evaluation or certification reports.

Axial Loads

An axial load is a load applied along or parallel to and concentric with the primary axis of a structural member. This is typically in relation to a bearing wall or a column, and usually refers to vertical loads such as the weight of the building itself.

These loads result in normal stresses similar to those of bending moments. However, their distribution across the panel's cross-section does not have the same linear relationship. Using a combination of displacement and force equilibriums, the resultant normal stresses found in the face and core (constant throughout each) can be calculated as follows:

$$\sigma_c \equiv \frac{E_c \cdot P}{A_c \cdot E_c + A_f \cdot E_f}$$

$$\sigma_f \equiv \frac{E_f \cdot P}{A_f \cdot E_f + A_c \cdot E_c}$$

By calculating values using these formulae, it is clear that the faces experience higher levels of normal stress than the core; this explains why the faces generally fail due to axial loads.

TESTING:

Per the IBC, if CSIPs will be used in any structural use, including concentrated loads, eccentric and side loads, Axial loading must be accounted for. Test procedures developed by ASTM and specified in local codes must be followed. Axial load tests are designed to determine panel's capacity to carry vertical loads from roofs, floors and walls and to lateral loads from wind forces. The ICC Acceptance Criteria for Sandwich Panels requires that: "load-bearing wall panels shall support an axial loading applied with an eccentricity of 1/6 the panel thickness to the interior or towards the weaker facing material of an interior panel." ICC determines the allowable axial load by dividing the ultimate load (a load that when applied will result in failure) by a factor of safety (see below for more information on factors of safety).

Allowed loads can also be established by finding the load at which the axial deformation is at or below 0.125 inches (if this load is lower than the load obtained by dividing the ultimate load by a factor of safety).

The test performed is a derivative of the test apparatus that is recommended by ASTM E72. A load is applied uniformly to the top of the panel, where two compressometers are placed 2 inches from each corner to read the axial compressive load. Deflectometers are positioned at mid-span to measure by how much the specimen deflects.

According to ICC, the allowable axial load is determined by dividing the ultimate load by a factor of safety. Factors of Safety are explained above under the 'ICC Acceptance Criteria for Sandwich Panels (usually 3.0, since it is used for all loading conditions).

RESULTS:

The following are test results from CSIP manufacturers demonstrating typical design test results and design values. It is important to note, however, that any values listed in this report should not be used in the engineering or design of a SIP building. Products differ with varied manufacturing techniques and quality control procedures, and only values from a certified report from a trusted third party organization (the ICC-ES, IAS Guide 65 Product Certification Program, etc.) should be used in the engineering of a SIP construction project.

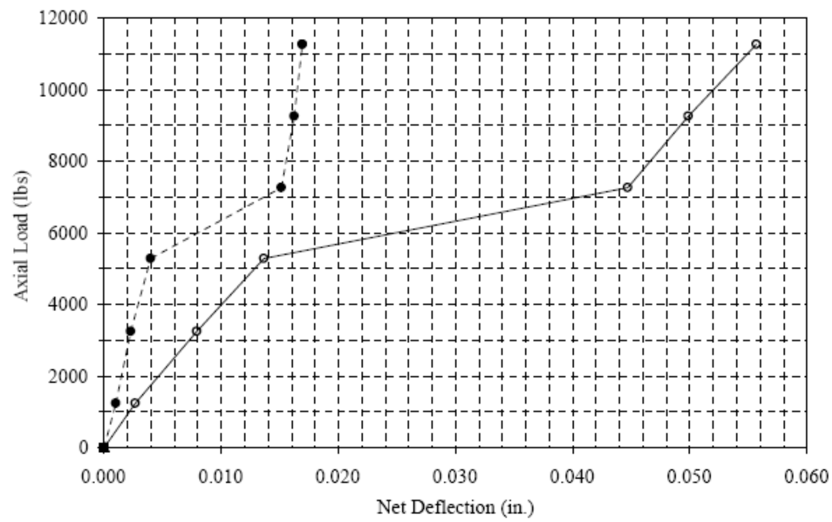


Figure A1: Load vs. Deflection Plot

The approximate design value for the axial loading of CSIPs (with a safety factor of 3) is around 1400 pounds per linear foot (plf). However, actual design values should only be taken from manufacturer product evaluation or certification reports.

Racking and Shear Loads

A racking load is a load applied in the plane of an assembly in such manner as to lengthen one diagonal and shorten the other. A shear load is any applied external, translational load which creates shear stresses in a reacting structure. Per the IBC, if CSIPs will be used in any structural use, including shear walls, racking and shear loading must be accounted for. Racking and shear loads must also be accounted for in seismic zones. The requirements depend upon the local building code, as well as any regional supplements.

TESTING:

Racking shear tests are required for shear walls that resist wind and seismic loads. According to the ICC Acceptance Criteria, the allowable shear load is determined from the racking load at which a net horizontal deflection of ½ inch (12.7mm) occurs, or by dividing the ultimate load by a factor of safety as listed under the ICC Acceptance Criteria for Axial Wall Tests.

ASTM E 72 standards are designed to measure “the resistance of panels, having a standard wood frame, and sheathed with sheet materials such as structural insulating board, plywood, gypsum board, and so forth, to a racking load such as would be by winds.” Performance of the sheathing is, therefore, defined as the test objective. Test set-up according to ASTM standards calls for the specimen to be attached to a timber or a steel plate. This plate is then attached firmly to the base of a loading frame in such a way that will not let racking to bear on the loading frame. A hold-down is also required to prevent the panel to rise as racking load is applied, and since "the amount of tension in the rods of the hold-down may have an effect on the results of the test, nuts on the hold-down rods shall be tightened prior to load application so that the total force in each rod does not exceed 90 N at the beginning of the test as determined by previous calibration. Loading is then applied through the timber that is bolted to the upper plates of the specimen. Lateral guides and deflection measuring devices are required. Deflectometers should be located in the lower left (to measure any rotation of the panel), lower right (to measure any slippage), and upper right corners (the total of the two plus the deformation of the panel) of the assembly. Load is then applied continuously.

The panels are tested using a variant of the ASTM standard with some exceptions: The timber load distribution member recommended by ASTM was eliminated and was replaced with "a steel sleeve to fit over a short block glued to the top plate;" and the apparatus for measuring deformation was simplified. The method that was used eliminated "the need for uplift, crushing and sliding gauges through the use of a light aluminum triangular frame resting on thin steel plates attached to the bottom plate."

RESTULTS:

The following are test results from CSIP manufacturers demonstrating typical design test results and design values. It is important to note, however, that any values listed in this report should not be used in the engineering or design of a SIP building. Products differ with varied manufacturing techniques and quality control procedures, and only values from a certified report from a trusted third party organization (the ICC-ES, IAS Guide 65 Product Certification Program, etc.) should be used in the engineering of a SIP construction project.

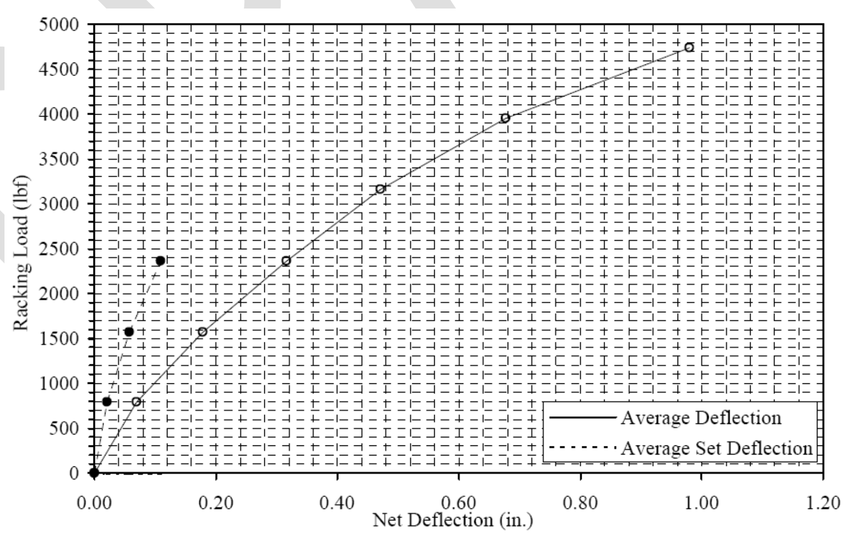


Figure A1: Load vs. Deflection Plot

The approximate design values for the shear loading of CSIPs (with a safety factor of 3) is around 200 pounds per linear foot (plf). However, actual design values should only be taken from manufacturer product evaluation or certification reports.

Appendix C - Construction and Weatherization Details

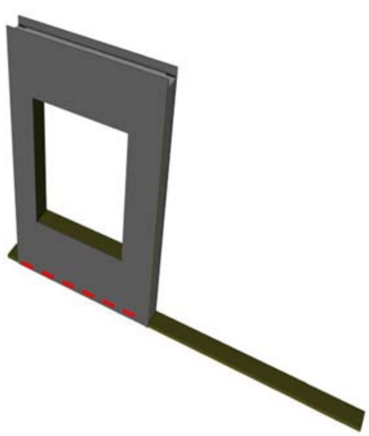
Installation of Typical Wall Panels

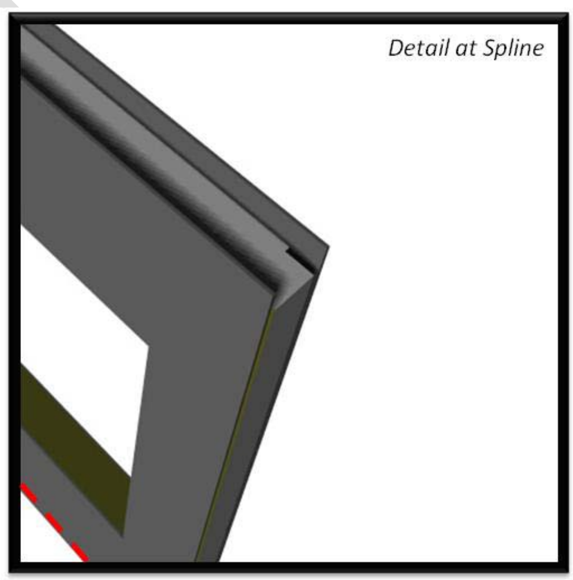
1. Installation of bottom plate: Connection to foundation system or horizontal plate: Bottom plate is installed with a capillary break between plate and foundation. The bottom plate must be fastened and properly sealed to prevent air infiltration. Where required by code, metal Z-flashing can be installed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

1. Installation to bottom plate

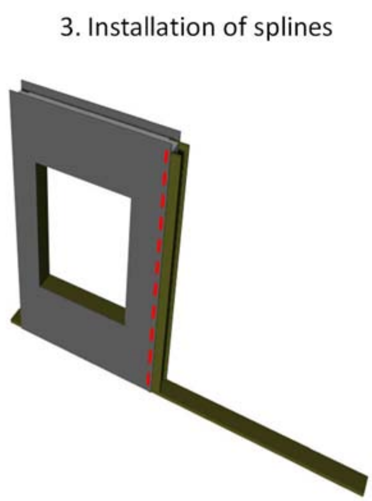
2. Installation of panel one: CSIP panel slips over bottom plate. Blocking installed in window penetrations at window opening. Note: window blocking installed at factory.

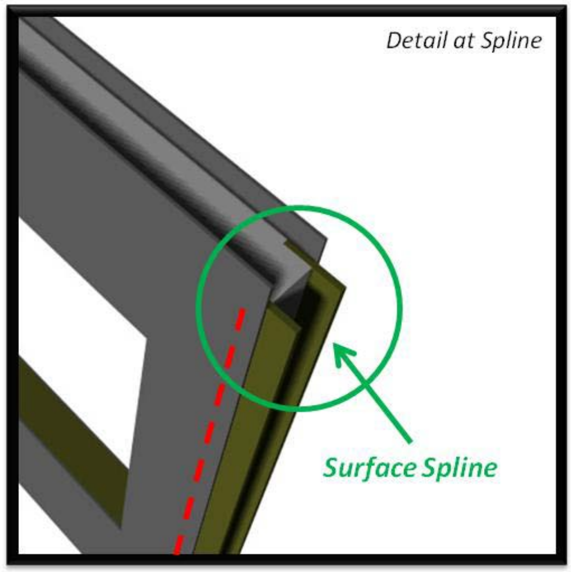
2. Installation of panel one



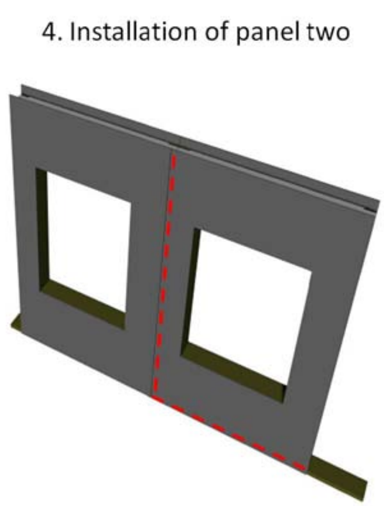


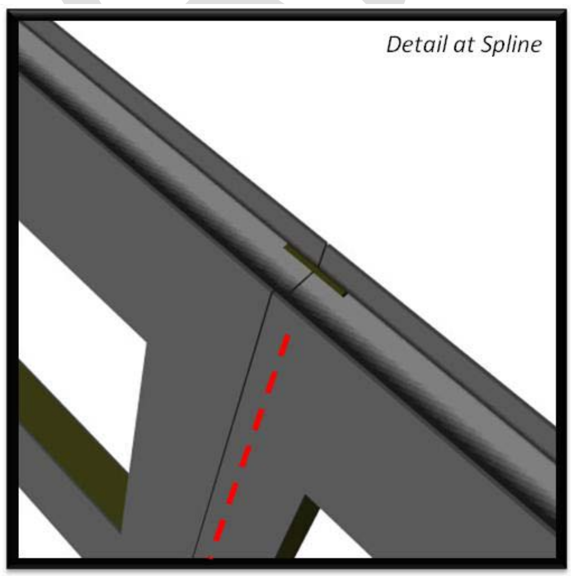
3. Installation of spline: Splines are comprised of 19/32 OSB or better splines, cut 5.5” wide to prevent telegraphing or “saw toothing” of panels. This detail recognizes the industry need to give generous spline widths and meet code minimums for fastening depth through the spline. More spline types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





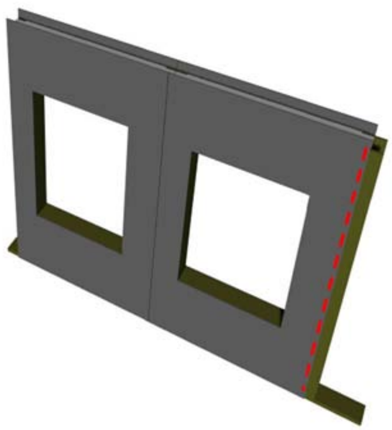
4. Installation of panel two: Refer to step 2.

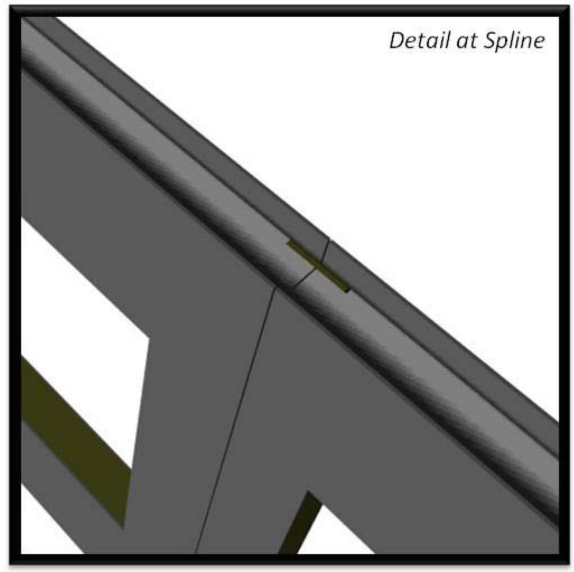




5. Installation of panel splines: Refer to step 3.

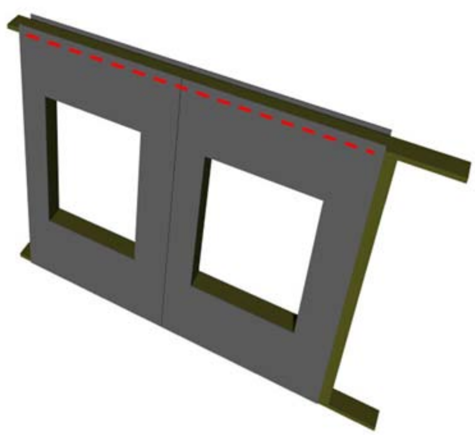
5. Installation of splines

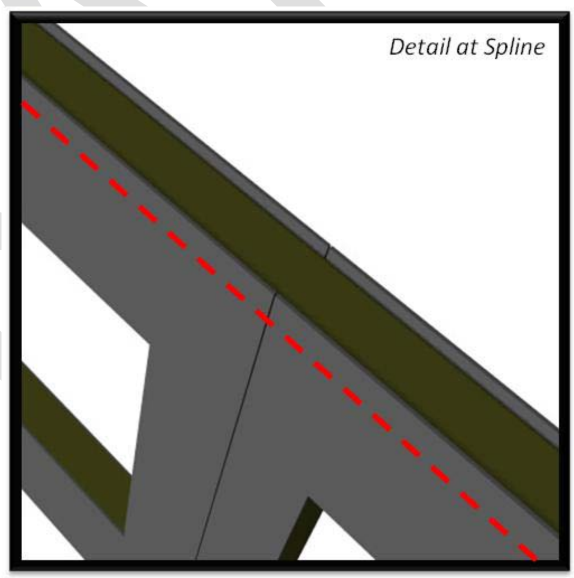




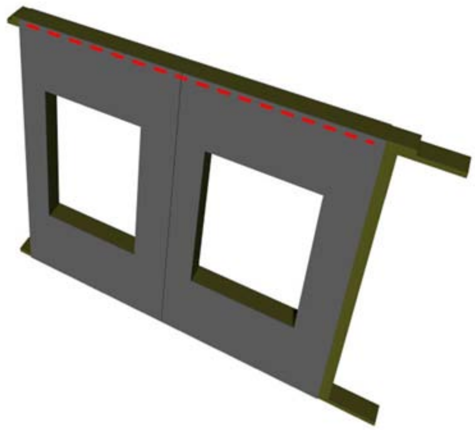
6 & 7. Installation of band plate and top plate: installed with 2x6 #3 or better. Plates must be tied together horizontally with and to the panel, and must be tied together vertically.

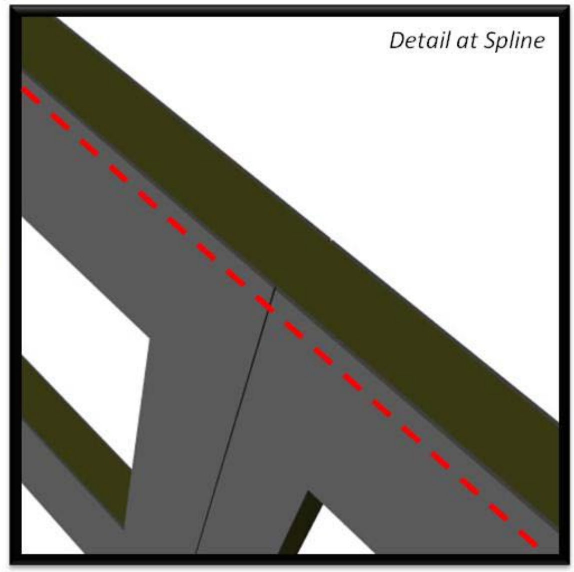
6. Install band plate





7. Install top plate





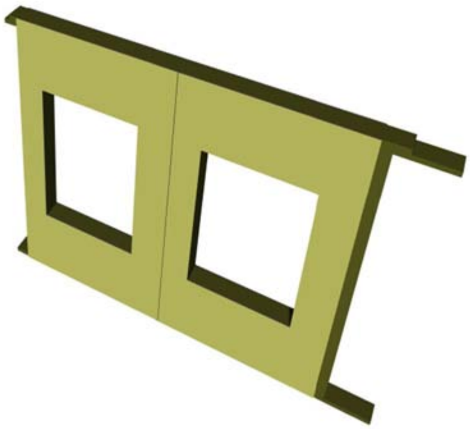
This concludes installing a basic panel. Subsequent panels tie directly into the installed panel to continue the wall plane.

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

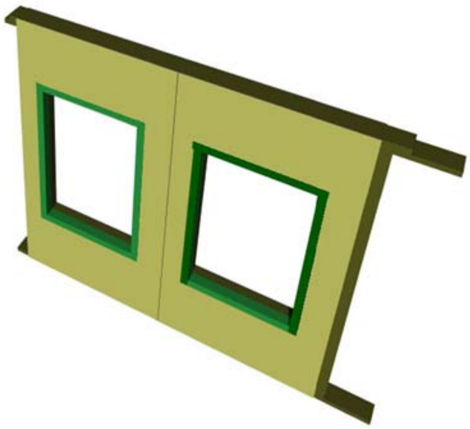


9a. Installation of pan flashing: Using self-adhering flexible flashing for pan flashing such as Dupont FlexWrap or StraightFlash to protect horizontal penetrations. This flashing must be cut ends to extend past window openings and fasten inner legs into jamb (minimum 1”) by slitting the flashing so 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



a

b

c

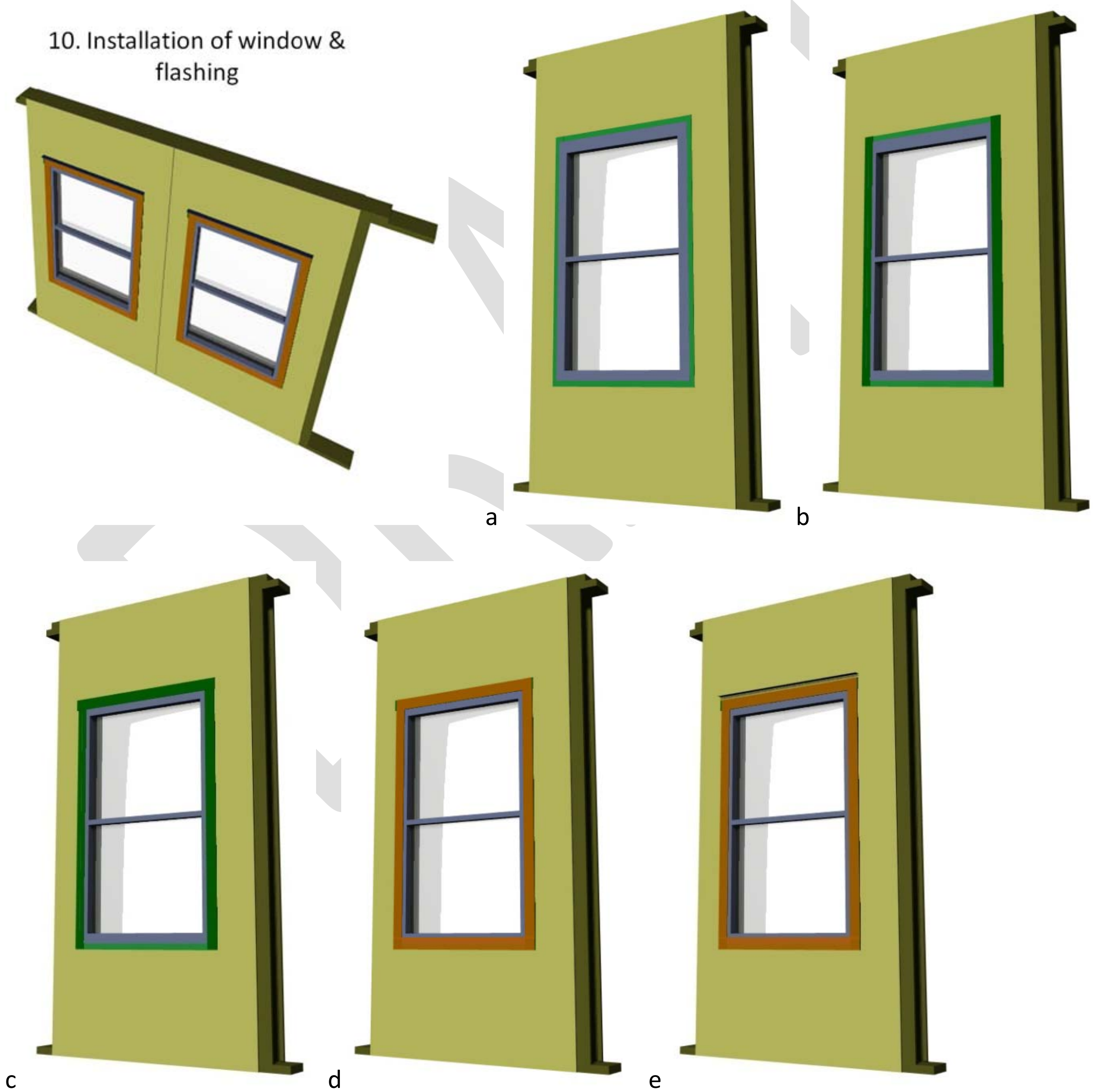
10a. Installation of window set: Only use windows with outer flange (i.e. nailing flange). Be sure to back caulk window by applying sealant at window jambs and head. Use sealant at sill where required. Then set window by installing the window level and plumb per manufacturer's specifications.

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

Thermal Barriers: Understanding Thermal Control Measures

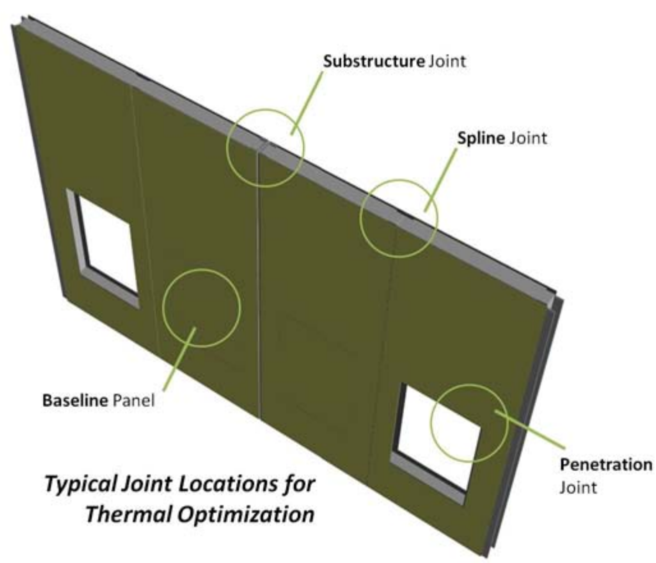
The energy saving potential of building with CSIPs is the most apparent sustainable advantage of utilizing CSIPs as walls units. A CSIP building envelope provides high levels of insulation and is extremely airtight. This means significantly lower operating costs for an owner, as well as a smaller contribution 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) <u>Temperature driven heat transfer:</u> 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). Heat transfer is drive by three mechanisms…
   a. Conduction is the heat traveling through a solid material,
   b. Convection is the transfer of heat by the movement of gases or liquids through a system, and
   c. 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) <u>Infiltration:</u> 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 panel areas must be optimized to use CSIPs as an effective envelope system (illustrated below):

- Baseline Panel by optimizing the CSIP panel thickness,
- Substructure Joints by examining the CSIP to curtain wall unit boundaries and curtain wall units interaction and connections,
- Spline Joints by optimizing CSIP to CSIP connection, and
- Penetration Joints by optimizing the CSIP to penetrating unit connections (such as windows).



Typical Joint Locations for Thermal Optimization

For a discussion of panel optimization and how heat transfers through CSIP panels refer to section 2.3.1.Note that each manufacturer and project will have specific details that need selection, analysis, modeling, and optimization and it is recommended designers discuss this with the panel manufacturers.

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. Typical window and wall details for penetrations are illustrated in section 1.5.2 and section 3.6, but have so far been limited to residential construction.

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

Appendix D – Panel Fabrication

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.

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.

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.

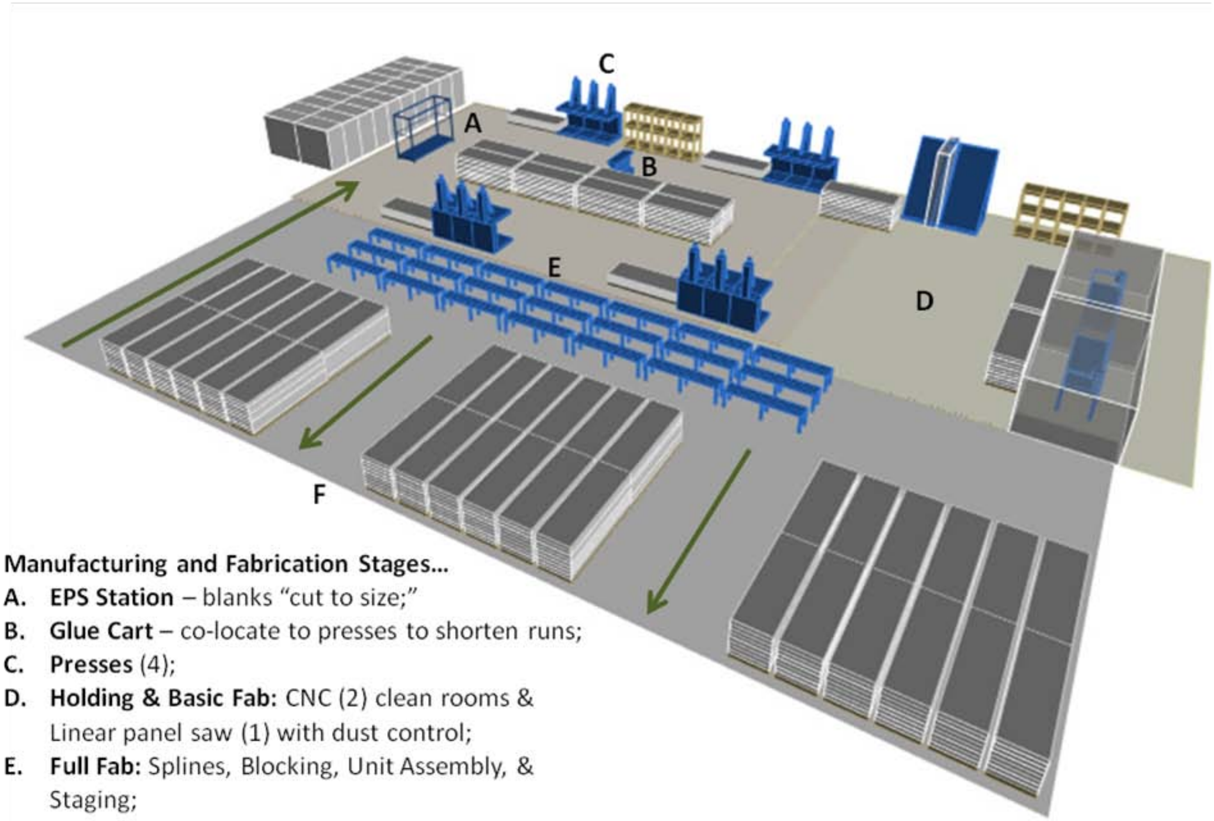
After removing from the press, panels are set aside to cure for 24 hours. Once cured, they are moved to the fabrication section of the plant, where windows, doors, electrical chases, and other openings specific to the project are prepared.

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.

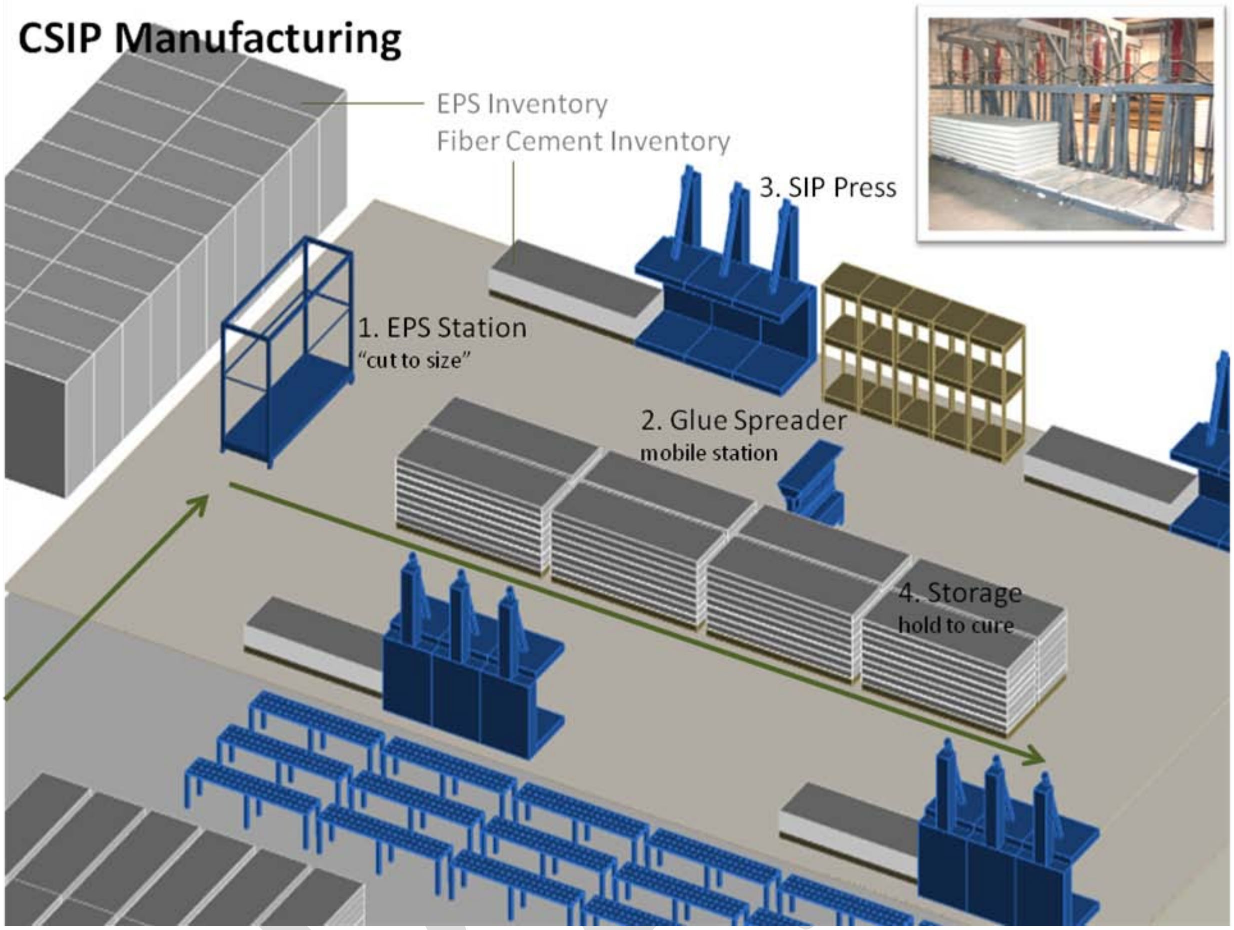
The following diagrams show a typical CSIP plant layout:

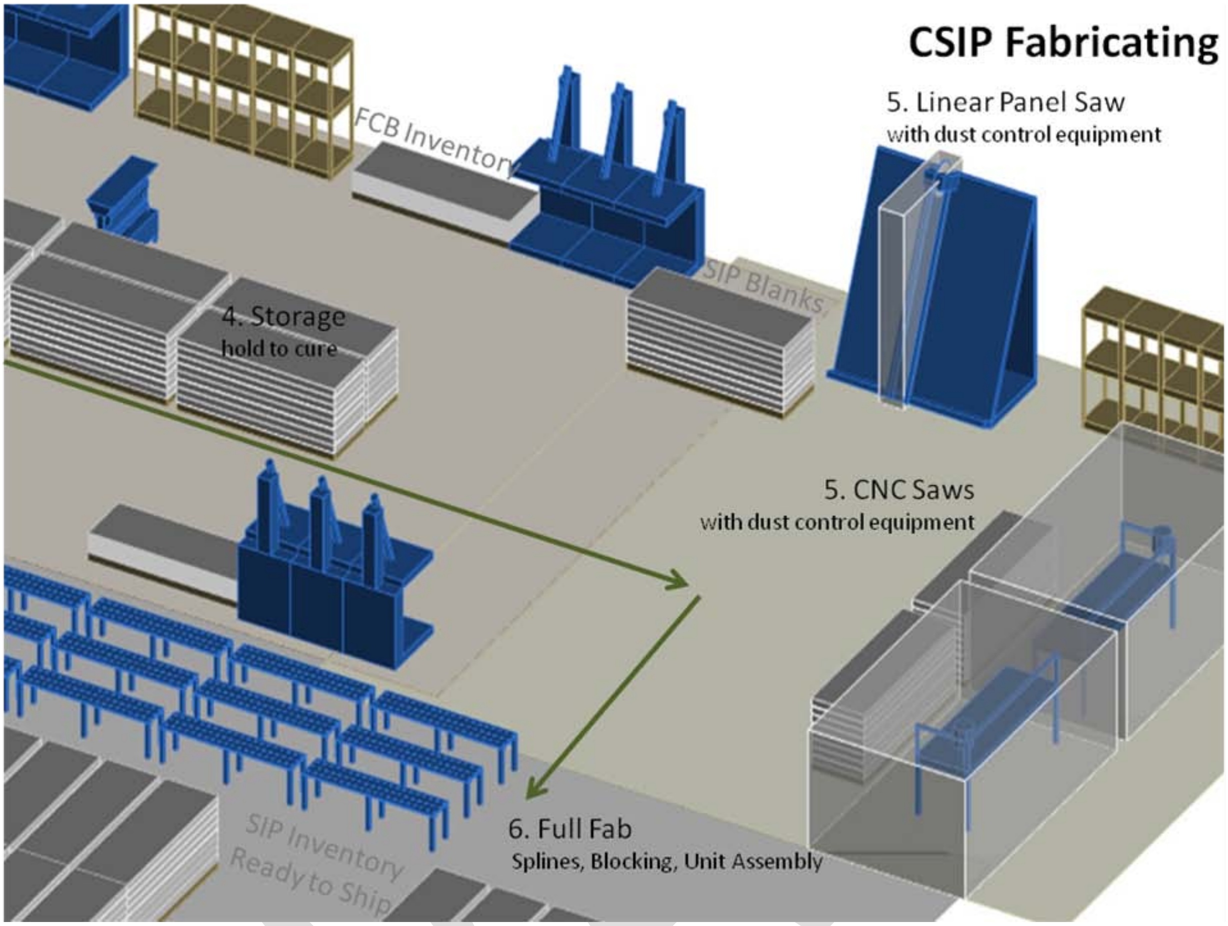
Basic CSIP Manufacturing and Fabricating

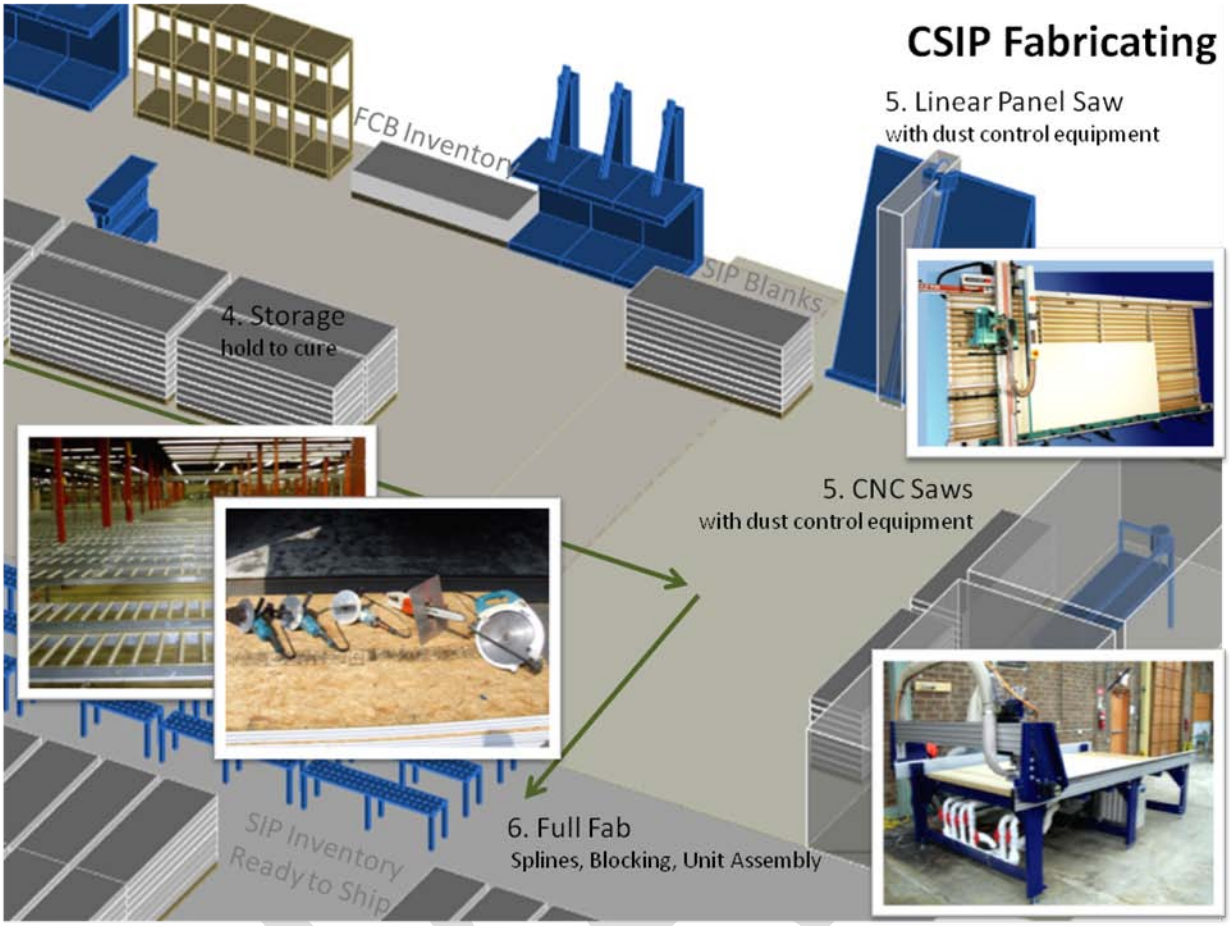


Manufacturing and Fabrication Stages…

A. EPS Station – blanks "cut to size;"
B. Glue Cart – co-locate to presses to shorten runs;
C. Presses (4);
D. Holding & Basic Fab: CNC (2) clean rooms & Linear panel saw (1) with dust control;
E. Full Fab: Splines, Blocking, Unit Assembly, & Staging;
F. Shipping


CSIP Manufacturing
EPS Inventory
Fiber Cement Inventory
3. SIP Press
1. EPS Station
"cut to size"
2. Glue Spreader
mobile station
4. Storage
hold to cure


CSIP Fabricating
5. Linear Panel Saw
with dust control equipment
FCB Inventory
SIP Blanks
4. Storage
hold to cure
5. CNC Saws
with dust control equipment
6. Full Fab
Splines, Blocking, Unit Assembly
SIP Inventory
Ready to Ship


CSIP Fabricating
5. Linear Panel Saw
with dust control equipment
FCB Inventory
SIP Blanks
4. Storage
hold to cure
5. CNC Saws
with dust control equipment
6. Full Fab
Splines, Blocking, Unit Assembly
SIP Inventory
Ready to Ship