Structural Insulated Panels: Impact on the Residential Construction Process

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Abstract: Uncertainty and risk have contributed to the reluctance of U.S. homebuilders to embrace new construction technologies. This paper explores one innovative, but underutilized building technology, structural insulated panels (SIPs), and its impact on the residential construction process. The paper presents findings from a side-by-side case study of the construction of two Habitat for Humanity homes, one SIP and one conventional wood-framing. Although the study focuses on labor productivity and cycle time during framing, other key construction performance metrics are assessed including worker safety, quality/workmanship, material waste, worker skill levels, and equipment requirements. Findings indicate that SIPs saved about two-thirds of the site framing labor for walls and roofs, with cycle time savings of similar magnitude. No significant impacts on other construction performance metrics were observed, however, size of the panels did require a lift truck and construction crane. While conclusions are limited by the scope of the case study, the writers believe that building with SIPs can be very efficient. The paper identifies key actions required of builders and SIP manufacturers to maximize potential benefits.

DOI: 10.1061/(ASCE)0733-9364(2006)132:7(786)

CE Database subject headings: Construction management; Productivity; Risk management; Technology; Insulation; Panels.

Introduction

United States homebuilders have been reluctant to embrace new construction technologies (Obrien et al. 2000). Residential construction has changed little since the introduction of platform framing in the nineteenth century. Uncertainty and risk—about the future of the housing market, about homebuyer acceptance, about local building code official approval, about long-term durability, about impacts on the supply chain, about impacts on the construction process—all contribute to this lack of acceptance. This paper explores one innovative, but underutilized building technology, structural insulated panels, and its impact on the residential construction process. The paper also provides a methodology for assessing the impact of an alternative building system.

Structural Insulated Panels

As shown in Fig. 1, a structural insulated panel (SIP) typically consists of two sheets of oriented strand board (OSB) sandwiching a rigid sheet of expanded polystyrene (EPS) foam that has been coated with a structural adhesive (Tracy 2000). Other SIP configurations use liquid polyurethane or polyisocyanurate foam-in-place technology to fill the cavity between the two OSB skins. Plywood and concrete sheathing are also used for the structural skins. SIP size is limited by the size of the structural skins, ranging from 1.2 m×2.4 m(4 ft×8 ft) to 2.4 m×7.3 m (8 ft×24 ft). Panels are joined in the same plane by a spline(s) at each joint, either one piece of dimensional lumber of the same depth as the foam core or two narrow strips of OSB placed in spline channels immediately below each skin.

At the component level, SIPs can be used to construct an energy efficient curtain wall over timber framing. However, when employed to form a complete wall, wall/roof, or wall/roof/floor system, SIPs can create a strong, energy efficient building envelope (Andrews 1992). The insulation capability of SIP construction can be engineered by varying foam type and thickness. For example, a SIP wall with an 8.9 cm. (3.5 in.) EPS foam core has a "whole-wall" *R*-value of 14 compared to *R*-9.8 for a comparably sized wood-framed wall insulated with *R*-11 fiberglass batt insulation (Christian and Kosny 1995). When the performance of the entire wall system is considered, SIPs perform better than conventional wood frame systems because they are constructed from large, uniformly insulated, airtight components. The length of the SIP panel also means that there are fewer thermal "shorts" or penetrations in the wall, and the relatively few joints are designed for effective field installation, further reducing air infiltration (Rudd and Chandra 1994).

Another advantage of SIP construction is that the controlled factory production environment produces a panel of higher dimensional quality (Gagnon and Adams 1999). Dimensional quality translates to higher efficiency on the construction site. For example, flatter panels minimize drywall shimming, reduce scrib-

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Note. Discussion open until December 1, 2006. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this technical note was submitted for review and possible publication on June 29, 2004; approved on October 25, 2005. This technical note is part of the ***Journal of Construction Engineering and Management***, Vol. 132, No. 7, July 1, 2006. ©ASCE, ISSN 0733-9364/2006/7-786–794/$25.00.

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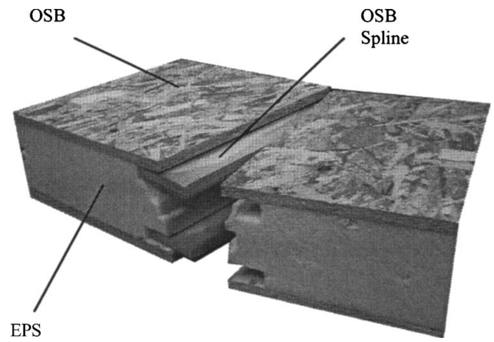

Fig. 1. Typical structural insulated panel configuration

ing of cabinets/countertops, and simplify siding installation (Tracy 2000). Panelization, in general, simplifies the construction process, making it more controllable, systematic, and faster (Gagnon and Adams 1999). Simplification also reduces the need for skilled framers, since assembly requires less plan interpretation than framing (Tracy 2000). This is particularly critical in areas experiencing shortages in the skilled trades.

SIPs have been available for over 50 years. The past decade has seen an increase in their popularity, and SIPs are now one of the fastest growing industrialized homebuilding technologies with over 50% growth in the last 5 years. Despite their rapid growth, SIPs are only used in about 1% of new homes (SIP 2003). Several factors limit SIP growth. SIP construction is more expensive than comparable wood-frame construction. Marginal costs estimates vary: 10–20% more for the structure (Toole and Tonyan 1992), 10–20% more for fully finished walls (Mullens et al. 1994), and 5–10% more for the structure (Gagnon and Adams 1999). Material costs were generally cited as the largest driver of the cost premium. Providing the only quantitive cost analysis, Mullens et al. (1994) found that erection costs could also be higher for SIPs. Contributing factors included labor intensive on-site window/door framing and the common use of smaller $1.2\ \text{m} \times 2.4\ \text{m}$ ($4\ \text{ft} \times 8\ \text{ft}$) SIP panels that require extra handling and joining. In addition to cost, technological and strategic uncertainty, wary first-time buyers, fragmentation of the industry, and short-term SIP company management practices also contribute to low market penetration by SIPs (Gagnon and Adams 1999; Tracy 2000). The key issue of uncertainty was underscored by survey results indicating that builders needed more information about SIPs before they would consider their use (Gagnon and Adams 1997).

Impacts on Construction Process

In assessing the market penetration of innovative residential building envelope systems—SIPs, insulated concrete forms (ICF), and aerated autoclaved concrete (AAC)—Bashford (2004) observes that these systems are marketed as if they were *product innovations*, easily interchangeable with conventional wood-frame construction. He notes, however, that they substantially impact the way trade contractors perform their work. Every critical construction performance metric is affected: worker safety, quality/workmanship of the finished structure, labor productivity, construction cycle time, and construction material waste. Worker skill levels and equipment can also be affected. Bashford (2004) also points out that any innovation that impacts multiple trades creates even more uncertainty because it can impact existing supply chain relationships. For example, alternative envelope systems interface with other building systems: foundations, roofs, utilities, windows/doors, and interior/exterior finishes. Other trades typically provide these systems.

Overview

The energy efficiency of innovative building envelope systems such as SIPs is well-documented in the literature. However, their impact on construction processes is not. This paper documents findings from a side-by-side case study that seeks to provide a better quantitative understanding of these impacts. The paper describes the research approach used, documents the construction processes observed, summarizes findings, documents conclusions, and recommends future research.

Research Approach

In 1997 researchers from the University of Central Florida Housing Constructability Laboratory were given the opportunity to monitor the construction of two similar homes for Habitat for Humanity. The first home (Fig. 2), a $120\ \text{m}^2$ (1,293 sq ft) four bedroom ranch, was framed in Sedro-Woolley, Wash. on August 15 to 16, 1997. SIPs were used to construct the entire building envelope—floor, walls, and roof. The second home (Fig. 3), a $99\ \text{m}^2$ (1,064 sq ft) four-bedroom ranch, was framed outside Plains, Ga. on October 16–18, 1997.

To gather labor and cycle time data, two researchers observed the construction process and recorded the start and completion times and the number of workers involved in each activity. When the number of workers changed during the course of an activity, the time of the change and the new number of workers were recorded. When more than two activities were occurring at the same time, researchers cycled frequently between activities. Observations were supplemented by video recordings from two cameras that operated continuously. Cameras were mounted on tripods and relocated as required to maximize visibility of each activity. Video images were time stamped to simplify analysis.

Material waste and worker perceptions were also formally measured for each home. Material in the scrap pile was sorted and documented before framing began and after framing was completed. Each worker was interviewed after framing was completed to assess their previous construction experience and their perception of the technologies.

All observation and measurement were limited to on-site, structural framing activities, not including interior walls. This began with the delivery and unloading of materials on the site and concluded with erection of roof panels for the SIP home and installation of exterior sheathing and insulation for the wood-framed home. This limited scope allowed researchers to capture the primary impact of the envelope technology without the lengthy (weeks/months) on-site measurement required to observe the complete construction process.

Data Analysis and Results

Work Force and Experience

Habitat for Humanity is a unique construction environment. Volunteers build each home under the guidance of an experienced homebuilder. A nationally recognized contractor credited with building over 600 SIP homes guided construction of the SIP home. An experienced Habitat builder directed construction of the

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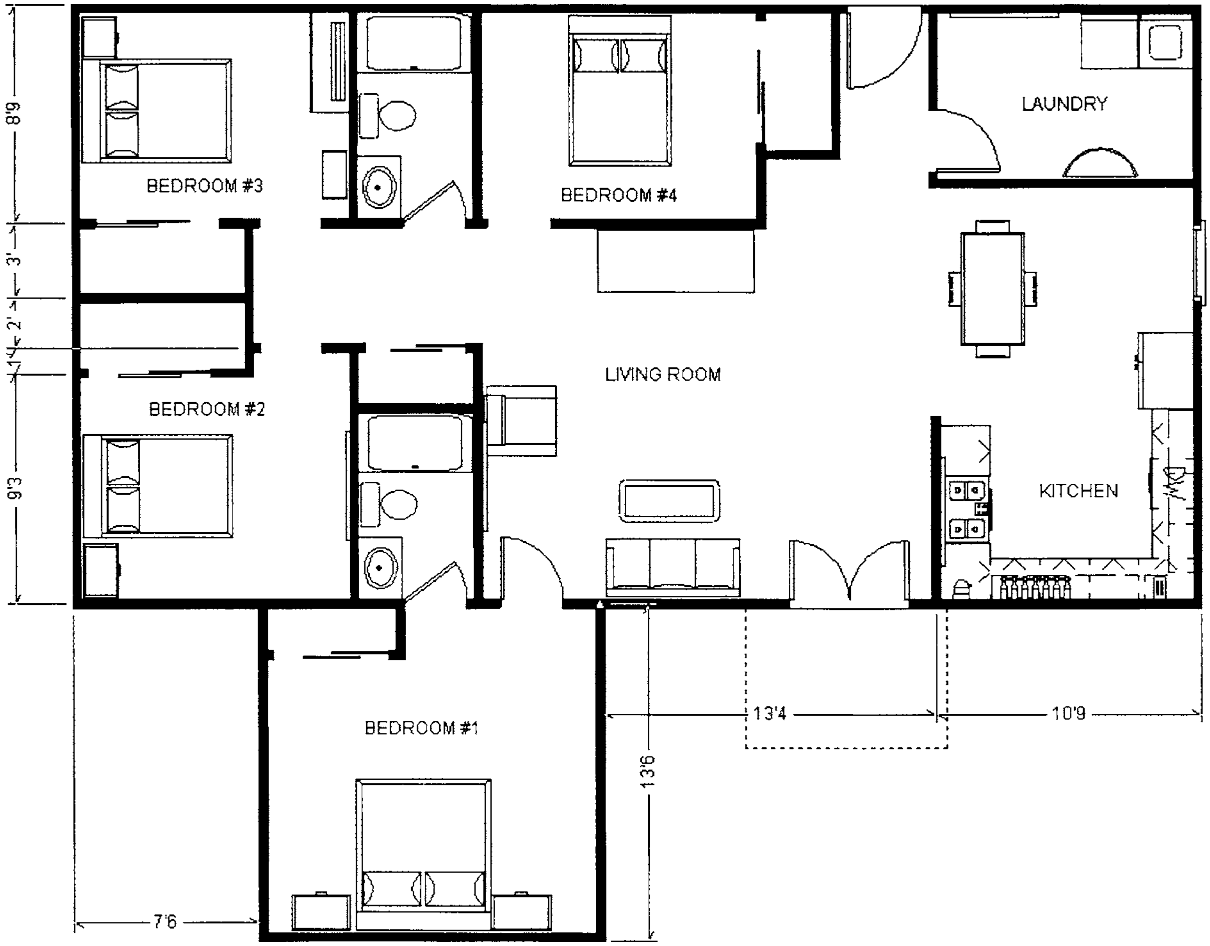

Fig. 2. Floor plan of SIP home

wood-framed home. Over 50 volunteers participated in the construction of each home, serving as workers, greeters, and construction coordinators. Volunteers arrived and departed continuously throughout the process. Workers were interviewed after framing was completed to assess their previous construction experience. Detailed volunteer experience profiles are shown in Mullens and Arif (1998). The data suggest that the construction experience of volunteers was reasonably comparable for both homes. Both homes had volunteers with a wide range of construction experience, from novices to highly experienced professionals. Approximately five construction professionals participated on each house. These professionals were supported by approximately twice that number of nonprofessionals, a few having significant building experience. One important factor not evident in the data is that the volunteers for the SIP home had no prior SIP construction experience.

The unique nature of the Habitat workforce often resulted in less than ideal efficiency on the construction site. More than ten volunteers routinely moved and positioned large SIPs, when significantly fewer could have moved the panels safely and efficiently. Construction activities were routinely accomplished in series (one-at-a-time), rather than in parallel, so that the expert could ensure both safety and quality. In several cases the expert asked volunteers to rework unacceptable product. These times are included in the reported data. To maximize safety (and possibly because of the abundance of labor), Habitat has a policy of limiting the use of nail-guns. The only exception to this policy was a 0.22 caliber nail-gun used to anchor wall sill plates to a concrete slab in the wood-frame home.

Construction Processes

Construction processes differed significantly between the two building systems. Mullens and Arif (1998) describe the construction process in detail. A summary of the construction processes follows.

Framing materials for the wood-framed home were delivered early and, therefore, researchers were not able to observe the unloading process. The wood-framed home was built on a monolithic concrete slab (slab-on-grade construction). No floor framing was required. Exterior walls were framed using 38×89 mm (2 in. $\times$ 4 in. nominal) dimensional lumber. Lumber was hand-carried from the staging area to the slab, where the walls were framed horizontally. The leader marked the top and bottom plates for stud and window/door openings. Precut studs and window/door opening subassemblies were then positioned and attached using nails. Window/door openings were preassembled in the Habitat "factory" in Americus, Ga. The slab was swept, chalk lines were snapped, silicone sealant was applied, and pressure treated sill plates were attached to the slab using a 0.22 caliber nail gun. The exterior walls were mounted on the sill plate and attached using nails. OSB was cut on a portable table saw and

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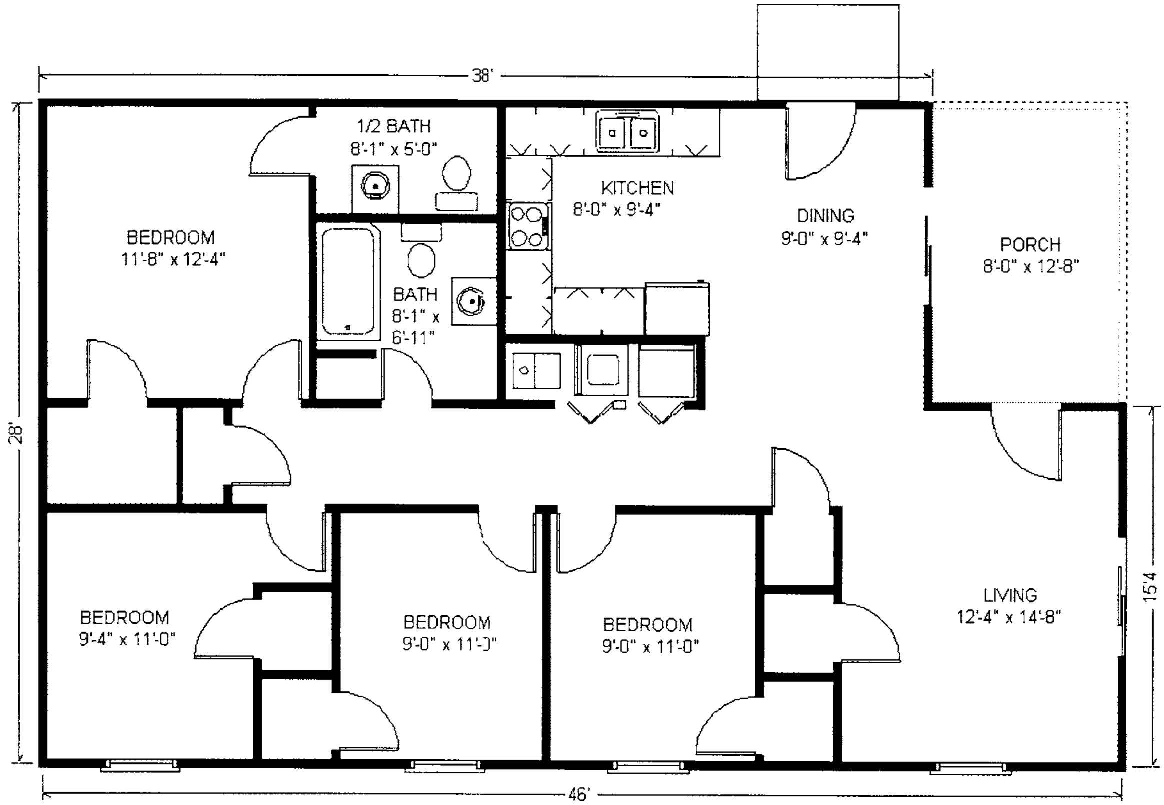

Fig. 3. Floor plan for conventional wood-framed home

attached at the corners of the structure to prevent racking. Anchors that had been embedded in the slab were nailed to the frame. Blocking was added as needed. A second top plate was nailed in place to tie the wall frames together. Styrofoam sheathing was nailed to the exterior of the wall for insulation. Installation of fiberglass batt insulation was not observed, but labor estimates were obtained from a local contractor.

Roof trusses were used to frame the roof of the wood-framed home. Trusses were preassembled in the Habitat "factory" in Americus, Ga. After delivery to the site, face plates and styrofoam insulation were nailed to the gable end trusses. The styrofoam was then cut to match the outer truss profile. Truss plates were salvaged from a truss that had the plates incorrectly installed on both sides of the truss. Before installing the trusses, the exterior walls were squared. To maintain square during truss set, temporary bracing was installed, extending from the top plate to the slab inside the home. Each truss was lifted manually and stacked near its final position on the roof. Trusses were erected manually, squared, and nailed to the walls. Lumber running on top of the trusses was used for bracing during erection. Trusses were attached to the walls using truss hangers. Lumber was nailed spanning the trusses inside the attic to create a catwalk. OSB roof decking was lifted to the roof and nailed. Installation of fiberglass batt insulation in the attic was not observed, but labor estimates were obtained from a local contractor.

SIPs were used for the floor, walls, and roof of the SIP home. Floor and wall panels were 152 mm (6 in.) wide and roof panels were 203 mm (8 in.) wide. Large panels were used, up to 2.4 m $\times$ 7.3 m (8 ft $\times$ 24 ft). Wall and roof panel layouts for the SIP home are shown in Figs. 4 and 5, respectively. The panels came virtually ready for assembly. The SIP supplier completed many value-added activities in the factory including precutting (length, width, gables, windows, and doors), preframing for windows and doors, and preinstallation of splines in the wall panels. All framing materials were delivered on the same load. A large lift truck supported by four volunteers was used to unload the framing lumber and panels and stage them adjacent to the foundation.

The floor framing system was mounted on a poured concrete kneewall and steel post bases embedded in poured concrete piers. Sill plates were already mounted on the kneewall when observation began. A theodolite and measuring tape were used to check the height of each post base. A polyethylene sheet was spread over the ground as a moisture barrier. Posts to support the floor girders were fabricated using two pieces of lumber nailed and glued together. On each side of the post an additional piece of

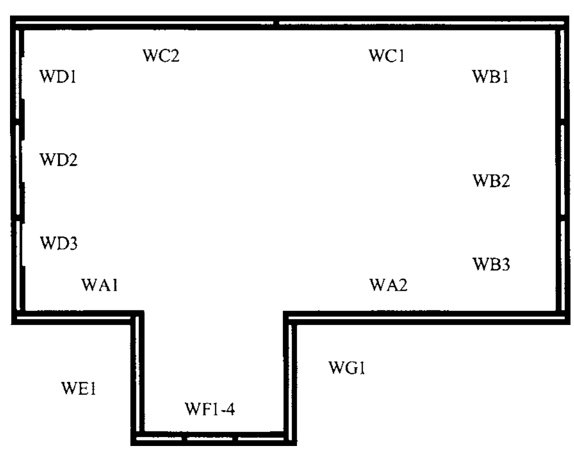

Fig. 4. Wall panel layout for SIP home

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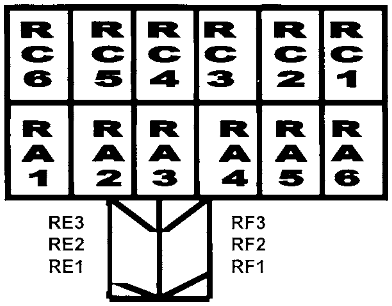

Fig. 5. Roof panel layout for SIP home

lumber was nailed, extending beyond the end of the post and forming a cavity for the girders. The posts were mounted and attached to the steel post bases. OSB was used as shims to adjust height. Floor girders were fabricated by nailing and gluing two pieces of laminated veneer lumber (LVL). Floor girders were cut-to-size using a circular saw. Floor girders were transported manually and positioned atop the posts and kneewall. Several girders were too long and were recut. Abutting girders were joined using a gusset plate placed at the T-joint formed by the girders and the post. To provide more continuous support for the floor panels, a second dimensional lumber sill plate was stacked on the first plate already mounted on the kneewall. This change also required a sill plate to be placed on top of each girder.

Floor panels were installed on top of the floor girders. Floor panels were transported manually to the perimeter of the house. Dimensional lumber splines were pre-assembled in the floor panels in the factory. Adhesive was applied to the top-side of the spline. Panels were positioned and snugged using a come-along and sledgehammer. Nails were used for joining panels along the splines. 254 mm (10 in.) screws were used to fasten panels to sill plates and to girders.

Before erecting the exterior walls, chalk lines were snapped on the perimeter of the installed floor panels and dimensional lumber bottom plates were transported, measured, cut-to-size, positioned, and glued/nailed to the floor panels. Adhesive was applied to the outer side of the bottom plate and plate channel (in the panel). Each wall panel was transported manually, set on the bottom plate, snugged to the adjacent panel using a come-along and sledgehammer, and nailed to the bottom plate and the spline of the adjacent wall panel. Dimensional lumber splines in the wall panels were factory-installed so that only two seams (one inside and one outside) were nailed per joint. Window/door openings were also precut and framed in the factory using dimensional lumber.

Panels forming the front and rear walls of the home required modification, due to a last minute change in wall depth that was not comprehended in the manufacturing plans. The ends of the panels were cut with a circular saw and foam was stripped using a hot melt tool to form a spline channel.

Roof assembly for the SIP home began by framing the ridge beam support structure. Chalk lines were snapped to position interior walls and the supporting posts that are embedded in these walls. Holes for the posts were cut in the floor panels. Posts were fabricated from two pieces of dimensional lumber sandwiching an OSB strip. Components were moved to the point-of-use, measured, cut-to-size, and assembled using nails. Posts were then erected, leveled, and braced using temporary supports. Each ridge beam was lifted using a crane and placed atop posts and/or walls. A cavity for the ridge beam was precut in the walls when necessary. Posts were then releveled.

Before the roof panels were set, adhesive was applied to the top plate installed in the exterior wall panels. Each roof panel was prepped at ground level before lifting. Prep involved snapping lines to facilitate final positioning, starting large 254 mm (10 in.) screws for attaching the panel to exterior walls and ridge beams, and attaching dimensional lumber used to attach the lifting hook and to serve as a safety stop for roof workers. Each panel was lifted and positioned by crane. Roof panels were fastened by driving the prestarted large screws into the wall panels and the ridge beams. Two OSB splines per joint were then inserted from the end into the factory-made spline channels. The crew attempted several modifications to this procedure: (1) installing splines on a panel after it had been positioned, but before the next panel was lifted and (2) applying adhesive to the splines before insertion. Neither practice was effective and both were discontinued. After inserting the splines (without adhesive), the joint was nailed from the top—two rows of nails, one row on each panel. Note that the bottom spline was not fastened to either panel. Several roof panels had to be modified to accommodate the porch, which was not in the original plan. This was done using a circular saw and a hot-melt foam cutter.

Labor Productivity and Cycle Time

Using the elemental labor data collected during home construction, estimates of labor (labor-minutes) and duration (minutes) were calculated for each activity (Mullens and Arif 1998). When there was any question about the accuracy of the written information, the video tapes were replayed to verify the written data. Results for the SIP home are summarized in Table 1. The total cycle time from unloading to roof panel installation was 1,053 min (18 h). The total labor required was 7,194 labor-min (120 labor-h). The floor system required the most labor (39%), followed by the roof and wall systems (27 and 23%, respectively). Framing the support structures for the floor and roof systems accounted for over 60% of their labor effort. Results for the

Table 1. Labor Productivity and Cycle Time Summary Results for SIP Home

	Framing tasks		Panel tasks		Total		
System	Cycle (min)	Labor (labor-min)	Cycle (min)	Labor (labor-min)	Cycle (min)	Labor (labor-min)	Percent
Unload	5	20	200	800	205	820	11
Floor	265	1,750	148	1,032	423	2,782	39
Walls	0	0	279	1,678	279	1,678	23
Roof	367	1,137	208	777	596	1,914	27
Total	—	2,907	—	4,287	1,053	7,194	100

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Table 2. Labor Productivity and Cycle Time Summary Results for Wood-Frame Home

System	Cycle (min)	Labor (labor-min)	Percent
Wall	1,202	3,219	38
Roof	1,026	5,202	62
Total	2,016	8,421	100

wood-framed home are summarized in Table 2. The total cycle time for framing the walls and roof was 2,016 min (34 h). The total labor required was 8,421 labor-min (140 labor-h). The truss roof required almost two-thirds of this effort.

Although the SIP home was clearly framed faster than the wood-framed home, several factors must be considered before comparing the two sets of construction results. First, unloading of materials was not observed for the wood-framed home. Second, the home designs were not identical. The SIP home was over 20% larger and was built over a crawl space, which required a raised floor system. The wood-framed home was built using slab-on-grade construction, which did not require a separate floor. Note that the SIP home could have been built on a slab rather than on a crawl space.

Focusing on the common elements of both home designs, the wall and roof systems, and normalizing the results based on the area of the homes allows direct comparison of the results (Table 3). The normalized results indicate that the SIP home was constructed with 65% less site labor than the wood-framed home. Cycle time results are of similar magnitude. The reduction in labor for roof construction was 70% and wall construction was 57%.

Table 4 provides additional detail about panel-related construction activities for the SIP home. In addition to the effort required to frame the panel support structure for the floor and roof (described earlier in Table 1), modifying, positioning, and fastening panels also required considerable effort. Modification was required on several wall panels due to a miscommunication between design and manufacturing at the manufacturing plant. An average of 49 labor min per panel (overall 16 wall panels) was needed to complete the repair. Positioning and fastening floor panels averaged 46 and 73 labor min, respectively. Floor panels were difficult to position because of their size. While size also affected fastening time, fastening was further complicated by the types of fastening required. Factory installed splines used to connect adjoining panels required adhesive and a single row of nails on the top side. Large screws were used to attach panels to the sill plates over the knee walls and to the sill plates over the girders (across the middle of the panels). It is interesting to note that floor panels not only require substantial support framing effort, but also require twice as much labor per panel as wall and roof panels (if one assumes that wall modifications are not routinely required).

Table 5 provides additional detail about construction activities for the wood-frame home. Sheathing accounts for 38% of all effort, primarily due to manual handling of OSB and nailing. Framing accounts for another 18% of the effort. Wall framing consists of building small sections of exterior wall horizontally on the slab. These sections will later be tilted up and erected. Roof framing is primarily manual nailing of the truss hangers and nailing the attic catwalk. Both activities take place after the trusses have been lifted and positioned.

Since alternative envelope systems interface with other building systems—foundations, roofs, utilities, windows/doors, interior walls, and interior/exterior finishes—it is important to consider the impacts on these systems as well. These impacts were not fully measured because of the extended time that would have been required on site. Although the two building systems considered in this study used different foundation/floor systems, this was not dictated by the technology. For example, the SIP home could have been built on the same slab, using the same pressure treated sill plate as the wood-frame home. Thus building envelope technology should have little or no impact on the foundation system. The roof system was largely included in both studies; therefore the impact is already included in the results. Although installation of roofing paper and shingles were not measured, they will not be impacted by the building system. Window/door framing was included in both studies and the impact is included in the results. The interface of both building systems with interior walls and with interior/exterior finishes is virtually identical, except that the drywall contractor does not need to "hit the studs" on the interior of a SIP wall or ceiling.

Utilities—plumbing, electric, and heating/ventilation/air conditioning (HVAC)—may be affected by the building system. Fresh/waste water lines rarely run through exterior walls or through the roof and should be unaffected. Plumbing stacks for venting wastewater lines may need to run through an exterior wall, requiring an additional channel to be cut in a SIP. The same stack is easily run through the cavity of a wood-frame wall. Wiring is often run through both walls and roofs and will be affected. Instead of running wire through the cavities in the frame wall/roof, electricians will need to run wire through precut wiring channels that run horizontally and vertically through the SIPs. Although this will require more effort, it is not believed to be substantial. Forced air heating/cooling systems require ducts to deliver conditioned air from the central air-handler and to return unconditioned air to the air-handler. Ducts are typically run below the floor in a crawl-space or basement and/or in the attic above the ceiling. In these cases the building system will not affect the HVAC contractor. In the case of a two-story home with a single air-handler, a separate chase is typically constructed inside the home to bridge the basement and attic duct systems. This technique can also be used for SIP construction.

Table 3. Normalized Labor Productivity and Cycle Time Summary Results

System	Wood frame		SIP		SIP savings	
	Cycle (min/m^2)	Labor ($labor\text{-}min/m^2$)	Cycle (min/m^2)	Labor ($labor\text{-}min/m^2$)	Cycle (min/m^2)	Labor ($labor\text{-}min/m^2$)
Wall	12	33	2	14	10	19 (57%)
Roof	10	53	5	16	5	37 (70%)
Total	20	86	6	30	14	56 (65%)

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Table 4. Labor Productivity Results for Panel-Related Construction Activities on SIP Home

	Labor (labor min)							
	Floor		Walls		Roof		Total	
	Average/panel	Total	Average/panel	Total	Average/panel	Total	Average/panel	Total
Prepare panels	—	—	—	—	8.8	159	3.8	159
Plates & splines	—	—	14.8	237	0.3	6	5.8	243
Transport panels	10.3	82	9.9	159	0.5	9	6.0	250
Modify panels	—	—	49.4	791	3.6	65	20.4	856
Position panels	45.9	367	15.5	248	15.7	283	21.4	898
Fasten panels	72.9	583	15.2	243	14.2	255	25.7	1,081
Total	129.0	1,032	104.9	1,678	43.2	777	83.0	3,487

Safety and Quality of Workmanship

The safety and quality of workmanship of the two homes was not explicitly measured during the study. No significant injuries were sustained during framing of the two homes. While the framing of both homes passed an inspection by the leader, significant rework was required on the SIP home requiring a total of 856 labor min (about 14 labor h). All rework was caused by lack of communication between design and manufacturing personnel. No rework was caused by poor workmanship on the site.

Construction Material Waste

Framing material was counted and documented as it was delivered and material in the scrap pile was sorted and documented before framing began and after framing was completed. Results are detailed in Mullens and Arif (1998). All waste was termed "potential" since Habitat attempts to reuse all excess materials. The primary form of waste for the SIP home was scrap from cutting the panels to size and cutting window/door openings. These scraps were generated in the factory and were estimated, not observed. A total of 12% of panel area was lost in the factory. Other significant losses on-site included dimensional lumber (7%) and OSB (29%). The OSB loss was actually minimal because of the small quantity used. The total wood product loss (including estimated loss in the factory) is estimated at 1,084 kg (2,390 lb) or 9 kg/m^2 (2 lb/ft^2) of finished floorspace. Material usage was less controlled on the stick-built site. Three homes were being built simultaneously and it was impossible to accurately monitor overall usage and waste of common materials. However, very little wood waste was actually observed during construction of the wood-frame home. This is due to Habitat's dedication to reducing waste and the fact that several wood-frame homes were under construction at the same location, producing ample opportunities to use scraps. As a reference point, Laquatra and Pierce (2004) report that a typical 176 m^2 (1,894 ft^2) wood-frame single-family home generates over 635 kg (1,400 lb) of wood scraps or 4 kg/m^2 (0.7 lb/ft^2) of floor area. This is less than one-half of the rate of wood scrap produced during production/construction of the SIP home. Note that some scrap in the SIP factory might be usable for other homes; i.e., below larger windows where it may not be practical to cut the opening out of a single larger panel.

Equipment Requirements

With the exception of the forklift and crane required for framing the SIP home over the two-day duration, both homes required comparable tools and equipment.

Perceptions

Volunteers were interviewed after framing the SIP house to gauge their perception of SIP construction. The results (Mullens and Arif 1998) suggest that both construction professionals and other less-experienced volunteers believed that SIPs reduced construction effort significantly, averaging about one-half the effort of conventional wood-frame construction.

Conclusions and Future Research

Energy studies have demonstrated that SIPs can produce more airtight and energy efficient homes. SIP suppliers also promise significant construction advantages. Yet, SIPs are only used in about 1% of new homes and survey results indicate that homebuilders need more information about SIPs before considering their use. This situation demonstrates, on a small scale, how uncertainty and risk have contributed to the reluctance of U.S. homebuilders to embrace new construction technologies.

This paper has documented findings from a side-by-side case study of the construction of two Habitat for Humanity homes, one SIP and one conventional wood-framing. Although the study focused on labor productivity and cycle time, other key construction performance metrics were assessed including worker safety, quality/workmanship, material waste, worker skill levels, and equipment requirements.

Findings indicate that SIPs saved about two-thirds of the site

Table 5. Labor Productivity by Activity for Wood-Frame Home

	Total labor min	
	Walls	Roof
Prepare	65	577
Position	214	345
Framing	761	789
Fasten	241	—
Sheathing	1,411	1,800
Insulate	399	120
Lift truss	—	259
Erect truss, nail	—	457
Lookout	—	455
Subfacia	—	220
Other	128	180
Total	3,219	5,202

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framing labor for walls and roofs. Cycle time savings were of similar magnitude. Volunteers interviewed after framing the SIP home believed that SIPs reduced construction effort significantly, averaging about one-half the effort of conventional wood-frame construction. These results are significantly better than previous comparative findings (Mullens et al. 1994). Key productivity improvements include the use of jumbo-size panels (requiring fewer joints) and more value added work performed in the factory—cut-to-size, installation of splines in wall panels, and installation of door and window framing. While these features will raise factory costs, their impact on the construction site is remarkable. Although alternative building envelope systems interface with other building systems—foundations, roofs, utilities, windows/doors, interior walls, and interior/exterior finishes, these impacts were not fully measured because of the extended time that would have been required on site. A conceptual analysis of process differences was used to demonstrate that additional construction impacts are likely to be minimal.

Several emerging market trends are likely to further impact the productivity of SIP construction. Concrete skins are now being offered, reducing the likelihood of moisture damage and eliminating the need for drywall installation. On a less positive note, the leading supplier of OSB sheathing has announced that it will no longer produce jumbo-size OSB, a critical component in jumbo-size SIPs ("Weyerhaeuser" 2004). Their rationale is that the relatively small SIP industry is the only significant market for the product.

Although the safety and quality of workmanship of the two homes was not explicitly measured during the study, no significant injuries were sustained during framing of the two homes and both homes passed quality inspections by their respective leaders. Significant rework was required on the SIP home to remedy design/production communication breakdowns at the SIP factory. Although the construction experience of the volunteer crews was similar, only the crew leader had any experience in SIP homebuilding. This suggests that construction quality and productivity using SIPs is not highly dependent on workforce experience with the technology. The size of the SIPs required some heavy equipment, a lift truck and construction crane, during the two day framing process. There was little construction waste generated on the construction site as a result of framing both homes. However, estimates of factory waste suggested that 12% of the SIP panel area was lost when cutting the panels to size and cutting window/door openings. The corresponding wood product waste alone for these panels is about twice that of a typical wood-frame home.

The conclusions that can be drawn from this study are limited due to sample size, different home designs, different volunteer crews, and the uniqueness of Habitat construction. However, several factors discourage us from dismissing the results as random occurrences: (1) similarity of home designs, (2) expertise of responsible contractors, and (3) magnitude of savings. Therefore we believe that the SIP building system can be highly efficient on the construction site, substantially reducing site framing labor and cycle time. However, attaining these benefits requires the following of the homebuilder: (1) use jumbo panels, (2) have panels delivered to the site ready to install (cut-to-size, framed window/door openings, installed splines), (3) use construction crane and lift truck for site material handling, and (4) thoroughly plan both the home design and the construction process to capture the potential benefits. SIP manufacturers must support homebuilders by: (1) migrating construction tasks into the factory as premium, value-added product features, (2) strengthening the design-to-manufacturing link and upgrading quality systems to ensure that delivered panels meet homebuilder specifications, (3) utilize panel waste resulting from cutting-to-size, and (4) controlling costs and prices to keep SIP homebuilding cost competitive at the systems level.

These findings provide practical, yet rigorous insight for homebuilders considering the use of SIPs or similar innovative building systems. Researchers who are active in product and/or process design will also find the paper of value. Building system researchers interested in the constructability of their product will find the construction process descriptions and quantitative estimates useful as they explore the next generation of building products. Building system researchers interested in benchmarking innovative systems will also be interested in the systematic evaluation of construction process impacts.

Further research is needed to better define the advantages and disadvantages of innovative building systems on the construction site. This knowledge will not only equip homebuilders to make better choices, but also provide focus for researchers/designers as they develop the next generation of building systems. Focusing on SIPs, additional studies providing larger samples on more conventionally mechanized construction sites would be invaluable. Research scope should be extended to formally capture the impacts of the building envelope system on related systems, including foundations, roofs, utilities, windows/doors, interior walls, and interior/exterior finishes. Targeted studies are needed to examine the differential impacts of various skin materials (e.g., OSB versus concrete) and panel size (e.g., small panel versus jumbo panel). Additional research is needed to explore more efficient framing techniques to support SIP floor and roof systems. Extending the study to explore the impacts of other innovative building systems (e.g., ICF, AAC) would be useful. At a more fundamental level, research is needed to define better metrics and data collection approaches for factors other than productivity.

Acknowledgments

This research was sponsored by the U.S. Department of Energy, Office of Building Technology, State and Community Programs—Energy Efficient Industrialized Housing Program. The writers appreciate the encouragement and support of our program manager, Mr. George James. The writers also appreciate the cooperation and efforts of Ms. Cynthia Gardstein, Executive Director of the Structural Insulated Panel Association (SIPA), Mr. Bill Garner, Executive Director of the Skagit Habitat for Humanity, and the many volunteers who participated in the construction.

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