REPORT

A COST ASSESSMENT OF INNOVATIVE HOMEBUILDING TECHNOLOGIES USED TO CONSTRUCT EXTERIOR STRUCTURAL WALLS

ENERGY EFFICIENT INDUSTRIALIZED HOUSING (EEIH) RESEARCH PROGRAM

(The EEIH project is jointly conducted by the Center for Housing Innovation, University of Oregon, the Florida Solar Energy Center and the Department of Industrial Engineering and Management Systems, University of Central Florida.)

Sponsored by:

United States Department of Energy
Contract No. DE-FC03-89SF17960

September 1994

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EXECUTIVE SUMMARY

The primary objective of this research is to benchmark construction costs for three homebuilding technologies used to build exterior structural walls: conventional site-built (or stick-built) wood frame construction, factory-produced panelized wood-frame construction, and stress skin insulated core (SSIC) panel construction. *Benchmarking* refers to the direct comparison of a product's performance against that of established competitors with regard to certain metrics of interest. *Construction cost* is defined as the summation of all resources required to construct the house or its primary components. Construction cost is an important performance metric for a homebuilding technology. It plays a vital role in determining price, profitability and eventual acceptance of the technology. At an elemental level, it can suggest both product and process improvement opportunities. Benchmarking construction costs for innovative homebuilding technologies offers unique challenges as compared to conventional cost estimating. It is labor intensive and difficult to develop comparable estimates. These challenges have been an impediment to solid, quantitative cost reporting.

The first step in this research was the development of a construction cost benchmarking methodology which could deal effectively with these challenges. The methodology was based on a bottom-up or industrial engineering approach and involved estimating labor-hours and materials for each element of work, and pricing and accumulating all costs into a total cost estimate. The methodology included a set of guidelines to promote efficiency and enhance comparability of results.

Research findings indicated that conventional wood framed construction costs were similar for both stick-built and factory panelized construction. SSIC construction costs were 17% higher than frame construction of comparable depth, driven primarily by cost differences in materials and labor. These results were consistent with those of Toole and Tonyan [4] who asserted that for most home designs SSIC costs appeared to average 10% to 20% higher than for conventional stick built construction, primarily due to higher material costs. Related sensitivity analyses suggested that future cost differentials may be less than 10%. A more detailed analysis of cost results suggested several avenues for improving SSIC cost competitiveness: 1) development of alternative panel sheathing materials, 2) use of "long" panels versus the conventional 4x8 ft panel, 3) development of alternative materials and processes for framing windows and doors and 4) quantification of potential energy savings and other life cycle cost advantages to justify apparently higher construction cost.

Several limitations of the research restrict generalization of findings. First, results are based on a small sample of homebuilders. Second, results reflect costs associated with the construction of an exterior, structural wall. Finally, results do not explicitly comprehend a number of factory and job site overhead costs (for example, engineering, indirect materials, insurance, property taxes, construction supervision, temporary site office, performance bonds, temporary site utilities, temporary buildings/enclosures, barricades, clean-up, permits/licenses, dust/erosion control). The implicit assumption is that these items are largely independent of technology.

INTRODUCTION AND BACKGROUND

The objective of this report is to document research findings from the Energy Efficient Industrialized Housing (EEIH) project sponsored by the by the U.S. Department of Energy Office of Building Technology, George James, Program Manager - Tel. (202)-586-9472. The EEIH project is a collaborative research effort involving the University of Oregon Center for Housing Innovation, the Florida Solar Energy Center (FSEC) and the University of Central Florida (UCF) Department of Industrial Engineering and Management Systems (IEMS). The project goal is to develop techniques to produce marketable industrialized housing that is 25% more energy-efficient than currently required by the most stringent U.S. residential codes, and at less cost.

This report documents research performed by UCF IEMS from March 1992 through the present. The primary objective of this research is to benchmark construction costs for three homebuilding technologies used to build exterior structural walls: conventional site-built wood frame construction, factory-produced panelized wood-frame construction and stress skin insulated core (SSIC) panel construction. Exterior, structural walls represent a legitimate domain for cost analysis. They are a primary component of most houses and contribute significantly to total construction cost and thermal efficiency.

Before proceeding it is useful to define several key terms. *Site-built wood frame construction* is, by far, the most common homebuilding technology used in the U.S. Dimensional lumber, sheathing and other building materials are delivered directly to the construction site. Walls are framed on site, then plumbed, wired, insulated, and finished. *Wood frame panelized construction* has become the homebuilding technology of choice for a number of large production builders. "Open" (framed and sheathed) panels are manufactured in a factory and shipped to the construction site. They arrive at the site as preconstructed wall, floor, and ceiling assemblies that workers erect and join. Once erected, the walls are virtually indistinguishable from conventional site-built construction. All electrical, plumbing and code inspections are completed on-site, as is most finishing. An *SSIC panel* is a prefabricated panel consisting of an insulative foam core sandwiched between two structural faces [1]. SSIC panels are used to build exterior structural walls, roofs and floors in light commercial and home construction applications. Although widely available commercially for over 10 years, SSIC panels have made only marginal market penetrations and, in many ways, resemble an emerging technology. Current DOE interest stems from the fact that SSIC panels provide significant thermal benefits over conventional wood frame construction of comparable depth.

Benchmarking refers to the direct comparison of a product's performance against that of established competitors with regard to certain metrics of interest. This form of product benchmarking is widely used in new product development [2]. *Cost* has been defined as "the summation of all resources required to produce the product" [3]. *Construction cost* is similarly defined as the summation of all resources required to construct the house or its primary components.

Construction cost is a critical metric for most stakeholders in the homebuilding process. For builders, construction cost drives pricing and profit, impacting market share and total profitability. Because construction cost drives pricing, it impacts the size and quality of home which the homebuyer can afford. Given these dynamics, both homebuyers and builders are generally very sensitive to construction costs [4]. For manufacturers of innovative homebuilding components, construction cost drives market acceptance and long term technology viability. From a societal perspective, construction cost provides a common denominator for initial resource consumption (materials, labor, capital, etc.). When coupled with other life cycle costs (e.g., energy, maintenance) and compared to competing technologies, construction cost can be used to help establish the relative efficiency or value of an innovative homebuilding technology. Construction costs are also valuable at the elemental level. Detailed construction costs can serve as process benchmarking metrics, used by the component manufacturer and the homebuilder to identify and evaluate potential product and process improvement opportunities.

Published construction cost estimating tables are widely available for most conventional homebuilding technologies. McDonald [5] provides an extensive list of these references. In contrast, few comparable quantitative costs have been reported for innovative homebuilding technologies. Friedman [6] compared the "cost" (actually price), production time and quality of homes built using conventional (stick built) and prefabricated (modular, panelized and pre-cut) construction. His methodology utilized price quotes from builders/manufacturers for comparable architectural house designs. He concluded that conventional construction was less expensive than prefabricated construction, but it took longer to build. Laquatra et al. [7] compared panel manufacturing costs for an innovative Optimum Value Engineered long-wall panel against a more typical short wood frame panel. The costing methodology used was not described in the paper.

Several studies have addressed the cost of SSIC construction. Toole and Tonyan [4] asserted that for most home designs SSIC costs appear to average 10% to 20% higher than for conventional stick built construction, primarily due to higher material costs. They provided no substantiating data. Fischer [8], reporting recent side-by-side demonstration results, reported that the actual cost of constructing an SSIC home was lower than the cost of an architecturally similar stick built home with the same thermal specifications. No substantiating data was provided. Brown [9] suggested that when SSIC panels are used for floor, wall *and* roof framing, cycle time reduction can be significant and can reduce time related costs such as financing and insurance. Brown concluded that when combined with an innovative house design tailored to SSIC panels, initial costs might be comparable or even lower than a conventional, stick-built benchmark. These results are indicative of the varied and conflicting perceptions regarding SSIC construction costs, many legitimately rooted in real world pricing experiences.

In a more focused study, Smith, Grobler and Miller [10] compared framing labor productivity between traditional (stick built) and systems (modular) home construction.

The authors used a more detailed engineering methodology, utilizing video-taped field study results which were analyzed to estimate elemental production process times. Their findings suggested that, ideally, systems framing labor should be significantly less than that for traditional framing methods; however, in practice, the savings were not significant. Another important finding of their study was the difficulty in assuring comparable results. They concluded that the time required to collect and analyze results has been the major impediment to solid, quantitative cost reporting.

The process of estimating costs (cost engineering) has been extensively addressed in the literature for both manufacturing and construction environments [11,5,3]. However, the process of benchmarking construction costs for innovative homebuilding technologies offers several unique challenges. First, conventional cost estimating approaches involve estimating costs for a specific design, as opposed to a technology capable of producing many designs. Second, the house is a very large scale product. Smith, Grobler and Miller's [10] conclusion, that the time required to collect and analyze results has been the major impediment to solid, quantitative cost reporting, is valid. Third, Stewart [3] has observed that operating data obtained from field studies are not of uniformly high quality. This is particularly true of innovative technologies in the early stages of commercialization which are likely to be poorly-defined and highly variable. Associated problems which were observed repeatedly in the field include: quality problems from the factory, ill-defined and poorly engineered assembly methods, and poorly trained and unmotivated crews. More mature innovative technologies may be better defined, but may still be particularly susceptible to market fluctuations and resulting plant inefficiencies (e.g., low utilization and high inventories). These factors can make comparisons difficult, particularly when compared to more stable conventional technologies. The methodology utilized in this report extends accepted cost estimating approaches to address the unique challenges associated with benchmarking innovative homebuilding technologies.

The paper is presented in four sections. First, the construction cost benchmarking methodology is described. Second, application of the methodology to the three wall construction technologies is discussed. Results from a small sample of manufacturers are then presented and discussed. Finally, the report is summarized and conclusions are noted.

CONSTRUCTION COST BENCHMARKING METHODOLOGY

There are two general approaches for estimating costs [3]: 1) the top-down or parametric approach and 2) the bottom-up or industrial engineering approach. The latter approach, also called definitive estimating [5] and detailed estimating [11], provides the most credible, supportable, usable and accurate estimate when a detailed definition of work is available [3]. The approach involves estimating labor-hours and materials for each element of work and pricing and accumulating all costs into a total cost estimate. This approach is used as the basis of the construction cost estimating methodology described in this section. The methodology has three components: a set of guidelines for applying the methodology, a construction cost model, and a cost estimating procedure.

Guidelines

As stated in the Introduction, the process of benchmarking construction costs for innovative homebuilding technologies offers unique challenges to the cost estimator. This section describes guidelines for applying the methodology which address these challenges. The first set of guidelines deals with cost estimation for a technology capable of producing multiple designs. A common housing element should be defined to serve as the basis for costing each technology. The element should be typical of new housing and, if less than a complete house, should be of sufficient size/scope to assess whole-house technology performance. At the same time size/scope should be limited to reduce unnecessary cost estimation efforts. The element should be interchangeable between technologies and have no significant residual impact on other housing systems.

The second set of guidelines addresses Smith, Grobler and Miller's [10] conclusion that the time required to collect and analyze results has been the major impediment to solid, quantitative cost reporting. These guidelines seek to improve efficiency in data collection and analysis. Thuesen and Fabrycky [12] have observed that in evaluating economic alternatives, only the *differences* between alternatives are relevant. Therefore, estimating effort should be focussed on those elements which are likely to differ between alternative technologies. Finally, Pareto analyses can serve to focus efforts on the most significant cost items. These guidelines are useful both in defining the size/scope of the common housing element to be costed as well as in selecting the cost components to be considered. They can be of particular importance when addressing the many components of overhead cost.

The third set of guidelines deals with Stewart's [3] observation that operating data obtained from field studies are not of uniformly high quality. Due to the lack of solid, quantitative data for many innovative technologies, resource requirements needed for costing should be independently developed from on-site field studies. To minimize bias and improve comparability, the estimator should be diligent in identifying and adjusting for non-standard operations, poor business practices, etc. which are not inherent to the technology. A key element of this adjustment process is to assume standard resource utilization rates for common resources (when low utilization is not inherent to the technology). For example, factory labor utilization, site labor utilization and capital facility/equipment utilization should be assumed comparable across technologies.

Finally, rates for materials, wages, and overhead items (production space, equipment, etc.) differ by location and may differ between builders/manufacturers in the same location depending on volume, negotiating expertise, etc. To minimize bias and enhance comparability, standard resource costing rates should be used for common resources (when a rate differential is not inherent to the technology).

Construction Cost Model

The cost model is used to identify elemental cost components and to establish their relationships in defining construction cost. The cost model (Equation 1) consists of two primary components, factory cost and site cost. Innovative homebuilding technologies often utilize innovative factory manufactured components. The first term in the model reflects the sum of the resources required to produce these components. Homebuilding also requires various construction site activities. The resources required to complete these activities are included in the second term.

$$CC = FC + SC \tag{1}$$

where

CC = construction cost
FC = factory cost
SC = site cost

Factory cost (Equation 2) is the sum of direct material, direct labor and factory overhead [5] and is comparable to the factory cost developed in the Cost of Goods Sold financial statement. Factory cost does not include several non-production cost components which contribute to total cost, including administrative expense (executive salaries, office space, office supplies, office equipment, legal, auditing and other services, etc.) and selling expense (sales/marketing salaries, commissions, office space, travel, entertainment, etc.). The rationale for excluding these costs is that they are far removed from production and less likely to be a function of the homebuilding technologies being considered. Profit is also excluded from factory cost.

Direct material cost is the purchase price of all materials which are directly used in manufacturing the component and become part of the component. This includes the waste and scrap generated by normal processing. Typical material categories include raw materials, purchase parts and sub-assemblies. Direct labor cost reflects all labor performed on the component to convert it to its final shape, including fabrication and assembly. Labor cost consists of wages and fringe benefits, including paid holidays/vacations, sick leave, health insurance, social security, etc. Manufacturing overhead includes all other expenses incurred in production which are not charged to the product as direct material or labor. A partial list includes the amortization of capital expenditures (e.g., facilities, equipment, inventories, software), indirect labor (e.g., manufacturing supervision, janitorial, maintenance, material handling, material procurement, inspection/test, engineering), and other indirect operating expenditures (e.g., facility/equipment rental, utilities, indirect materials, insurance, property taxes).

$$FC = DM_F + DL_F + OH_F \tag{2}$$

where

DM_F = direct material cost in manufactured components
DL_F = direct labor cost in manufactured components
OH_F = manufacturing overhead in manufactured components

Site cost (Equation 3) is analogous to factory cost where the construction site is the "factory" [11]. Like factory cost, site cost excludes non-production costs associated with general (off-site) office activities. Dagostino [11] refers to these costs as general overhead. Profit is also excluded from site cost.

Direct material and labor cost components of site cost are analogous to those of factory cost. Note that the homebuilding components manufactured in the factory cost analysis are also direct materials for the construction site; however, they are not double-counted. Also note that their cost estimates do not include separate administrative expenses, selling expenses and profit for the manufacturer. This is consistent with the scenario of a large, vertically integrated homebuilder seeking an optimal production strategy. Job site overhead [11] includes all other expenses incurred on the construction site or as a result of the job which are not charged to the product as direct material or labor. The following is a partial list of job site overhead items which may be applicable to homebuilding: salaries (construction supervision), temporary office (rent, setup and removal, utilities, office equipment, office supplies), bonds (performance), insurance (fire, theft, property damage, liability), temporary utilities (including sanitary), and other miscellaneous (temporary buildings/enclosures, barricades, engineering services, clean-up, repair of street and pavement, damage to adjoining structures/property, permits/licenses, tools/equipment, signs, dust/erosion control, fuels).

$$SC = DM_S + DL_S + OH_S \tag{3}$$

where

DM_S = direct material cost for materials added on site
DL_S = direct labor cost for site operations
OH_S = job overhead

Cost Estimating Procedure

The final component of the construction cost benchmarking methodology is a structured procedure for estimating the construction costs required by the cost model. The bottom-up cost estimating procedure described by Stewart [3] consists of the following steps:

1. Collect and review all relevant drawings, documents, and other specifications to develop an understanding of the scope of work and deliverables required.
2. Based on the specifications, develop a detailed process plan describing the

manufacturing, construction and support activities which must be performed and their precedence relationships.
3. Perform a material take-off, identifying the types and quantities of material required for each activity.
4. Perform a labor take-off. Breakdown each activity into estimatable units by discipline. Use industrial engineering standards, judgement of skilled personnel and other accepted estimating methods to estimate labor requirements (man-hours) for each activity unit. Identify and apply applicable allowances to account for expected performance against these estimates.
5. Cost material and labor using standard unit prices and current wage and fringe rates.
6. Identify and develop best estimates for overhead expenses.

Published Cost Estimating Tables

A legitimate question is why Means [13] or Walkers [14] published data were not used as the basis for cost development. There are several reasons:

1. Published construction data do not address innovative technologies such as wood frame panelization and SSIC panels. Note that although published data were available for site-built wood frame construction, actual field study results were used to insure comparability with the other technologies whose results could only be obtained in the field.
2. Published construction data do not address differences between site vs. factory construction processes, including differences in capital equipment and facilities requirements.
3. Field studies provide additional insight into improvement opportunities, opportunities often masked by published data.

A final note is that Walkers [14] was used to obtain estimates for processes essentially common to all technologies, such as drywall hanging and finishing.

APPLICATION OF THE BENCHMARKING METHODOLOGY

In this section the construction cost benchmarking methodology is applied to the specific problem of interest, the comparison of innovative homebuilding technologies used for constructing exterior, structural walls. The first task is identification and documentation of the common housing element to be analyzed. The common element selected (termed the standard wall) was a single exterior structural wall, 40 ft long by 8 ft high, containing 3 windows and 1 door, and standing on-site, fully assembled and finished. The interior is specified as 1/2 in. sheetrock, finished and painted. Vinyl siding is specified for the exterior surface. It is assumed that the walls are constructed on a completed floor surface (either slab-on-grade or raised deck). It is also assumed that the wall will eventually be joined to a roof system (conventional truss or SSIC panel) and to other walls, both exterior end walls and interior walls. These connection costs are assumed to be similar for all technologies and are not included in the analysis. Configurations of the standard wall are shown in Figures 1 through 6 for the following technologies: 2x4 stick built, 2x6 stick built, 2x4 factory frame #1, 2x4 factory frame #2, 2x6 factory frame, 4 in. SSIC #1, and 4 in. SSIC #2.

The standard wall satisfies the intent of the guidelines regarding selection of a common housing element. The wall construction technologies under consideration are largely interchangeable and have little residual cost impact on the rest of the house. Therefore, the impact of wall construction technology on whole-house cost can be assessed by focusing on the walls. The standard wall was defined to be of sufficient size and scope to represent all exterior structural walls in a new house and to be typical for new housing in general. Also note that the theoretical thermal performance of the standard wall differs between technologies. Duplicate studs in the panelized wall increase the level of thermal conduction slightly over that of a stick-built wall. The SSIC panelized wall has significant thermal advantages over the competing wood frame wall technologies, including reduced conduction and lowered air infiltration [15].

The second step of the procedure involves development of detailed process plans describing the manufacturing, construction and support activities required for production of the standard wall. Data for the process plans were obtained during detailed field studies at four panel factories and six construction sites (see Table 1). Methods of data collection included: personal observation, conversations with laborers and supervision, video taping and work sampling. Observers also maintained written documentation of deviations from standard practice and their cause (weather, defects from factory, assembly difficulties, problems with interfacing systems, crew training, material shortages, delivery delays, inspection delays, supervision problems, etc.). Process activities were identified during subsequent analysis of field study results. All non-standard activities were identified and eliminated, as suggested by guidelines regarding the quality of field data. Activities were documented using Boothroyd-Dewhurst's Design for Assembly (DFA) software [16]. Activities were added to the DFA User Operations Library, which serves as a database for all homebuilding activities. The activities were then used to construct the appropriate DFA Structure Charts and DFA Worksheets for each technology. A sample DFA Structure Chart and detailed DFA Worksheet for the SSIC configuration of the standard wall are shown in Figures 7 and 8 respectively. Note that the model is a hierarchical representation of the product, with parts, sub-assemblies and activities defined at each level. A full set of process charts and worksheets is shown in Appendix A.

Technology	Location	Dates
Site-built, 2x4 Frame	Site	9/94
Site-built, 2x6 Frame	Site	1/93
2x4 Frame Panel #1	Factory	5/92
	Site	5/92
2x4 Frame Panel #2	Factory	5/92
	Site	5/92
2x6 Frame Panel	Factory *	-
	Site *	-
4" SSIC Panel #1	Factory	5/92
	Site	5/92
4" SSIC Panel #2	Factory	10/92
	Site	10/92
6" SSIC Panel	Factory *	-
	Site *	-

Note: * Indicates that technology costs were estimated rather than observed.

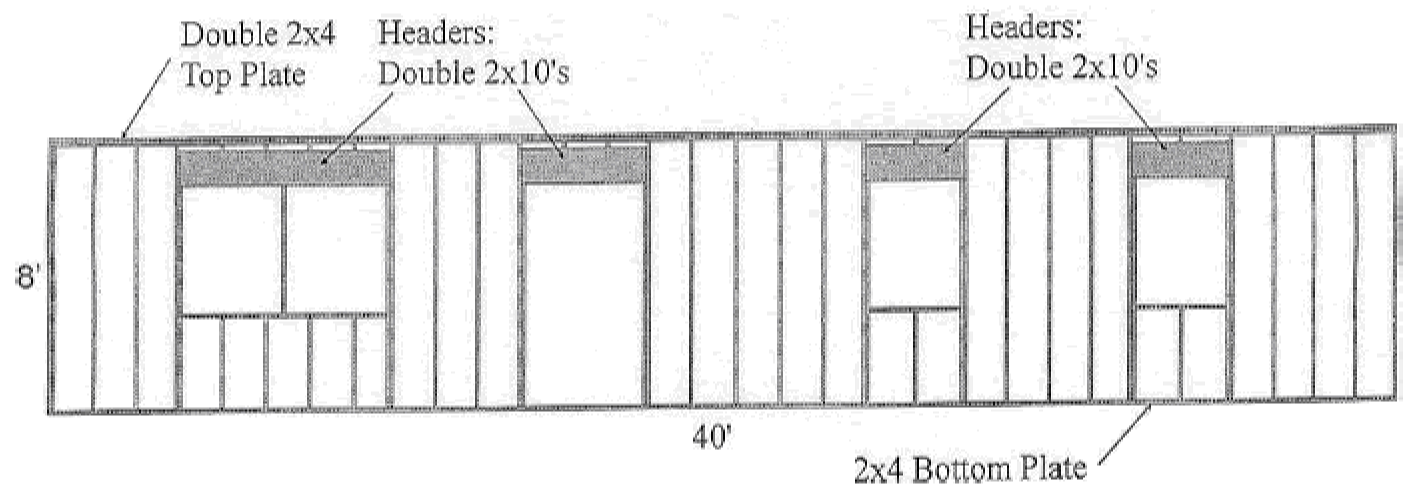
Table 1. Field Study Sites

In the third step of the procedure a material takeoff was performed, identifying the types and quantities of materials required for each activity. Data was generated from the drawings shown in Figures 1 through 6 and information gathered during the field studies. Materials were added to the DFA User Items Library (the materials database) and then added to the DFA Structure Charts and DFA Worksheets. The DFA User Items Library is shown in Appendix B.

In the fourth step of the procedure, the labor take-off was completed. To quantify the labor requirements for each activity, methods and time studies were performed on the video taped field operations. To calculate the standard time for an operation, multiple

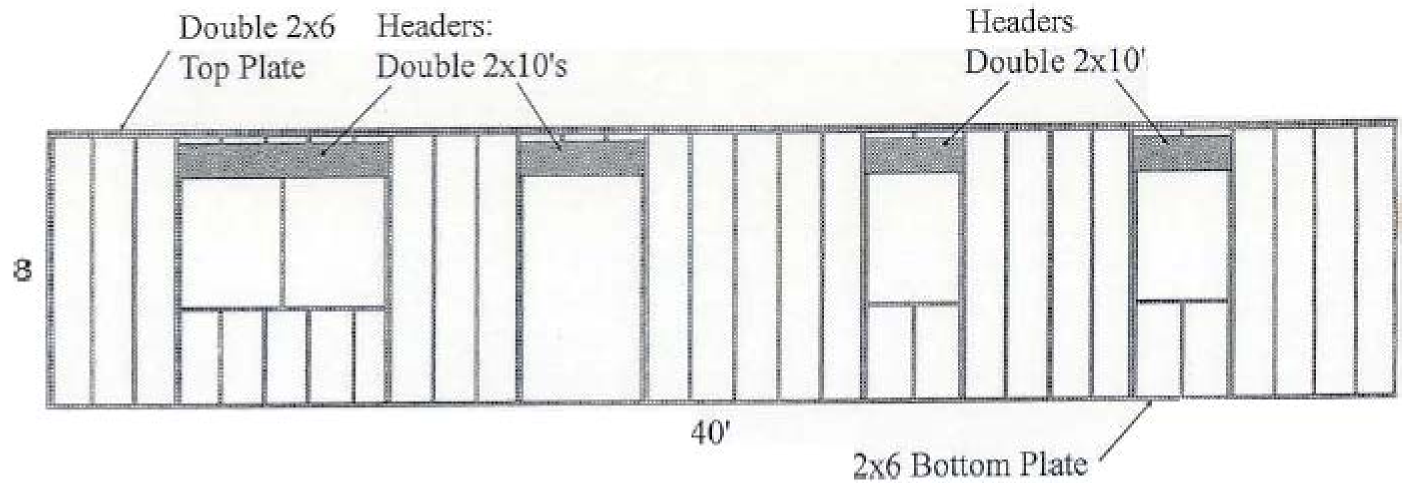
Figure 1

4" STICK BUILT



Wood Frame Construction Specifications:
Studs at 16" O.C., 7/16" OSB skins, 1/2" sheetrock interior sheathing, wiring and rough electric completed, windows and door installed, taping and spackling completed, interior painting completed, and vinyl siding installed.

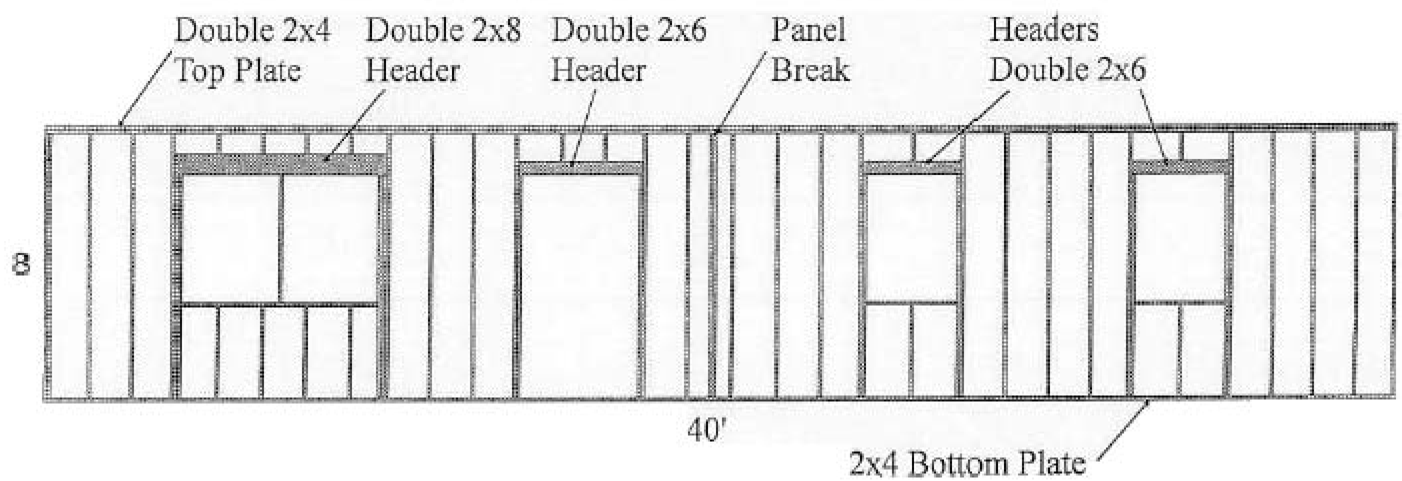
Figure 2
6 STICK BUILT



Wood Frame Construction Specifications
Studs at 6 O.C., 7/16" OSB skins, 1/2" sheetrock interior sheathing, wiring and rough e ectric completed, windows and door installed, taping and spackling **completed,** interior painting completed, and **vinyl** siding installed.

Figure 3

4 FACTORY FRAME #1

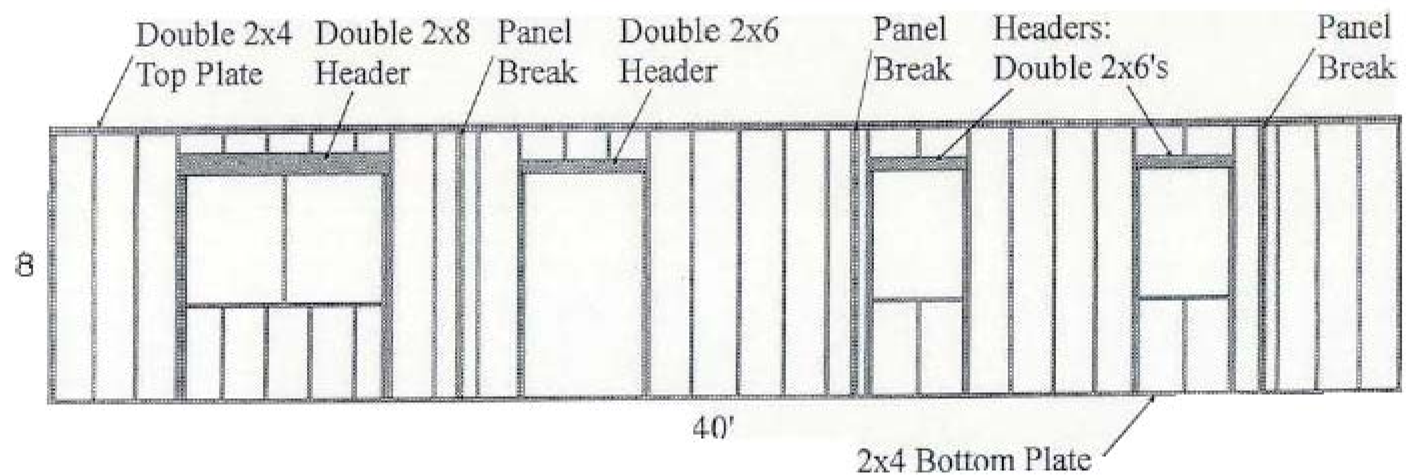


Wood Frame Construction Specification

Studs at 6 O.C **7/16" OSB skin:** 2 sheetrock interior heathing, wiring and rough :lectric com**pleted, windows** and door installed, taping and spackling comp. eted, interior painting completed, and viny' siding installed.

Figure 4

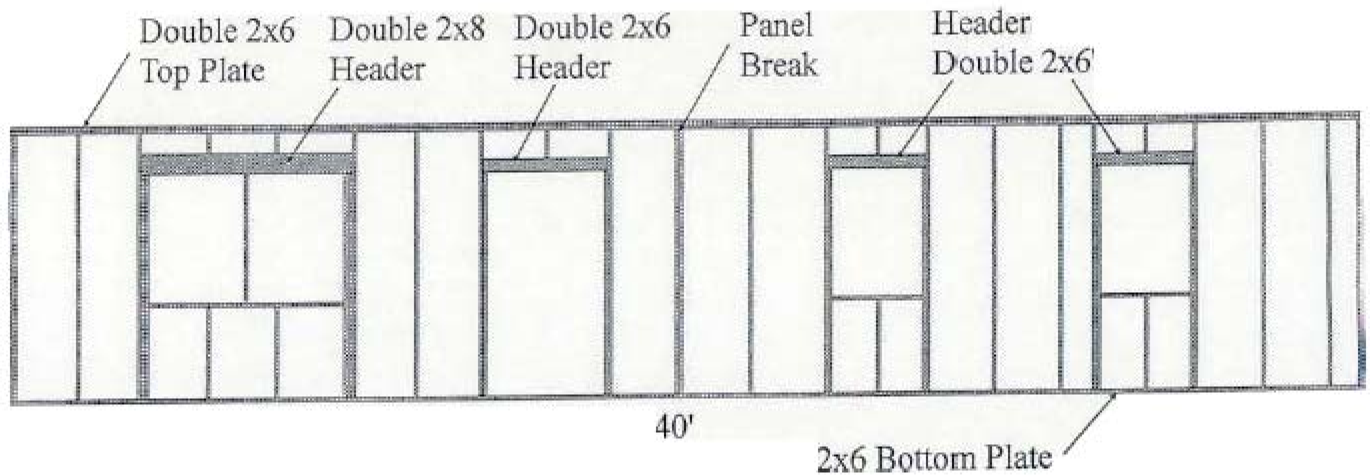
4 FACTORY FRAME #2



Wood Fram Con truc on Sp c fi ation:
tuds a 6 O.C. / Thermo P kin 2 h tro k interior h athing, w ring and rough tric comp ted, window and door n a ed, tapin and p ckl n comp d, in rior p intıng omp ted, and v ny ding instal ed

Figure 5

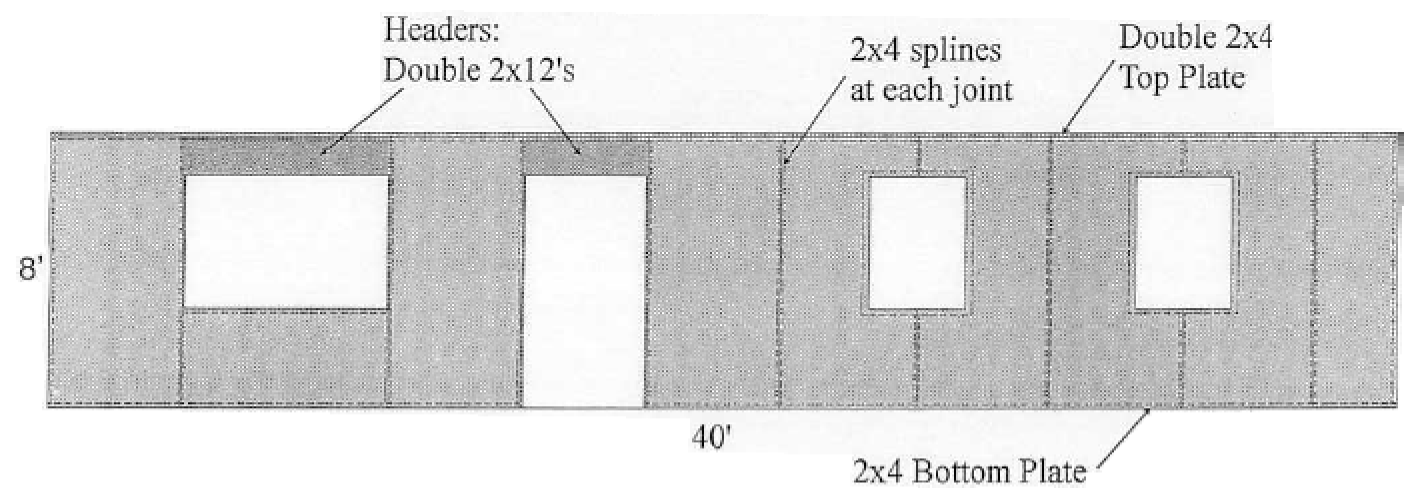
6 FACTORY FRAME



Wood Frame Con truction Spec fication
Stud a 24 O.C. 7 6 O B kins. heetrock nter or h ath ng wiring and rough ectric comp ted window and door nstal ed. ap ng and packling comp ted, interior painting comp ed, and vinyl siding instal ed.

Figure 6

4" SSIC #1 & #2



Stress Skin Construction Specifications:
3 5/8" thick EPS insulation, 7/16" OSB skins, 1/2" sheetrock interior sheathing, wiring and rough electric completed, windows and door installed, taping and spackling completed, interior painting completed, and vinyl siding installed.

replications were located on the tape, timed and averaged. Observed work pace was assumed to be 100% of a reasonable, sustainable daily rate. Observations influenced by obvious anomalies or off-standard conditions were eliminated, as suggested by guidelines regarding the quality of field data. Standard times were added to the corresponding activities in the DFA User Operations Library and then to the DFA Structure Charts and DFA Worksheets. A final task in the fourth step involved identifying and applying applicable allowances to account for expected performance against the time estimates. Factors to account for personal, fatigue and delay (PF&D) were estimated to be 25% and 40% for factory labor and site labor respectively. The same PF&D factors were applied to all technologies as suggested by the guideline regarding the use of standard resource utilization rates. The factory PF&D labor factor is consistent with results obtained during a series of Process and Energy Efficiency Reviews (PEER) field studies [16,17,18] as well as the independent study reported by Smith, Grobler and Miller [10]. The site PF&D labor factor is based on the general perception that construction site labor is more susceptible to lost time due to climactic conditions, working conditions, etc. [11]. This estimate conflicts with the results reported by Smith, Grobler and Miller [10] which indicated a site PF&D factor of 4%.

Elemental times for a limited number of wall-building activities (e.g., door and window installation, drywall hanging, finishing, painting, siding installation, and rough and finish electrical) were thought to be relatively constant and were developed using published cost estimating tables [14]. Electrical labor was assumed 25% higher for the SSIC options, reflecting the judgement of the electrician at one SSIC construction site. The Walker estimates included PF&D factors and, thus, did not need further adjustment.

The fifth step in the procedure was to cost the material and labor requirements identified in the take-offs. The guideline regarding the use of standard resource costing rates was utilized to minimize bias and enhance comparability. Unit material costs were estimated using a local modular manufacturer's computerized purchasing data base, effective March 1989. The prices were thought to be generally representative of current prices except for wood products which had recently risen approximately 90% [19]. These prices were adjusted accordingly. A 5% premium was added to the cost of materials used on the construction site to reflect additional handling. Unit material costs were added to the DFA User Items Library and then to the DFA Structure Charts and DFA Worksheets. Wage rates for all technologies were estimated to be $10 per hour in the factory and $15 per hour on site, including fringes. These rates were estimated by an experienced industrialized homebuilder on the project team and were judged to be reflective of local wage rates. Wage rates were added to the DFA Structure Charts and DFA worksheets. The DFA software automatically calculates direct material and labor costs. The labor costs were then adjusted using the appropriate PF&D factors.

The sixth and final step of the procedure was the identification and estimation of overhead costs. These costs were the most difficult to assess as evidenced by the number of simplifying assumptions and liberal use of guidelines to reduce the data collection and analysis effort. In summary, we sought to include only those costs which were significant in magnitude and which were likely to differ between technologies.

Figure 7

DFA Structure Chart For SSIC Standard Wall

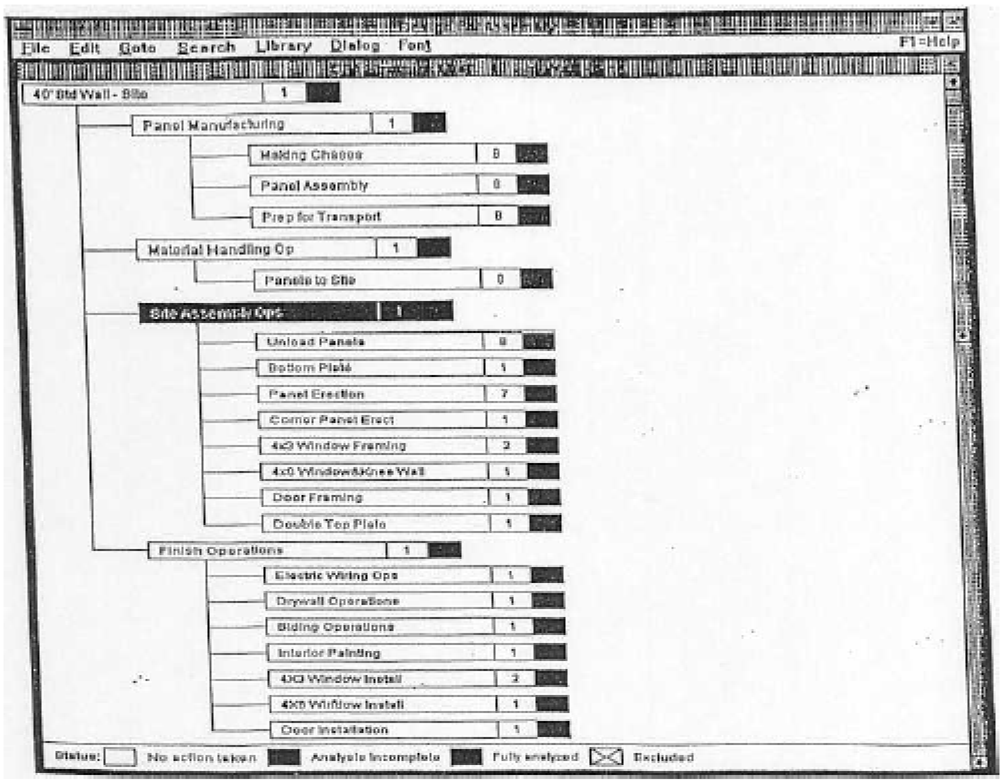


Figure 8

Typ cal DFA Worksheet For SS C Standard Wa E ement

Design For Assembly — F1=Help

File Edit Goto Search Library Dialog Font

DFA Structure Chart - 40' Std Wall - Site

DFA Worksheet - Panel Erection

Subassembly: Panel Erection — Labor rate: 12.50/hr — DFA index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost	Item Weig
1	Oper	Picking Up Glue Gun	1	-	-	-	-	5.0	0.02	0.00	0	0.
2	Oper	Applying Glue to B P	1	-	-	-	-	12.0	0.04	0.00	0	0.
3	Part	Constn Glue/Bottom	1	0	0.0	0.0	0.0	0.0	0.00	0.56	0	0.
4	Oper	Carrying the Panel	1	-	-	-	-	33.0	0.11	0.00	0	0.
5	Oper	Placing the Panel	1	-	-	-	-	32.0	0.11	0.00	0	0.
6	Oper	Picking Up StapleGun	1	-	-	-	-	30.0	0.10	0.00	0	0.
7	Oper	Stapling Panel	2	-	-	-	-	16.0	0.06	0.00	0	0.
8	Part	Staples/Bottom Plate	1	0	0.0	0.0	0.0	0.0	0.00	0.12	0	0.
9	Oper	Stapling the Spline	2	-	-	-	-	53.2	0.18	0.00	0	0.
10	Part	4x8' Wall Panel	1	0	0.0	0.0	0.0	0.0	0.00	0.00	0	0.
11	Part	Staples/Spline	1	0	0.0	0.0	0.0	0.0	0.00	0.24	0	0.
12	Oper	Applying Glue	1	-	-	-	-	19.0	0.07	0.00	0	0.
13	Part	Constn Glue/Spline	1	0	0.0	0.0	0.0	0.0	0.00	0.56	0	0.
14	Oper	Picking Up Spline	1	-	-	-	-	21.0	0.07	0.00	0	0.
15	Oper	Placing 2x4 Spline	1	-	-	-	-	12.5	0.04	0.00	0	0.
16	Part	2X4X8' Stud	1	0	0.0	0.0	0.0	0.0	0.00	1.93	0	0.
17	Oper	Stapling the Spline	2	-	-	-	-	53.2	0.18	0.00	0	0.
18	Part	Staples/Spline	1	0	0.0	0.0	0.0	0.0	0.00	0.24	0	0.
19	Oper	Apply Glue to Spline	1	-	-	-	-	19.0	0.07	0.00	0	0.
20	Part	Const Glue/Spline	1	0	0.0	0.0	0.0	0.0	0.00	1.12	0	0.
21	Oper	Pick Squaring Jig	1	-	-	-	-	21.0	0.07	0.00	0	0.
Totals:			24	0				326.9	1.14	4.77	0	0.0

Several other guidelines were widely used in estimating overhead costs. These included: 1) standard resource costing rates were used for resources common to multiple technologies (e.g., floorspace), 2) standard resource utilization rates were used for resources common to multiple technologies (e.g., facility/equipment utilization) and 3) adjustments were made to compensate for poor business practices.

A partial list of manufacturing overhead items includes the amortization of capital expenditures (e.g., facilities, equipment, inventories, software), indirect labor (e.g., manufacturing supervision, janitorial, maintenance, material handling, material procurement, inspection/test, engineering), and other indirect operating expenditures (e.g., facility/equipment rental, utilities, indirect materials, insurance, property taxes) The following capital items were included in the analysis: facility floorspace, equipment and inventory. Floorspace was measured during the field study and was valued at standard rates based on type of facility: \$10 per ft^2 for roof only, \$20 per ft^2 for a pre-engineered "Butler" type facility, and \$40 per ft^2 for a high value, high bay, industrial facility. Manufacturing process equipment was inventoried during the field study and costed at its suggested retail price. Inventory estimates for raw materials, work-in-process (WIP) and finished goods were taken from computerized inventory reports where available and on observation elsewhere. Obvious anomalies were noted for several capital items. For example, one SSIC panel manufacturer was observed to have considerably more floorspace and finished goods inventory than was appropriate. A discussion with factory management indicated that the situation was atypical and was being remedied. The data was adjusted to reflect more normal conditions. Capital costs were annualized using discounted annual worth [12], assuming a ten year study period and a 20% minimum attractive rate of return (MARR). This measure includes recovery of capital over the study period with compounded interest accruing at the MARR. The study period and MARR were estimated by the homebuilder serving on the project team and were judged to be reflective of current financial expectations in the industry. Note that the analysis was done on a "before income tax" basis and therefore the impact of accounting depreciation on taxes was not considered.
The only factory indirect labor overhead item considered in the analysis was manufacturing supervision. This was costed at the actual salary (including fringes) since the span of responsibility varied greatly between operations. All material handling, inspection/test and customer delivery functions associated with normal operations were included with the direct labor estimates. All of these functions (except delivery) were performed by production operators. Routine janitorial and maintenance functions were also performed by production operators and are, arguably, included in the 25% PF&D factor. Other routine overhead functions such as production scheduling and control were largely handled by the production supervisor in collaboration with sales, engineering and company executives. One important function which was not included in this analysis is engineering. Engineering related overhead includes salaries, office space, office equipment, computer hardware/ software and professional services. The implicit assumption was that total engineering costs, factory plus construction site, are comparable for all technologies. In fact, engineering costs appeared to be driven more by the level of value-added design services which the producer (manufacturer/builder) chose to provide than on the technology used. This was driven largely by the market(s) being served, high end custom homes which required

considerable design versus lower end standard designs.

Other factory indirect operating expenditures considered in the analysis included delivery truck lease and utilities. Annual delivery truck lease costs were estimated at standard market rate. Utility estimates provided by industry were used when available. Where these estimates were not available, estimates were provided by the homebuilder serving on the project team, estimated at local rates. No indirect materials, insurance or property taxes were considered in the analysis.

Annual factory overhead costs were then summed and distributed equally over the number of equivalent standard walls produced by the factory annually. It should be noted that several manufacturers were operating well below 100% capacity while others were operating above (including a partial second shift). Reflecting the guideline regarding the use of standard utilization rates, it was assumed that each factory produces panels at a rate equivalent to 100% of single shift capacity. Capacity estimates were provided by manufacturers and ranged from .4 to 3.5 million sq. ft. of wall annually, depending on technology and specific manufacturing system configuration. A MICROSOFT EXCEL™ spreadsheet was used to perform all factory overhead analyses. An example for SSIC manufacturing is shown in Figure 9. A complete set of factory overhead costs is given in Appendix C.

Job site overhead items include: salaries (construction supervision), temporary office (rent, setup and removal, utilities, office equipment, office supplies), bonds (performance), insurance (fire, theft, property damage, liability), temporary utilities (including sanitary), and other miscellaneous (temporary buildings/enclosures, barricades, engineering services, clean-up, repair of street and pavement, damage to adjoining structures/property, permits/licenses, tools/equipment, signs, dust/erosion control, fuels). With one exception, all job site overhead items were assumed comparable and largely independent of technology. The only item explicitly considered in the analysis was equipment rental for the construction crane when required. This was costed at the local market rate. Total crane costs for the job (construction of one house) included transport to/from site and the time on site (estimated from field study observations). Costs were allocated to the standard wall based on the fraction of crane time required to construct the wall versus the total time spent at the job-site.

After all cost components (direct labor, direct materials and overhead expenses) were estimated, they were summed to yield total construction cost for each technology.

Figure 9
Sample Overhead Cost Calculation Spreadsheet

			EEIH PROJECT		
		PANEL COST ANALYSIS: FIXED COSTS			
PANEL MANUFACTURER:			Current and Normalized Business Practice		
4" SSIC #2 & 6" SSIC					
STUDY PARAMETERS					
Max. Capital Recovery Period (yr.)		10			
Minimum Attractive Rate of Return		20%			
CAPITAL COSTS					
FACILITIES					
Mfg. Space (sq.ft.)		6,000			
Capital Cost per sq.ft.		$20			
Sub-Total			$120,000		
EQUIPMENT					
Roll Coater			$28,000		
Large Vacuum Press			$8,000		
Small Vacuum Press			$3,000		
Hot wiring table with jigs			$1,000		
Small forklift			$15,000		
Sub-Total			$55,000		
WORKING CAPITAL - INVENTORY					
Raw Materials			$43,379		
Work in Process			$0		
Finish Goods			$2,920		
Sub-Total			$46,299		
TOTAL CAPITAL COSTS			$221,299		
TOTAL ANNUAL EQUIV. CAPITAL			$52,784.85		
ANNUAL OPERATING EXPENSES					
Production Supervision			$40,000		
FACILITY LEASE					
Mfg. Space (sq.ft.)		6,000			
Annual lease cost per sq.ft.		$0.00			
Sub-Total			$0		
EQUIPMENT LEASE					
Delivery Trucks			$12,500		
Sub-Total			$12,500		
UTILITIES					
Utilities			$600		
Forklift			$1,200		
Vacuum Presses			$240		
Roll coater			$1,200		
Sub-Total			$3,240		
TOTAL ANNUAL OPERATING COSTS			$55,740		
TOTAL FIXED COST ANALYSIS					
TOTAL ANNUAL EQUIV. COSTS			$108,524.85		
PARAMETERS					
Plant Capacity (lineal ft. of wall)		52,000			
Length of Standard Wall (lineal ft.)		31			
COST/40 ft wall @ 33% CAPACITY			$196		
COST/40 ft wall @ 66% CAPACITY			$97		
COST/40 ft wall@ 100% CAPACITY			$65		

RESULTS

Summary cost results are presented and discussed in this section. Results are given for a base case as well as for several alternative scenarios. Note that the costs presented may differ significantly from those experienced by the manufacturers/builders observed during field studies. This results from the use of guidelines including: 1) the use of standardized resource cost and utilization rates and the exclusion of atypical cost elements (to promote comparability) and 2) the exclusion of cost elements judged to be insignificant or likely to be similar for the technologies considered (to simplify data collection and analysis). The *differences* in the costs reported, however, are thought to be indicative of actual cost differences between technologies.

Before examining the results, it is useful to summarize each alternative. The specific alternatives examined are characterized by the technology used, the wall panel design and the manufacturing/construction operations observed in the field study.

Homebuilding Technology Assumptions

2x4 Stick Built: The standard wall built using 2x4 conventional stick built construction is shown in Figure 1. No significant problems were observed on the construction site.

2x6 Stick Built: The configuration of the standard wall is shown in Figure 2. Note that studs were located on 16 in. centers (versus more typical 24 in. on center for 2x6 construction). Although plywood sheathing was used in the field, OSB was assumed for comparability. No significant problems were observed on the construction site.

2x4 Factory Frame # 1: The factory, a low cost open air facility built on a concrete slab, was operating near capacity. It utilized used Triad framing equipment including a roller deck framing table, an overhead shock cord-suspended router and a bridge-mounted sheathing stitcher. Windows were factory installed (actual factory installation time is used in lieu of Walkers [14] published estimates). The factory manufactured large (20 ft) panels. The panel layout for the standard wall, consisting of two large panels, is shown in Figure 3. Panels were installed on-site using a large rental crane, which was also used to set roof trusses. No significant problems were observed in either factory manufacturing or site construction operations.

2x4 Factory Frame # 2: The factory, a modern, high quality industrial facility, was operating near capacity. Raw materials were delivered to the line via overhead bridge crane. Panel manufacturing lines utilized Triad framing equipment including a roller deck framing table, an overhead shock cord-suspended router and a bridge-mounted sheathing stitcher. The panel layout for the standard wall, consisting of three 12 ft panels and one 4 ft panel, is shown in Figure 4. Light-weight insulative sheathing was used instead of OSB, also eliminating the need for felt. No construction crane was used on the construction site. All panels (and trusses) were man-handled. No problems were observed in either factory manufacturing or site construction operations.
2X6 Factory Frame: The panel layout for the standard wall is shown in Figure 5. This

option was not observed. Instead, cost results were extrapolated from those of the 2x4 Factory Frame # 1 option, using appropriate material and labor cost increases associated with handling larger components. It was assumed that studs are located on 24 in. centers.

4 in. SSIC # 1: The factory, a modern, high quality industrial facility, was operating at roughly one-third of its estimated capacity. Factory floorspace greatly exceeded that required for production. SSIC panel manufacturing equipment included powered hand tools for hot wire and cut-to-size work centers, a Black Brothers roll-coater for construction adhesive application, and two conveyorized laminating layup stations feeding two Black Brothers hydraulic platen presses. Material handling within the facility was by lift truck, hand cart and conveyor. Inventory levels for raw materials and finished goods were very high. Inventories were stored inside the facility and occupied a considerable amount of floorspace. The factory produced a range of panel sizes, from small (4x8 ft) to large (8x24 ft) panels. The standard wall (Figure 6) was constructed using 7.7 4x8 ft panels. Note that SSIC construction costs are very sensitive to scrap levels. A construction decision resulting in a square foot of SSIC panel scrap is much more costly than a similar decision impacting OSB or a cheaper grade of sheathing. This analysis assumed that the only SSIC panel scrap was that portion of the small window cutouts which were not used in the large window knee-wall. Panels were cut on site, not pre-cut in the factory. A standard 2x4 spline was used to join panels. Panels were joined to the floor via a single 2x4 bottom plate and attached to the roof via a double 2x4 top plate. The approach observed for rough electric (running wiring) was unique. The builder, a licensed electrician, ran the wiring as he erected each panel. Operational problems were observed in the factory and on the construction site. 30% of observed factory labor was devoted to understanding one hastily prepared set of shop drawings which were incomplete and unclear. 45% of observed factory labor was dedicated to moving materials which were blocked by other inventories, poorly placed columns, etc. On the construction site the crew had difficulty cutting a corner panel to size, requiring three attempts to cut it properly. After this effort, the panel was installed with little remaining EPS insulation.

After reviewing findings with factory management and the builder, it was concluded that several conditions were atypical and being remedied. Observed data were adjusted accordingly. Factory floorspace and inventories were reduced by 50% and the excess labor associated with off-standard conditions observed were not included in the study. The analysis also assumes that the builder will not be a licensed electrician and that wiring will be run conventionally . Elemental labor estimates for rough and finish electric is assumed 25% higher than for the wood framed technologies, reflecting the judgement of the electrician at one SSIC construction site.

4 in. SSIC # 2: The factory, a low cost pre-engineered industrial building, was operating far below capacity. Factory floorspace was well-used, if not tight. SSIC panel manufacturing equipment included a custom-built EPS foam cutting table with stationary hot wire, a Black Brothers roll-coater for construction adhesive application, two custom-built pneumatic vacuum presses and a cut-to-size work center which utilized powered hand tools. Material handling within the facility was by lift truck. Inventory levels for raw materials and finished goods were appropriate. Finished panels were wrapped in plastic and stored in the yard. The factory produced a range of panel sizes, from small (4x8 ft) to larger panels. The panel layout for the standard wall was the same as that used for the 4 in. SSIC # 1 option described above. Chase and spline cutting was not observed in the factory, but was assumed equivalent to that observed for the 4" SSIC # 1 option. No difficulties were observed in factory manufacturing operations; however, several problems at the construction site slowed panel erection. First, the bottom plate was over-sized, requiring the panels to be force-fit over the plate. After recognizing the problem, the bottom plates were cut down to 3 ½". A second problem arose when the interior walls were framed at 1-_" higher than the SSIC panels. To remedy this problem, _" of foam was removed from the top of each SSIC panel (using a hand held hot wire tool), allowing a second top plate to be installed. Both problems were assumed atypical and the associated labor was not included in the study. Note that the second top plate was included in the study.

6 in. SSIC: This option was not observed. Instead, cost results were extrapolated from those of the 4 in. SSIC # 2 option, using appropriate material cost increases.

Note that not all factors were standardized. For example, sheathing materials and panel sizes were allowed to vary for the wood frame technologies. The rationale for allowing this variation was to assess the impact of some common design variations within the technologies considered.

Results

A summary of cost results for the base case are shown in Table 2(a). A second level of cost detail for each cost category is shown in Tables 3 through 5. Key findings include:

1. Conventional wood framed construction costs were similar for both stick-built and factory panelized construction. Although capital costs were higher for factory panelized operations, this was partially recovered by labor savings. The lowest cost option, 4 in. Factory Frame #2, gains its cost advantage by the use of a light-weight insulative sheathing instead of the more expensive OSB. The 6 in. frame wall construction technologies were about 7% more costly than comparable 4 in. construction, largely the result of higher dimensional lumber cost.

2. The costs for the two 4 in. SSIC alternatives were similar, with the primary difference being greater capital facility costs for the 4 in. SSIC #1 option. The 6 in. SSIC costs were 6% higher than comparable 4 in. costs, the result of higher materials costs.

3. The 4 in. SSIC construction costs were 17% higher than 4 in. frame construction and 10% higher than 6 in. frame construction. For the 4 in. frame comparison, this is driven by cost differences in materials and labor.

Table 2
Cost Per Standard Wall

(a) Base Case

	4" Stick Built	6" Stick Built (16" OC)	4" Factory Frame #1	4" Factory Frame #2	6" Factory Frame (24" OC)	4" SSIC #1	4" SSIC #2	6" SSIC
Material	1140	1,230	1140	1060	1,200	1,260	1,240	1,350
Labor	390	390	340	370	340	440	450	450
Overhead	0	0	60	40	60	80	70	70
Total	1,530	1,620	1,540	1,470	1,600	1,780	1,760	1,870

(b) SSIC Cost Reduction Scenario

	4" Stick Built	6" Stick Built (16" OC)	4" Factory Frame #1	4" Factory Frame #2	6" Factory Frame (24" OC)	4" SSIC #1	4" SSIC #2	6" SSIC
Material	1140	1,230	1140	1060	1,200	1,260	1,240	1,350
Labor	390	390	340	370	340	350	360	360
Overhead	0	0	60	40	60	40	40	40
Total	1,530	1,620	1,540	1,470	1,600	1,650	1,640	1,750

NOTE: ALL COSTS ROUNDED TO NEAREST $1

Table 3

40 Foot Standard Wall
Cost Analysis: Material
(Lumber Price Increase Included)

Item	4" Stick Built	6" Stick Built (16" OC)	4" Factory Frame #1	4" Factory Frame #2	6" Factory Frame (24" OC)	4" SSIC#1	4" SSIC #2	6" SSIC
Windows/Doors	358	358	346	358	346	358	358	358
Siding	274	274	274	274	274	274	274	274
Wiring & Electrical	22	22	22	22	22	22	22	22
Drywall	69	69	69	69	69	69	69	69
Paint (interior)	20	20	20	20	20	20	20	20
Dimensional Lumber	248	313	232	248	262	161	161	201
OSB & Felt	113	113	131	38	131	196	196	196
Insulation/Foam	28	58	28	28	58	86	86	133
Glue (Factory & Site)	N/A	N/A	4	N/A	4	59	44	73
Fasteners	7	7	9	6	10	10	8	8
Total Material Costs	1,139	1,234	1,135	1,064	1,197	1,255	1,238	1,354

* 1/8" Thermo-Ply, no felt for 4" factory frame #2

Table 4
40 Foot Standard Wall
Cost Analysis: Labor

Item	4" Stick Built	6" Stick Built (16" OC)	4" Factory Frame #1	4" Factory Frame #2	6" Factory Frame (24" OC)	4" SSIC#1	4" SSIC #2	6" SSIC
Factory Fabrication. & Assy.	N/A	N/A	25	17	24	19	20	20
Factory Mat'l Handling	N/A	N/A	7	3	8	5	12	12
Transport Panels To Site	N/A	N/A	6	6	6	6	6	6
Assemble Panels on Site	55	56	25	16	25	78	84	84
Install Windows/Doors	69	69	17	69	17	69	69	69
Install Siding	83	83	76	76	76	83	83	83
Install Wiring & Electrical	60	60	50	60	60	75	75	75
Install Drywall	61	61	61	61	61	61	61	61
Paint (interior)	42	42	42	42	42	42	42	42
Insulation	18	22	18	18	22	Incl.	Incl.	Incl.
Total Labor Costs	387	392	338	368	341	438	452	452

Values include all applicable PF&D factors

Table 5

40 Foot Standard Wall

Cost Analysis: Overhead

Item	4" Stick Built	6" Stick Built (16" OC)	4" Factory Frame #1	4" Factory Frame #2	6" Factory Frame (24" OC)	4" SSIC#1	4" SSIC #2	6" SSIC
Capital Cost - Equipment	2,100	0	148,990	181,988	148,990	147,000	55,000	55,000
Capital Cost - Facility	133	0	58,500	200,000	58,500	733,080	120,000	120,000
Working Capital - Inventory	0	0	49,671	623,441	49,671	187,617	46,299	46,299
Total Annual Equivalent Capital Costs	533	0	61,339	239,818	61,339	254,670	52,785	52,785
Total Annual Operating Expenses	96	0	111,340	207,750	111,340	52,140	55,740	55,740
Total Annual Equivalent Costs	629	0	172,679	447,568	172,679	306,810	108,525	108,525
Production Capacity (LF/YR)	N/A	N/A	107,240	440,000	107,240	125,000	52,000	52,000
Cost Per 40' Wall @ 100% Capacity	N/A	N/A	64	41	64	76	65	65
* 20% MARR 10 Year Life								

Several sensitivity analyses provide additional insight from the cost results. First, consider the impact of market demand on cost. These results are shown in Figure 10. An important financial advantage of stick built construction is the flexibility of operating without significant fixed costs such as plant and equipment. This contrasts with the two factory technologies shown which experience significant per unit cost increases as demand falls, capacity utilization drops and fewer units of production are forced to absorb the same level of fixed costs. This becomes critical as utilization falls below 50% and costs rise at a greatly increasing rate. It should be noted that while the frame panel factories were observed to be operating at capacity (and even some overtime), the SSIC factories were observed to be operating at less than 50% of their available capacity. Finally, note that factory production of frame panels became more efficient than stick building when production exceeds 40% of plant capacity.

A second sensitivity analysis explored the impact of potential forest product price increases. The results are shown in Figure 11. Note that the SSIC technology did not become more competitive as the cost of forest products rose. In fact, the SSIC technology actually became less competitive with 4 in. Factory Frame #2. The reason for these results was that the SSIC technology has roughly the equivalent forest product cost of 4 in. Factory Frame #1 (which uses OSB as sheathing), and has greater cost than 4 in. Factory Frame #2 (which uses light-weight insulative sheathing).

A third sensitivity analysis addressed the longer term potential of SSIC technology as the industry matures into a major player in the homebuilding industry. It is possible that SSIC costs can decrease significantly as a result of productivity improvements in the factory and on the construction site. Factory improvements might be based on flexible manufacturing concepts, allowing the manufacturer to produce an increasing variety of "custom" shapes at high volumes. The introduction of automation will allow greatly increased capacity with minimal increase in personnel and floorspace, significantly lowering per unit factory production costs. Construction site improvements might be driven by better product designs, allowing more efficient erection and window installation. This scenario assumes that it will be possible to cut SSIC factory labor and overhead costs by 50% and assembly-related site labor by the same amount. Table 6 indicates the labor cost categories affected. Results shown in Table 2(b) indicate that 4 in. SSIC construction costs may be no more than 9% higher than 4 in. frame construction and roughly equivalent to 6 in. frame construction.

Figure 10
Impact of Demand on Total Cost

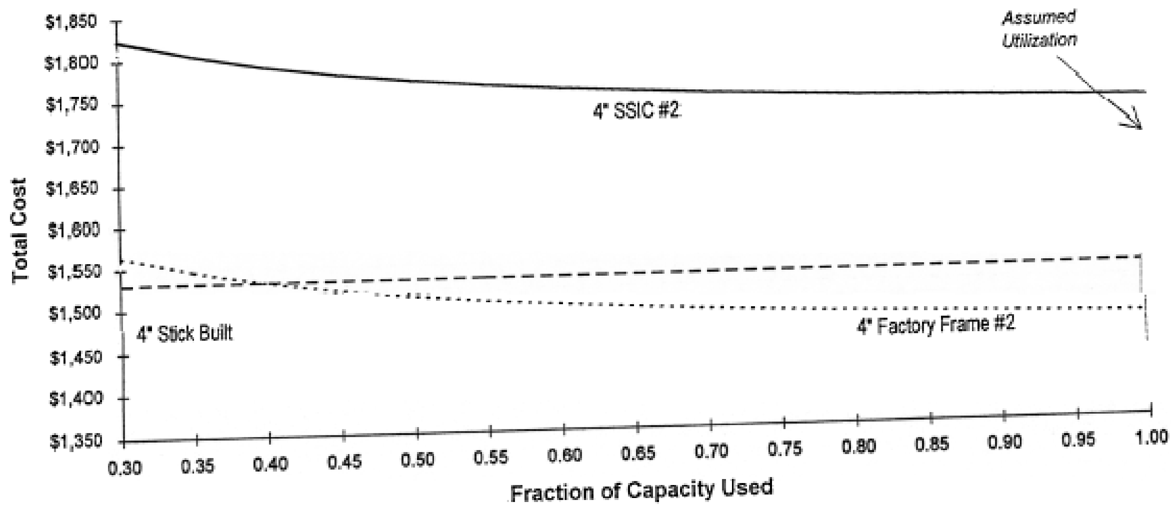


Figure 11
Impact of Forest Product Price on Total Cost

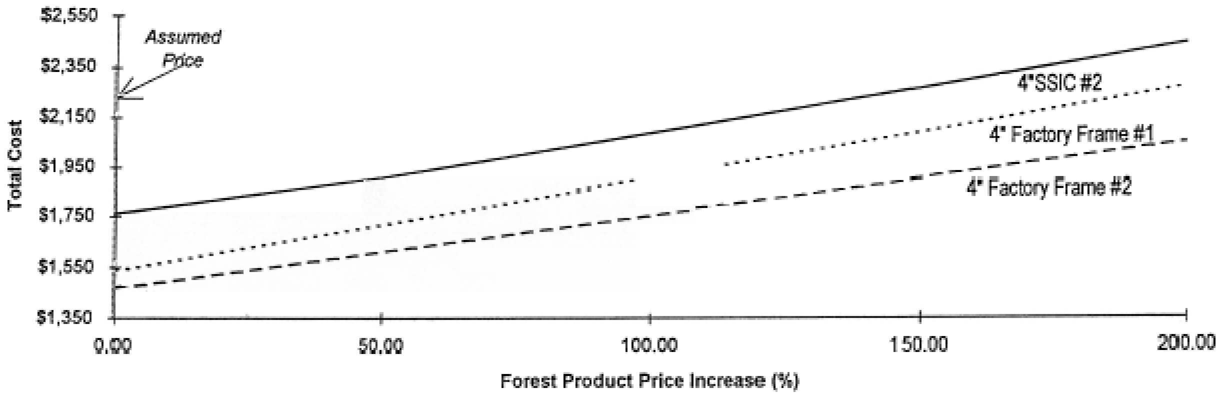


Table 6

40 Foot Standard Wall
Cost Analysis: Labor
(SSIC Cost Reduction Scenario)

Item	4" Stick Built	6" Stick Built (16" OC)	4" Factory Frame #1	4" Factory Frame #2	6" Factory Frame (24" OC)	4" SSIC#1	4" SSIC #2	6" SSIC
Factory Fabrication. & Assy.	N/A	N/A	25	17	24	10	10	10
Factory Mat1 Handling	N/A	N/A	7	3	8	2	6	6
Transport Panels To Site	N/A	N/A	6	6	6	6	6	6
Assemble Panels on Site	55	56	25	16	25	39	42	42
Install Windows/Doors	69	69	17	69	17	34	34	34
Install Siding	83	83	76	76	76	83	83	83
Install Wiring & Electrical	60	60	60	60	60	75	75	75
Install Drywall	61	61	61	61	61	61	61	61
Paint (interior)	42	42	42	42	42	42	42	42
Insulation	18	22	18	18	22	Incl.	Incl.	Incl.
Total Labor Costs	387	392	338	368	341	353	360	360

Values include all applicable PF&D factors

To assist in identifying long term cost improvement opportunities, key elemental cost differences were identified. The lowest cost SSIC alternative (4 in. SSIC #2) was benchmarked against the lowest cost frame alternative (4 in. Factory Frame #2). Base case scenario results are shown in Table 7. First, note that the six items shown described $223 of the $290 total cost differential. Second, note that the SSIC options did result in cost savings for certain items including dimensional lumber and site installation labor for insulation. However, these cost savings were more than offset by cost increases for materials (sheathing, adhesive, and insulation) and panel erection labor. This resulted in a net cost increase of $223 for the standard wall. Stated as a rate this differential represented:

- $ .70 per ft^2 of total wall area
- $ .88 per ft^2 of wall, excluding openings
- $5.76 per running foot of wall

Table 7.
Key Cost Differentials for "Base Case Scenario"

Line Item	4" Factory Frame # 2	4" SSIC # 2	Differential
Sheathing (incl. felt)	$ 38	$196	$158
Dimensional Lumber	$248	$161	[$ 87]
Insulation	$ 28	$ 86	$ 58
Adhesive (factory & site)	$ 0	$ 44	$ 44
Panel Erection	$ 16	$ 84	$ 68
Install Insulation (site)	$ 18	$ 0	[$ 18]
Total	**$348**	**$571**	**$223**

The top 4 items were construction material related. Sheathing was the largest single item. The SSIC technologies required 15.4 sheets of OSB to cover both the interior and exterior surface of the wall panels. In comparison, the Factory Frame # 2 option used a less expensive light-weight insulative sheathing on the exterior surface of the panel only. Other framing technologies used OSB on the exterior only. Dimensional lumber was required by both technologies for top plates, bottom plates and window and door framing. While the SSIC technologies had an advantage since they required no studs, they did require 2x4 splines on 4 ft centers. This advantage would be even greater if larger SSIC panels were used, thus requiring fewer splines. The third line item, construction adhesive, was used in the factory to manufacture SSIC panels and on the construction site for panel erection. Note again that the 4 ft SSIC panel required joints (which must be glued) on 4 ft centers. Using a larger SSIC panel would reduce the number of joints and conserve construction adhesive. Finally, the EPS foam cores used in SSIC panel production were significantly more expensive than the fiberglass batt insulation used in most framing applications. The only other significant line item was panel erection costs. There are several reasons why the SSIC technologies had higher erection costs. First, erection costs for the SSIC technologies included the cost of cutting and framing-out windows and doors, a very labor intensive process. Door and window framing were completed in the factory for the factory framing technologies. Second, the SSIC technologies utilized a small 4 ft x 8 ft panel, while the two factory frame technologies utilized larger panels, 20 ft x 8 ft and 12 ft x 8 ft respectively. This resulted in significantly more panel handling and joining for the SSIC technologies.

SUMMARY AND CONCLUSIONS

Conclusions from this research fall into one of two categories: 1) specific construction cost benchmarking results and 2) performance of the benchmarking methodology. The primary objective of this research was to benchmark construction costs for three homebuilding technologies used to build exterior structural walls. Research findings indicated that conventional wood framed construction costs were similar for both stick-built and factory panelized construction. SSIC construction costs were 17% higher than frame construction of comparable depth, driven primarily by cost differences in materials and labor. These results are consistent with those of Toole and Tonyan [4] who assert that for most home designs SSIC costs appear to average 10% to 20% higher than for conventional stick built construction, primarily due to higher material costs. Related sensitivity analyses suggest that future cost differentials may be less than 10%.

Several limitations of the research prevent findings from being generalized. Results are based on a small sample of homebuilders. Results do not explicitly comprehend a number of factory overhead costs (software, janitorial, maintenance, material procurement, engineering, indirect materials, insurance, and property taxes) or job site overhead costs (construction supervision, temporary site office, performance bonds, insurance, temporary site utilities, temporary buildings/enclosures, barricades, engineering services, clean-up, repair of street and pavement, damage to adjoining structures/property, permits/licenses, tools/equipment, signs, dust/erosion control, fuels). The implicit assumption is that these items are largely independent of technology.

Research findings suggest a number of future research areas: 1) development of alternative SSIC panel sheathing materials, 2) construction cost analysis of "long" SSIC panels versus the conventional 4x8 ft panel, 3) development of alternative materials and processes for framing windows and doors in SSIC construction and 4) consideration of potential energy savings [15] and other life cycle cost advantages of the SSIC technology against its apparently higher construction cost.

A secondary objective of the research was to develop a general methodology for comparative costing of innovative homebuilding technologies. Theoretically, the methodology is sufficiently robust to comprehend all production oriented costs including direct material, direct labor and manufacturing/job site overhead. Should the analyst wish to extend the model to include other more general cost elements such as general administrative expense, sales expense, and profit, they may be incorporated. From a practical standpoint, experience gained in using the methodology suggests that it can readily account for direct materials and direct labor. Overhead, however, is much more difficult to assess. There are many categories of overhead expense, both on the construction site and in the factory. Many overhead expenses are not well documented, making data collection difficult. Even when cost data is available, the relationship between overhead cost and technology is not always clear. This can make it difficult to determine how much of the observed overhead to attribute to the technology. An example is engineering costs which appear to be highly market dependent. Future research in this area might address white-collar business processes which support homebuilding, focusing on the differences between conventional and innovative technologies. This research might utilize business process re-engineering techniques using customer value-added as a primary criteria.

Additional research may improve on the selection of the common housing element used for analysis. It is likely that relative costs (between technologies) will change as the size, scope and design complexity of the common element changes. Future research might attempt to define these relationships and develop factors where appropriate. Future research might also consider the use of a sample of common housing elements, either selected randomly or purposely selected based on projected demand.

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APPENDIX A
PROCESS CHARTS AND WORKSHEETS

Notes:

1. Detailed DFA process charts were developed for the following options: 4" factory frame #1, 4" SSIC #1, and 4" SSIC #2. Simplified worksheets are provided for the other options.

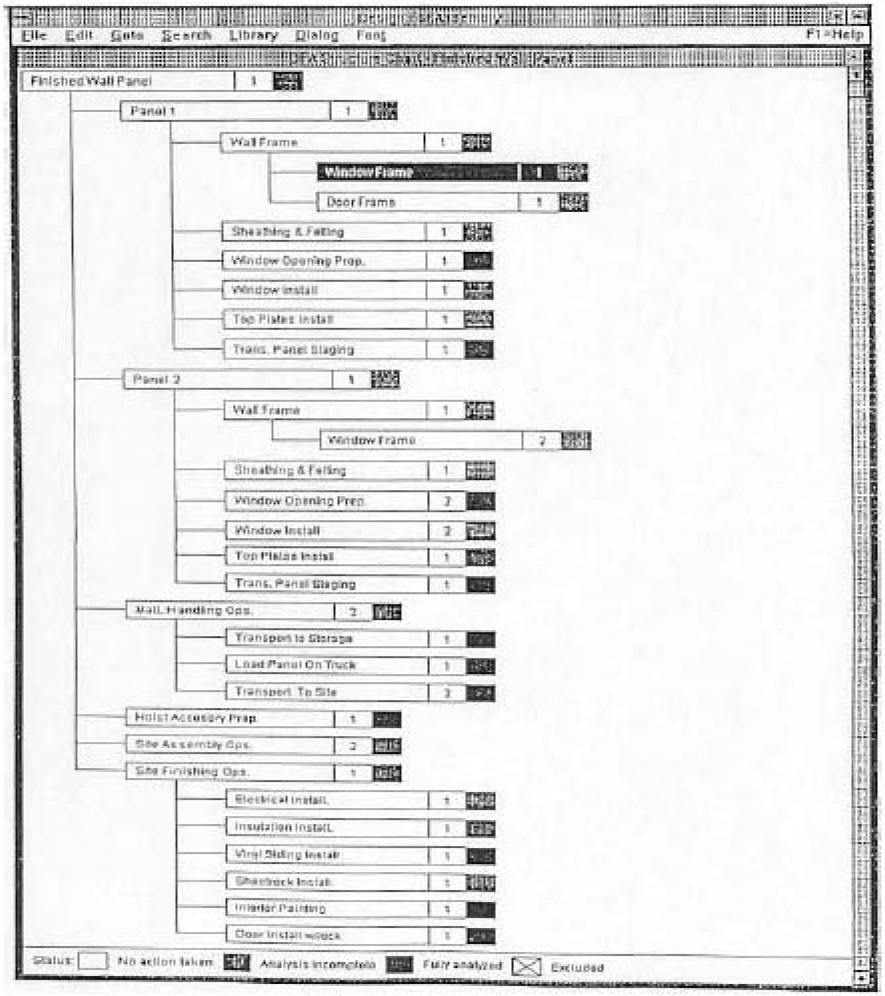
Appendix A
Worksheet
2 x 4 Stick Built

2 x 4 Stick Built		
Cost Summary		
	Labor Cost	Material Cost
Item Description		Incl. 5% site adjustment
		& lumber price increase
Mark & Prepare Foundation	0.58	0.00
Header Construction	3.20	54.15
Wall Framing	4.34	115.06
Window/Door Frame Assembly	7.24	82.51
Wall Frame Raising & Setting	10.25	0.19
Exterior Sheathing Installation	7.21	102.84
Framing Subtotal	32.82	354.75
Framing Subtotal including PF&D @ 40%	54.70	
Site Finishing Operations		
Electrical	60.00	21.92
Insulation	18.00	27.93
Vinyl Siding	83.00	287.57
Sheetrock	60.80	69.09
Interior Painting	42.00	20.16
Window Installation	56.25	257.54
Door site installed with lockset	12.50	100.44
Site Finishing Operations Subtotal	332.55	784.65
Grand Totals	365.37	1139.40
Grand Totals including PF&D factors	387.25	

Appendix A
Worksheet
2 x 6 Stick Built

2 x 6 Stick Built		
Cost Summary		
	Labor Cost	Material Cost
Item Description		Incl. 5% site adjustment
		& lumber price increase
Mark & Prepare Foundation		
Header Construction		
Wall Framing		
Window/Door Frame Assembly		
Wall Frame Raising & Setting	9.49	0.19
Exterior Sheathing Installation	7.21	102.84
Framing Subtotal	33.53	419.68
Framing Subtotal including PF&D @ 40%	55.88	
Site Finishing Operations		
Sheetrock		
Interior Painting	[illegible]	[illegible]
Window Installation	56.25	257.54
Door site installed with lockset	12.50	100.44
Site Finishing Operations Subtotal	336.28	814.89
Grand Totals	369.81	1234.57
Grand Totals including PF&D factors	392.16	

Appendix A
Top Level Process Flow Chart
2 4 Factory Frame #1



Appendix A
Second Level Process Flow Chart
2 x 4 Factory Frame #1

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DFA Structure Chart - Finished Wall Panel

Subassembly: Wall Frame   Labor rate: 10.00/hr   DFA index: 0.8

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Oper	retrieve plate	1	-	-	-	-	28.0	0.08	0.00	0
2	Oper	position plate	4	-	-	-	-	32.0	0.09	0.00	0
3	Part	2 X 4 X 14' Plate	3	0	0.0	0.0	0.0	0.0	0.00	2.88	0
4	Oper	retrieve studs	2	-	-	-	-	52.0	0.14	0.00	0
5	Oper	carry to table	2	-	-	-	-	20.0	0.06	0.00	0
6	Oper	position stud	8	-	-	-	-	80.0	0.22	0.00	0
7	Oper	fasten stud	8	-	-	-	-	64.0	0.18	0.00	0
8	Part	2 X 4 X 8' Stud	8	0	0.0	0.0	0.0	0.0	0.00	1.84	0
9	Part	3 3/4" 16D nails	32	0	0.0	0.0	0.0	0.0	0.00	0.01	0
10	Oper	retrieve subassy.	2	-	-	-	-	32.0	0.09	0.00	0
11	Oper	carry assy. to table	2	-	-	-	-	28.0	0.08	0.00	0
12	Oper	set subassy.	2	-	-	-	-	52.0	0.14	0.00	0
13	Oper	fasten subassy.	2	-	-	-	-	60.0	0.17	0.00	0
14	Sub	Window Frame	1	1	0.0	0.0	0.0	0.0	0.00	0.00	0
15	Sub	Door Frame	1	1	0.0	0.0	0.0	0.0	0.00	0.00	0
16	Part	3 3/4" 16D nails	48	0	0.0	0.0	0.0	0.0	0.00	0.01	0
17	Oper	retrieve cripples	2	-	-	-	-	6.0	0.02	0.00	0
18	Oper	carry cripples	2	-	-	-	-	4.0	0.01	0.00	0
19	Oper	position cripple	10	-	-	-	-	180.0	0.50	0.00	0
20	Oper	fasten cripple	10	-	-	-	-	70.0	0.19	0.00	0
21	Part	2 X 4 X 8' Stud	3	0	0.0	0.0	0.0	0.0	0.00	1.84	0
22	Part	3 3/4" 16D nails	40	0	0.0	0.0	0.0	0.0	0.00	0.01	0
Totals:			193	2				708.0	1.97	30.09	0

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DFA Structure Chart - Finished Wall Panel

Subassembly: Window Frame   Labor rate: 10.00/hr   DFA index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Oper	walk to lumber stock	3	-	-	-	-	21.0	0.06	0.00	0
2	Oper	retrieve lumber	3	-	-	-	-	9.0	0.03	0.00	0
3	Oper	carry lumber	3	-	-	-	-	30.0	0.08	0.00	0
4	Oper	measure wood for cut	9	-	-	-	-	45.0	0.12	0.00	0
5	Oper	position wood to saw	9	-	-	-	-	108.0	0.30	0.00	0
6	Oper	saw wood	6	-	-	-	-	36.0	0.10	0.00	0
7	Oper	dispose of scrap	9	-	-	-	-	45.0	0.12	0.00	0
8	Oper	carry lumber to stk	2	-	-	-	-	18.0	0.05	0.00	0
9	Oper	retrieve header lumb	1	-	-	-	-	6.0	0.02	0.00	0
10	Oper	set bottom header	1	-	-	-	-	3.0	0.01	0.00	0
11	Oper	retrieve spacers	1	-	-	-	-	3.0	0.01	0.00	0
12	Oper	fasten spacer	1	-	-	-	-	9.0	0.03	0.00	0
13	Part	2" X 2" X 1/2" spcr	14	0	0.0	0.0	0.0	0.0	0.00	0.04	0
14	Part	2 3/8" 8D nails	38	0	0.0	0.0	0.0	0.0	0.00	0.01	0
15	Oper	position header	1	-	-	-	-	7.0	0.02	0.00	0
16	Oper	fasten header assy	1	-	-	-	-	20.0	0.06	0.00	0
17	Part	2 X 8 X 10' Header	1	0	0.0	0.0	0.0	0.0	0.00	5.46	0
18	Part	3 3/4" 16D nails	14	0	0.0	0.0	0.0	0.0	0.00	0.01	0
19	Oper	carry assy to stagin	1	-	-	-	-	9.0	0.03	0.00	0
20	Oper	retrieve perimeter	6	-	-	-	-	60.0	0.17	0.00	0
21	Oper	position perimeter	6	-	-	-	-	60.0	0.17	0.00	0
22	Oper	fasten perimeter	6	-	-	-	-	78.0	0.22	0.00	0
23	Part	2 X 4 X 8' Stud	6	0	0.0	0.0	0.0	0.0	0.00	1.84	0
24	Part	3 3/4" 16D nails	34	0	0.0	0.0	0.0	0.0	0.00	0.01	0
Totals:			167	0				804.0	2.23	22.58	0

Appendix A
Second Level Process Flow Chart
2 x 4 Factory Frame #1

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DFA Structure Chart - Finished Wall Panel

Subassembly: Window Frame Labor rate: 10.00/hr DFA Index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
9	Oper	retrieve header lumb	1	-	-	-	-	6.0	0.02	0.00	0
10	Oper	set bottom header	1	-	-	-	-	3.0	0.01	0.00	0
11	Oper	retrieve spacers	1	-	-	-	-	3.0	0.01	0.00	0
12	Oper	fasten spacer	1	-	-	-	-	9.0	0.03	0.00	0
13	Part	3" X 3" X 1/2" spcr	14	0	0.0	0.0	0.0	0.0	0.00	0.04	0
14	Part	2 3/8" 8D nails	28	0	0.0	0.0	0.0	0.0	0.00	0.01	0
15	Oper	position header	1	-	-	-	-	7.0	0.02	0.00	0
16	Oper	fasten header assy.	1	-	-	-	-	20.0	0.06	0.00	0
17	Part	2 X 8 X 16' Header	1	0	0.0	0.0	0.0	0.0	0.00	6.48	0
18	Part	3 3/4" 16D nails	14	0	0.0	0.0	0.0	0.0	0.00	0.01	0
19	Oper	carry assy to stagin	1	-	-	-	-	9.0	0.03	0.00	0
20	Oper	retrieve perimeter	6	-	-	-	-	60.0	0.17	0.00	0
21	Oper	position perimeter	6	-	-	-	-	60.0	0.17	0.00	0
22	Oper	fasten perimeter	6	-	-	-	-	78.0	0.22	0.00	0
23	Part	2 X 4 X 8' Stud	6	0	0.0	0.0	0.0	0.0	0.00	1.84	0
24	Part	3 3/4" 16D nails	24	0	0.0	0.0	0.0	0.0	0.00	0.01	0
25	Oper	retrieve crosspiece	2	-	-	-	-	18.0	0.05	0.00	0
26	Oper	position crosspiece	3	-	-	-	-	69.0	0.19	0.00	0
27	Oper	fasten crosspiece	3	-	-	-	-	87.0	0.24	0.00	0
28	Part	2 X 4 X 8' Stud	2	0	0.0	0.0	0.0	0.0	0.00	1.84	0
29	Part	3 3/4" 16D nails	18	0	0.0	0.0	0.0	0.0	0.00	0.01	0
30	Oper	set assy. on cart	1	-	-	-	-	21.0	0.06	0.00	0
31	Oper	transport to line	1	-	-	-	-	42.0	0.12	0.00	0
Totals:			187	0				804.0	2.23	22.58	0

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DFA Structure Chart - Finished Wall Panel

Subassembly: Door Frame Labor rate: 10.00/hr DFA Index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Oper	walk to lumber stock	2	-	-	-	-	14.0	0.04	0.00	0
2	Oper	retrieve lumber	2	-	-	-	-	6.0	0.02	0.00	0
3	Oper	carry lumber	2	-	-	-	-	20.0	0.06	0.00	0
4	Oper	measure wood for cut	3	-	-	-	-	15.0	0.04	0.00	0
5	Oper	position wood to saw	3	-	-	-	-	36.0	0.10	0.00	0
6	Oper	saw wood	3	-	-	-	-	12.0	0.03	0.00	0
7	Oper	dispose of scrap	3	-	-	-	-	15.0	0.04	0.00	0
8	Oper	carry lumber to stk	1	-	-	-	-	9.0	0.03	0.00	0
9	Oper	retrieve header lumb	1	-	-	-	-	6.0	0.02	0.00	0
10	Oper	set bottom header	1	-	-	-	-	3.0	0.01	0.00	0
11	Oper	retrieve spacers	1	-	-	-	-	3.0	0.01	0.00	0
12	Oper	fasten spacer	1	-	-	-	-	9.0	0.03	0.00	0
13	Part	2 3/8" 8D nails	16	0	0.0	0.0	0.0	0.0	0.00	0.01	0
14	Part	3" X 3" X 1/2" spcr	8	0	0.0	0.0	0.0	0.0	0.00	0.04	0
15	Oper	position header	1	-	-	-	-	7.0	0.02	0.00	0
16	Oper	fasten header assy.	1	-	-	-	-	20.0	0.06	0.00	0
17	Oper	carry assy to stagin	1	-	-	-	-	9.0	0.03	0.00	0
18	Oper	retrieve perimeter	4	-	-	-	-	40.0	0.11	0.00	0
19	Oper	position perimeter	4	-	-	-	-	40.0	0.11	0.00	0
20	Oper	fasten perimeter	4	-	-	-	-	52.0	0.14	0.00	0
21	Part	2 X 4 X 8' Stud	4	0	0.0	0.0	0.0	0.0	0.00	1.84	0
22	Part	3 3/4" 16D nails	16	0	0.0	0.0	0.0	0.0	0.00	0.01	0
23	Oper	retrieve crosspiece	1	-	-	-	-	9.0	0.03	0.00	0
24	Oper	position crosspiece	1	-	-	-	-	23.0	0.06	0.00	0
Totals:			94	0				377.0	1.05	10.48	0

Appendix A
Second Level Process Flow Chart
2 x 4 Factory Frame #1

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DFA Structure Chart - Finished Wall Panel

DFA Worksheet - Door Frame

Subassembly: Door Frame Labor rate: 10.00/hr DFA index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
5	Oper	position wood to saw	3	-	-	-	-	36.0	0.10	0.00	0
6	Oper	saw wood	3	-	-	-	-	12.0	0.03	0.00	0
7	Oper	dispose of scrap	3	-	-	-	-	15.0	0.04	0.00	0
8	Oper	carry lumber to stk	1	-	-	-	-	9.0	0.03	0.00	0
9	Oper	retrieve header lumb	1	-	-	-	-	6.0	0.02	0.00	0
10	Oper	set bottom header	1	-	-	-	-	3.0	0.01	0.00	0
11	Oper	retrieve spacers	1	-	-	-	-	3.0	0.01	0.00	0
12	Oper	fasten spacer	1	-	-	-	-	9.0	0.03	0.00	0
13	Part	2 3/8" 8D nails	16	0	0.0	*0.0*	*0.0*	0.0	0.00	0.01	0
14	Part	3" X 3" X 1/2" spcr	8	0	0.0	*0.0*	*0.0*	0.0	0.00	0.04	0
15	Oper	position header	1	-	-	-	-	7.0	0.02	0.00	0
16	Oper	fasten header assy.	1	-	-	-	-	20.0	0.06	0.00	0
17	Oper	carry assy to stagin	1	-	-	-	-	9.0	0.03	0.00	0
18	Oper	retrieve perimeter	4	-	-	-	-	40.0	0.11	0.00	0
19	Oper	position perimeter	4	-	-	-	-	40.0	0.11	0.00	0
20	Oper	fasten perimeter	4	-	-	-	-	52.0	0.14	0.00	0
21	Part	2 X 4 X 8' Stud	4	0	0.0	*0.0*	*0.0*	0.0	0.00	1.84	0
22	Part	3 3/4" 16D nails	16	0	0.0	*0.0*	*0.0*	0.0	0.00	0.01	0
23	Oper	retrieve crosspiece	1	-	-	-	-	9.0	0.03	0.00	0
24	Oper	position crosspiece	1	-	-	-	-	23.0	0.06	0.00	0
25	Oper	fasten crosspiece	1	-	-	-	-	29.0	0.08	0.00	0
26	Part	2 X 6 X 8' Stud	1	0	0.0	*0.0*	*0.0*	0.0	0.00	2.40	0
27	Part	3 3/4" 16D nails	8	0	0.0	*0.0*	*0.0*	0.0	0.00	0.01	0
Totals:			94	0				377.0	1.05	10.40	0

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DFA Structure Chart - Finished Wall Panel

Subassembly: Sheathing & Felting Labor rate: 10.00/hr DFA index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Oper	retrieve roof felt	1	-	-	-	-	40.0	0.11	0.00	0
2	Oper	unroll felt	3	-	-	-	-	156.0	0.43	0.00	0
3	Oper	position felt	3	-	-	-	-	90.0	0.25	0.00	0
4	Oper	fasten felt	3	-	-	-	-	150.0	0.42	0.00	0
5	Part	15 # Felt Paper roll	1	0	0.0	*0.0*	*0.0*	0.0	0.00	6.15	0
6	Part	1/2 " for 10 staples	5	0	0.0	*0.0*	*0.0*	0.0	0.00	0.02	0
7	Oper	trim felt	1	-	-	-	-	20.0	0.06	0.00	0
8	Oper	slide panel	1	-	-	-	-	34.0	0.09	0.00	0
9	Oper	retrieve sheathing	5	-	-	-	-	100.0	0.28	0.00	0
10	Oper	carry OSB to table	5	-	-	-	-	35.0	0.10	0.00	0
11	Oper	set sheet on frame	5	-	-	-	-	35.0	0.10	0.00	0
12	Oper	position OSB sheet	5	-	-	-	-	25.0	0.07	0.00	0
13	Oper	fasten sheet perimet	5	-	-	-	-	50.0	0.14	0.00	0
14	Part	4' X 8' X 7/16" OSB	5	0	0.0	*0.0*	*0.0*	0.0	0.00	6.24	0
15	Part	2 3/8" 8D nails	48	0	0.0	*0.0*	*0.0*	0.0	0.00	0.01	0
16	Oper	fully sink perimeter	5	-	-	-	-	70.0	0.19	0.00	0
17	Oper	trim sheathing	1	-	-	-	-	122.0	0.34	0.00	0
18	Oper	dispose scrap sheath	1	-	-	-	-	9.0	0.03	0.00	0
19	Oper	slide panel	1	-	-	-	-	34.0	0.09	0.00	0
20	Oper	position over stud 1	1	-	-	-	-	13.0	0.04	0.00	0
21	Oper	position over stud	15	-	-	-	-	75.0	0.21	0.00	0
22	Part	2 3/8" 8D nails	150	0	0.0	*0.0*	*0.0*	0.0	0.00	0.01	0
23	Oper	fully sink nails	15	-	-	-	-	150.0	0.42	0.00	0
24	Oper	retract bridge	1	-	-	-	-	12.0	0.03	0.00	0
Totals:			288	0				1220.0	3.39	39.43	0

PROCESS CHARTS AND WORKSHEETS: 4" SSIC #1 and 2

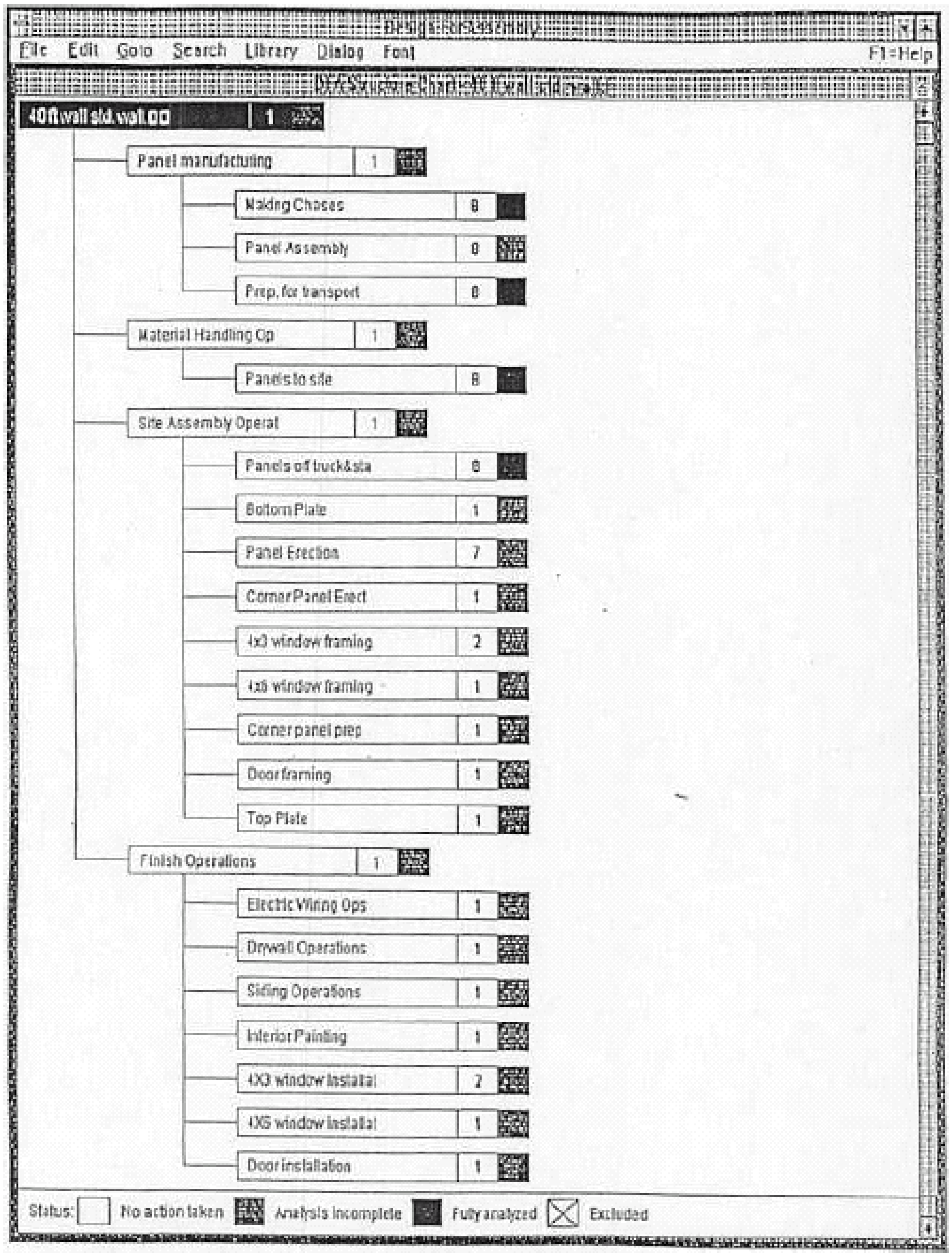
Notes:

1. DFA analysis requires integer components. Eight panels are shown in the analysis and results are manually adjusted to yield 7.7 panels.

Appendix A

Top Level Process Flow Chart

4" SSIC #1



Appendix A
Second Level Process Flow Chart
4" SSIC #1

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DFA Structure Chart - 40 ft std. wall

Subassembly: Panel Manufacturing Labor rate: 10.00/hr DFA index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Sub	Making Chases	8	1	0.0	0.0	0.0	0.0	0.00	-	0
2	Sub	Panel Assembly	8	1	0.0	0.0	0.0	0.0	0.00	-	0
3	Sub	Prep for Transport	8	1	0.0	0.0	0.0	0.0	0.00	-	0
Totals:			24	3				0.0	0.00	0.00	0

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DFA Structure Chart - 40 ft std. wall

Subassembly: Making Chases Labor rate: 10.00/hr DFA index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Oper	Picking Up EPS Block	1	-	-	-	-	1.7	0.00	0.00	0
2	Oper	Transporting EPS	1	-	-	-	-	4.8	0.01	0.00	0
3	Oper	Unloading the EPS	1	-	-	-	-	1.8	0.00	0.00	0
4	Oper	Getting HW ready	1	-	-	-	-	31.0	0.09	0.00	0
5	Oper	Placing EPS	1	-	-	-	-	12.2	0.03	0.00	0
6	Oper	Placing Cutting Jigs	1	-	-	-	-	23.8	0.07	0.00	0
7	Oper	Positioning the Jigs	2	-	-	-	-	61.9	0.17	0.00	0
8	Oper	Making H Chase	3	-	-	-	-	71.3	0.20	0.00	0
9	Oper	Removing Jigs	2	-	-	-	-	51.8	0.14	0.00	0
10	Oper	Positioning the Jigs	1	-	-	-	-	36.7	0.10	0.00	0
11	Oper	Making Vertical Chas	1	-	-	-	-	23.8	0.07	0.00	0
12	Oper	Removing Cutting Jig	1	-	-	-	-	79.2	0.22	0.00	0
13	Oper	Stacking EPS	1	-	-	-	-	18.0	0.05	0.00	0
Totals:			17	0				417.9	1.16	0.00	0

Appendix A
Second Level Process Flow Chart
4" SSIC #1

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DFA Structure Chart - 40 ft std. wall

Subassembly: Panel Assembly Labor rate: 10.00/hr DFA Index: 1.1

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Oper	L m/c to glue	1	-	-	-	-	1.4	0.00	0.00	0
2	Oper	Mixing up glue	1	-	-	-	-	20.2	0.08	0.00	0
3	Oper	Getting glue	1	-	-	-	-	1.4	0.00	0.00	0
4	Oper	Pouring Glue	1	-	-	-	-	15.8	0.04	0.00	0
5	Oper	Walking from L M/c	1	-	-	-	-	1.7	0.00	0.00	0
6	Oper	Weighing 5 styrofoam	1	-	-	-	-	17.3	0.05	0.00	0
7	Oper	Walking to L M/c	1	-	-	-	-	10.4	0.03	0.00	0
8	Oper	Running Styrofoam	1	-	-	-	-	3.6	0.01	0.00	0
9	Oper	Taking Sample EPS	1	-	-	-	-	1.0	0.00	0.00	0
10	Oper	Weighing Sample EPS	1	-	-	-	-	1.8	0.00	0.00	0
11	Oper	Picking OSB	2	-	-	-	-	3.2	0.01	0.00	0
12	Oper	Transporting OSB	2	-	-	-	-	3.7	0.01	0.00	0
13	Oper	Unloading OSB's	2	-	-	-	-	15.3	0.04	0.00	0
14	Oper	Transporting EPS	1	-	-	-	-	12.8	0.04	0.00	0
15	Oper	Placing OSB	2	-	-	-	-	56.2	0.16	0.00	0
16	Part	4'X 8'X 7/16" OSB	2	1	0.0	*0.0*	*0.0*	0.0	0.00	6.24	0
17	Oper	Running EPS	1	-	-	-	-	11.1	0.03	0.00	0
18	Part	Glue, Laminating M/c	1	0	0.0	*0.0*	*0.0*	0.0	0.00	4.25	0
19	Oper	Placing EPS on OSB	1	-	-	-	-	22.3	0.06	0.00	0
20	Part	4'X 8'X 3 5/8" EPS	1	0	0.0	*0.0*	*0.0*	0.0	0.00	11.11	0
21	Oper	Stamping Operation	1	-	-	-	-	46.8	0.13	0.00	0
22	Oper	Move Panels to Press	1	-	-	-	-	6.6	0.02	0.00	0
23	Oper	Picking Up Spacers	1	-	-	-	-	3.0	0.01	0.00	0
24	Oper	Walking Back	1	-	-	-	-	0.6	0.00	0.00	0
Totals:			31	1				261.5	0.73	27.84	0

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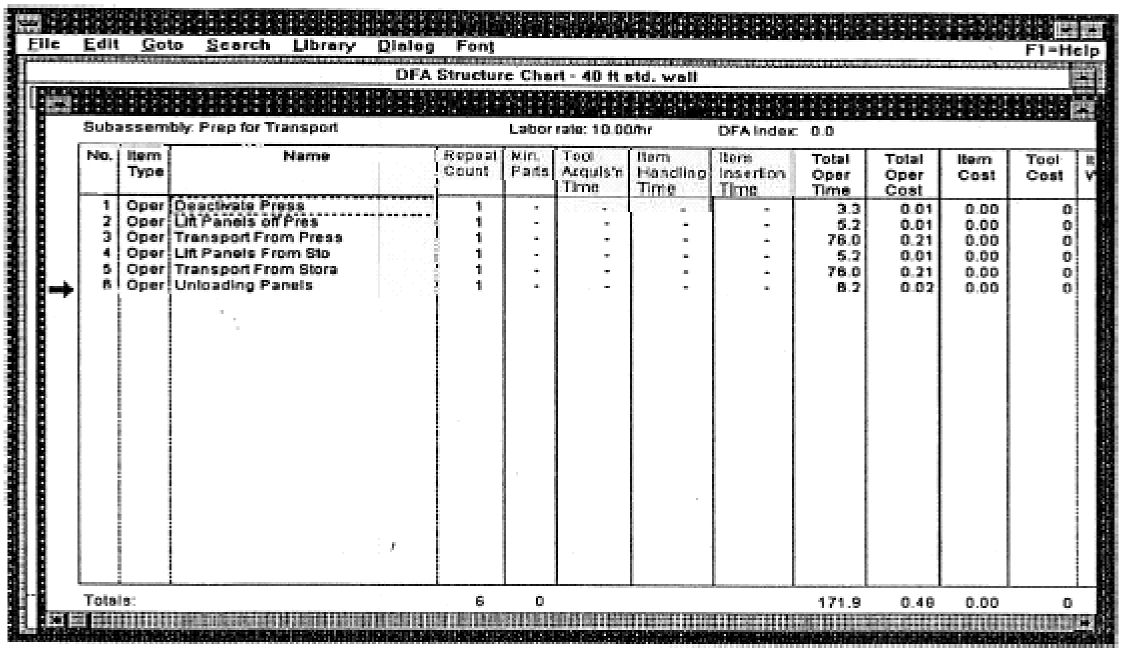
DFA Structure Chart - 40 ft std. wall

Subassembly: Panel Assembly Labor rate: 10.00/hr DFA Index: 1.1

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
4	Oper	Pouring Glue	1	-	-	-	-	15.8	0.04	0.00	0
5	Oper	Walking from L M/c	1	-	-	-	-	1.7	0.00	0.00	0
6	Oper	Weighing 5 styrofoam	1	-	-	-	-	17.3	0.05	0.00	0
7	Oper	Walking to L M/c	1	-	-	-	-	10.4	0.03	0.00	0
8	Oper	Running Styrofoam	1	-	-	-	-	3.6	0.01	0.00	0
9	Oper	Taking Sample EPS	1	-	-	-	-	1.0	0.00	0.00	0
10	Oper	Weighing Sample EPS	1	-	-	-	-	1.8	0.00	0.00	0
11	Oper	Picking OSB	2	-	-	-	-	3.2	0.01	0.00	0
12	Oper	Transporting OSB	2	-	-	-	-	3.7	0.01	0.00	0
13	Oper	Unloading OSB's	2	-	-	-	-	15.3	0.04	0.00	0
14	Oper	Transporting EPS	1	-	-	-	-	12.8	0.04	0.00	0
15	Oper	Placing OSB	2	-	-	-	-	56.2	0.16	0.00	0
16	Part	4'X 8'X 7/16" OSB	2	1	0.0	*0.0*	*0.0*	0.0	0.00	6.24	0
17	Oper	Running EPS	1	-	-	-	-	11.1	0.03	0.00	0
18	Part	Glue, Laminating M/c	1	0	0.0	*0.0*	*0.0*	0.0	0.00	4.25	0
19	Oper	Placing EPS on OSB	1	-	-	-	-	22.3	0.06	0.00	0
20	Part	4'X 8'X 3 5/8" EPS	1	0	0.0	*0.0*	*0.0*	0.0	0.00	11.11	0
21	Oper	Stamping Operation	1	-	-	-	-	46.8	0.13	0.00	0
22	Oper	Move Panels to Press	1	-	-	-	-	6.6	0.02	0.00	0
23	Oper	Picking Up Spacers	1	-	-	-	-	3.0	0.01	0.00	0
24	Oper	Walking Back	1	-	-	-	-	0.6	0.00	0.00	0
25	Oper	Placing 2 Spacers	1	-	-	-	-	2.3	0.01	0.00	0
26	Oper	Activate Press	1	-	-	-	-	3.3	0.01	0.00	0
Totals:			31	1				261.5	0.73	27.84	0

Appendix A
Second Level Process Flow Chart
4" SSIC #1



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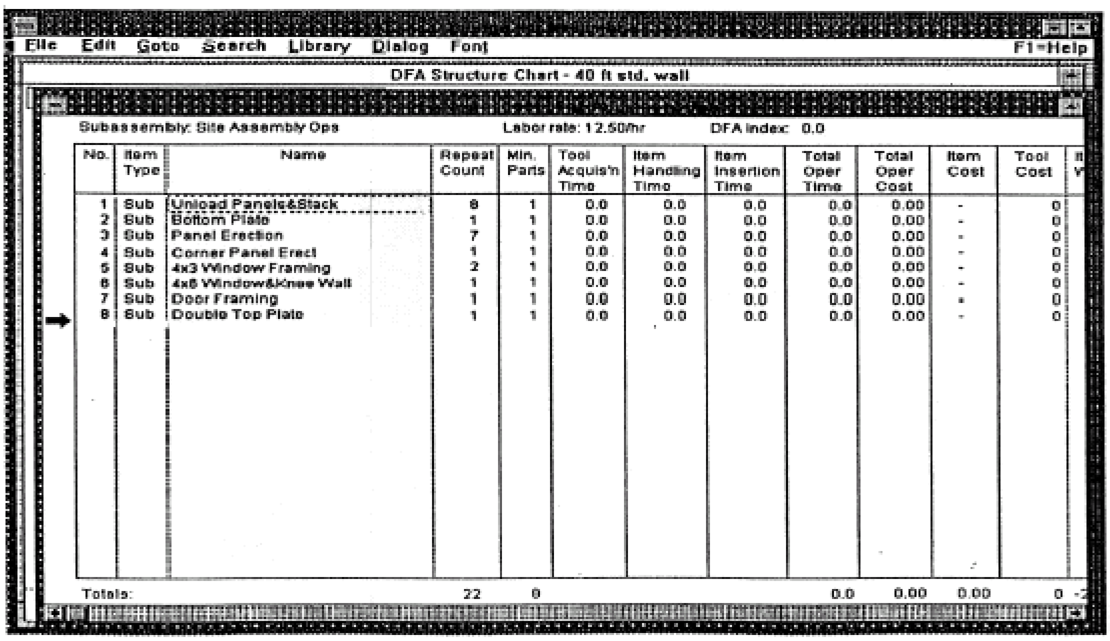
DFA Structure Chart - 40 ft std. wall

Subassembly: Prep for Transport Labor rate: 10.00/hr DFA Index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Oper	Deactivate Press	1	-	-	-	-	3.3	0.01	0.00	0
2	Oper	Lift Panels off Pres	1	-	-	-	-	5.2	0.01	0.00	0
3	Oper	Transport From Press	1	-	-	-	-	76.0	0.21	0.00	0
4	Oper	Lift Panels From Sto	1	-	-	-	-	5.2	0.01	0.00	0
5	Oper	Transport From Stora	1	-	-	-	-	76.0	0.21	0.00	0
6	Oper	Unloading Panels	1	-	-	-	-	8.2	0.02	0.00	0
Totals:			6	0				171.9	0.48	0.00	0



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DFA Structure Chart - 40 ft std. wall

Subassembly: Site Assembly Ops Labor rate: 12.50/hr DFA Index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Sub	Unload Panels&Stack	8	1	0.0	0.0	0.0	0.0	0.00	-	0
2	Sub	Bottom Plate	1	1	0.0	0.0	0.0	0.0	0.00	-	0
3	Sub	Panel Erection	7	1	0.0	0.0	0.0	0.0	0.00	-	0
4	Sub	Corner Panel Erect	1	1	0.0	0.0	0.0	0.0	0.00	-	0
5	Sub	4x3 Window Framing	2	1	0.0	0.0	0.0	0.0	0.00	-	0
6	Sub	4x6 Window&Knee Wall	1	1	0.0	0.0	0.0	0.0	0.00	-	0
7	Sub	Door Framing	1	1	0.0	0.0	0.0	0.0	0.00	-	0
8	Sub	Double Top Plate	1	1	0.0	0.0	0.0	0.0	0.00	-	0
Totals:			22	8				0.0	0.00	0.00	0

Appendix A
Second Level Process Flow Chart
4" SSIC #1

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DFA Structure Chart - 40 ft std. wall

Subassembly: Unload Panels&Stack Labor rate: 12.50/hr DFA Index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Oper	Unloading Panels	1	-	-	-	-	72.0	0.25	0.00	0
Totals:			1	0				72.0	0.25	0.00	0

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DFA Structure Chart - 40 ft std. wall

Subassembly: Bottom Plate Labor rate: 12.50/hr DFA Index: 0.0

No.	Item Type	Name	Repeat Count	Min. Parts	Tool Acquis'n Time	Item Handling Time	Item Insertion Time	Total Oper Time	Total Oper Cost	Item Cost	Tool Cost
1	Oper	Transport Bottom Pla	3	-	-	-	-	34.5	0.12	0.00	0
2	Oper	Position Bottom Plat	3	-	-	-	-	93.0	0.32	0.00	0
3	Oper	Mark On Foundation	1	-	-	-	-	77.5	0.27	0.00	0
4	Oper	Cleaning Foundation	1	-	-	-	-	183.8	0.64	0.00	0
5	Oper	Getting Tape Ready	1	-	-	-	-	150.0	0.52	0.00	0
6	Oper	Taping Operation	1	-	-	-	-	107.5	0.37	0.00	0
7	Oper	Mark Bottom Plate	1	-	-	-	-	257.5	0.89	0.00	0
8	Oper	Drilling Holes In Pl	10	-	-	-	-	116.0	0.40	0.00	0
9	Oper	Cutting Lumber	1	-	-	-	-	6.3	0.02	0.00	0
10	Oper	Position Bottom Plat	3	-	-	-	-	1119.0	3.89	0.00	0
11	Oper	Chiseling Out Wood	10	-	-	-	-	320.0	1.11	0.00	0
12	Oper	Putting a Nut on the	10	-	-	-	-	330.0	1.15	0.00	0
13	Part	2x4x14' Plate	3	0	0.0	0.0	0.0	0.0	0.00	3.02	0
Totals:			40	0				2795.1	9.71	9.06	0

PROCESS CHARTS AND WORKSHEETS: 6" SSIC PANELS

This option was not actually observed. The same panel layout and factory used for the 4" SSIC # 2 option is assumed. Material and labor costs for the 6" SSIC panel technology are estimated using the process flowcharts for the 4" SSIC # 2 technology. Specific cost assumptions included the material cost increases described below and no increase in either factory or site labor associated with handling the larger components.

Material related incremental costs for 6" SSIC construction are as follows:

Additional EPS foam required to build standard wall:

92,160 in.^{3} @ \$.000596 per in.^{3} = \$55.00

Additional lumber required to build standard wall:

72 board feet @ \$300.00/1000 per board foot = \$21.60

Total cost difference per standard wall \$76.60

APPENDIX B
DFA MATERIALS LIBRARY

Some items *not* used in the analysis are entered with $0 cost.

University of Central Florida, Dept. of
Industrial Eng. and Management Systems.

Date of printing: Wed Sep 22 10:46:50 1993

Item Type	Name	Part Number	Item Cost
Category	-Dimensional Lumber-	--------------------	
Part	2 X 4 X 8' Stud		1.84
Part	2 X 4 X 4' Plate		0.92
Part	2 X 4 X 10' Stud		2.05
Part	2 X 4 X 14' Plate		2.88
Part	2 X 6 X 14' Header		4.06
Part	2 X 8 X 12' Header		4.88
Part	2 X 8 X 18' Header		6.48
Part	2 X 10 X 12' Header		6.69
Part	1 X 4 X 8' cedar trm		3.36
Part	3" X 3" X 1/2" spcr		0.04
Part	Cedar Shim		0.02
Category	-Exterior Sheathing-	--------------------	
Part	4' X 8' X 7/16" OSB		6.24
Part	4' X 8' X 5/8" OSB		0.00
Part	4' X 8' X 1/2" PLYW		15.71
Part	4' X 8' X 5/8" PARTB		8.80
Part	4' X 8' X 5/8" RBRD		0.00
Part	4' X 8' X 5/8" DUROK		0.00
Category	--Vapor Barrier-----	--------------------	
Part	15 # Felt Paper roll		6.15
Part	30 # Felt Paper roll		6.25
Part	?		0.00
Category	----Fasteners-------	--------------------	
Part	3 3/4" 16D nails		0.01
Part	2 3/8" 8D nails		0.01
Part	8D finish nails		0.02
Part	1 1/2" for 10staples		0.03
Part	2 1/4" for 10staples		0.05
Part	1/2 " for 10 staples		0.02
Part	#11 1/2" nails		0.00
Category	------Doors --------	--------------------	
Part	Ext. door w/o hdwre.		86.06
Part	Lockset		9.60
Category	-----Windows--------	--------------------	
Part	window #3044 3' X 4'		53.85
Part	double #3044 6' X 4'		108.70
Category	----Insulation------	--------------------	
Part	R-11 15"X91" Kraft		0.11
Part	R-11 15"X40" Kraft		0.00
Part	R-19 15"X48" Kraft		0.00
Part	R-19 23"X48" Kraft		0.00
Part	R-30 24"X48" Kraft		0.00

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Appendix B
Material Database for Factory
Framing Technologies

Date of printing: Wed Sep 22 10:46:50 1993

Item Type	Name	Part Number	Item Cost
Part	R-13 W/Vapor Barr.		0.00
Part	R-30 W/Vapor Barr.		0.00
Part	R-38 W/ Vapor Barr.		0.00
Part	4' X 8' X 3 5/8" EPS		0.00
Part	4' X 8' X 5 5/8" EPS		0.00
Part	4' X 8' X 7 5/8" EPS		0.00
Part	4' X 8' X 3 5/8" URE		0.00
Category	----Electrical------	--------------------	
Part	12-2 Romex wire		0.13
Part	Duplex recept.		0.43
Part	switch plate single		0.15
Part	recept plate single		0.15
Part	single pole switch		0.55
Part	single gang box		0.28
Category	-----Drywall--------	--------------------	
Part	4' X 8' X 1/2" SHRK		3.46
Part	4' X 8' X 5/8" SHRK		0.00
Part	4' X 8' X 5/8" FIRE		0.00
Part	4' X 8' X 1/2" WPRF		0.00
Part	Joint Tape roll LF		0.00
Part	Joint Tape Fbgls LF		0.00
Part	Joint Cmpnd. 5 gal.		0.00
Part	Joint Cmpnd. 25 lb.		0.00
Category	--Glues & Caulks----	--------------------	
Part	Clr. Latex Wnd Caulk		0.05
Part	Acry. Latex Found. C		0.05
Part	Drywall adhesive		0.07
Category	-Exterior Siding----	--------------------	
Part	Vinyl Dbl. 4"		0.00
Part	Vinyl Dbl. 5"		0.00
Part	Vinyl corner pt. 10'		0.00
Part	Vinyl inside pt. 10'		0.00
Part	Vinyl 12' J channel		0.00
Part	Vinyl 12' Starter		0.00
Category	------Paints--------	--------------------	
Part	Interior flat latex		0.03

Appendix B
Material Database for Factory Framing Technologies

Industrial Eng. and Management Systems.

Date of printing: Wed Sep 22 10:50:05 1993

Item Type	Name	Part Number	Item Cost
Category	-Doors and windows		
Part	Door and lockset		95.66
Category	-Dimensional Lumber-		
Part	2X4X2' lumber		0.46
Part	2X4X6' lumber		1.38
Part	2 X 4 X 8' Stud		1.84
Part	2 X 4 X 4' Plate		0.92
Part	2 X 4 X 10' Stud		2.05
Part	2 X 4 X 14' Plate		2.88
Part	2 X 6 X 14' Header		4.06
Part	2 X 8 X 12' Header		4.88
Part	2 X 10 X 12' Header		6.69
Part	2X10X6' Header		3.35
Part	2X12-14'		11.76
Category	-Exterior Sheathing-		
Part	6'X2'10"X7/16" OSB		3.31
Part	4' X 8' X 7/16" OSB		6.24
Part	1'X8'X7/16" OSB		1.56
Part	4' X 8' X 5/8" OSB		0.00
Part	4' X 8' X 5/8" PLYW		15.71
Part	4' X 8' X 5/8" PARTB		8.80
Part	4' X 8' X 5/8" RBRD		0.00
Part	4' X 8' X 5/8" DUROK		0.00
Category	--Vapor Barrier-----		
Part	15 # Felt Paper roll		6.15
Part	30 # Felt Paper roll		6.25
Part	?		0.00
Category	----Fasteners-------		
Part	Nails/top plate(8')		0.08
Part	Drywall Nails		0.00
Part	Staples/bottom plate		0.12
Part	Staples/spline		0.24
Part	Staples/2ft groove		0.06
Part	Staples/6ft groove		0.18
Part	Bolt/bottom plate		3.89
Part	Nut/bottom plate		0.43
Part	Washers/b. plate		0.60
Category	------Doors --------	--------------------	
Category	-----Windows--------	--------------------	
Category	----Insulation------		
Part	R-11 15"X91" Kraft		0.00
Part	R-11 15"X40" Kraft		0.00
Part	R-19 15"X48" Kraft		0.00

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Appendix B
Material Database for SSIC

Industrial Eng. and Management Systems.

Date of printing: Wed Sep 22 10:50:05 1993

Item Type	Name	Part Number	Item Cost
Part	R-19 23"X48" Kraft		0.00
Part	R-30 24"X48" Kraft		0.00
Part	R-13 W/Vapor Barr.		0.00
Part	R-30 W/Vapor Barr.		0.00
Part	R-38 W/ Vapor Barr.		0.00
Part	6'X2'10"X3 5/8"EPS		0.00
Part	4' X 8' X 3 5/8" EPS		0.00
Part	1'X8'X 3 5/8" EPS		2.78
Part	4' X 8' X 5 5/8" EPS		0.00
Part	4' X 8' X 7 5/8" EPS		0.00
Part	4' X 8' X 3 5/8" URE		0.00
Category	----Electrical------		
Category	-----Drywall--------		
Part	4' X 8' X 1/2" SHRK		0.00
Part	4' X 8' X 5/8" SHRK		0.00
Part	4' X 8' X 5/8" FIRE		0.00
Part	4' X 8' X 1/2" WPRF		0.00
Part	Joint Tape roll LF		0.00
Part	Joint Tape Fbgls LF		0.00
Part	Joint Cmpnd. 5 gal.		0.00
Part	Joint Cmpnd. 25 lb.		0.00
Part	Spackling compou/ft2		0.02
Part	Constn glue/8 ft		0.56
Category	--Glues & Caulks----		
Part	Constn glue/bottom p		0.56
Part	Const glue/spline		0.56
Part	Const glue/6ft		0.42
Part	Const glue/2ft		0.14
Part	laminating glue/c.pa		1.06
Part	29 oz. tube adhesv.		0.00
Part	Acry. Ltx caulk tube		0.00
Part	Butylseal caulk tube		0.00
Part	29 oz. tube caulk		0.00
Part	Can foam-in		0.00
Part	Gun foam-in		0.00
Category	-Exterior Siding----		
Part	Vinyl Dbl. 4"		0.00
Part	Vinyl Dbl. 5"		0.00
Part	Vinyl corner pt. 10'		0.00
Part	Vinyl inside pt. 10'		0.00
Part	Vinyl 12' J channel		0.00
Part	Vinyl 12' Starter		0.00
Part	4X8 wall panel		0.00

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Appendix B
Material Database for SSIC Technologies

Date of printing: Wed Sep 22 10:50:05 1993

Item Type	Name	Part Number	Item Cost
Part	1.3x8 wall panel		9.28
Part	4 sq.ft wall panel		3.33
Category	----Finishing-------	--------------------	
Part	Paint(1 coat, 40 ft)		20.00

APPENDIX C
OVERHEAD COSTS

Notes:

1. Fixed costs for the 2 stick built options are assumed to be $0.
2. Fixed costs for the 2x6" factory frame and the 6" SSIC options are assumed identical to those of the 2x4" factory frame # 1 and the 4" SSIC # 2 options respectively.

Appendix C
Overhead Cost Spreadsheet

		EEIH PROJECT	
	PANEL COST ANALYSIS: OVERHEAD COST		
PANEL MANUFACTURER:		Current Business Practice	
4" Factory Frame #1 & 6" Factory Frame			
STUDY PARAMETERS			
Max. Capital Recovery Period (yr.)	10		
Minimum Attractive Rate of Return	20%		
CAPITAL COSTS			
FACILITIES			
Mfg. Space (sq.ft.)	3,850		
Capital Cost per sq.ft.	$10		
Yard Storage Space	20,000		
Capital Cost per sq.ft.	$1		
Sub-Total		$58,500	
		$22,212	All Triad equipment assumed purchased used
		$11,215	
		$17,586	
		$400	
		$2,082	
		$2,400	
		$40,000	
Sub-Total		$95,895	
WORKING CAPITAL - INVENTORY			
Raw Materials		$24,383	
Work in Process		$0	
Finish Goods		$25,284	
Sub-Total		$49,671	
TOTAL CAPITAL COSTS		$204,066	
TOTAL ANNUAL EQUIV. CAPITAL		$48,674	
ANNUAL OPERATING EXPENSES			
Production Supervision		$18,200	
EQUIPMENT LEASE			
Delivery Trucks (2)		$16,800	
Sub-Total		$16,800	
EQUIPMENT OPER. COSTS			
Crane Rental (annual)		$66,000	
Forklift Operating & Maint. Costs		$4,000	
Sub-Total		$70,000	
UTILITIES			
Gas/oil		$0	
Electric		$2,200	
Water		$180	
Waste Disposal		$3,960	
Sub-Total		$6,340	
TOTAL ANNUAL OPERATING COSTS		$111,340	
TOTAL FIXED COST ANALYSIS			
TOTAL ANNUAL EQUIV. COSTS		$160,014	
PARAMETERS			
Plant Capacity (lineal ft. of wall)	107,240		3 houses/day, 1 shift
Length of Standard Wall (lineal ft.)	40		
COST/STD. WALL @ 33% CAPACITY		$181	
COST/STD. WALL @ 66% CAPACITY		$89	
COST/STD. WALL @ 100% CAPACITY		$60	

Appendix C
Overhead Cost Spreadsheet

	EEIH PROJECT		
	PANEL COST ANALYSIS: OVERHEAD COST		
PANEL MANUFACTURER:	Current Business Practice		
STUDY PARAMETERS			
Max. Capital Recovery Period (yr.)	10		
Minimum Attractive Rate of Return	20%		
CAPITAL COSTS			
FACILITIES			
Mfg. Space (sq.ft.)	5,000		
Capital Cost per sq ft.	$40		
	0		
Sub-Total		$200,000	
EQUIPMENT			
Triad Framing Table (3)	$33,318		All Triad equipment assumed purchased used
Triad Sheathing Table (3)	$16,823		
Triad Sheathing Stitcher (3)	$26,379		
Portable Router (3)	$300		
Outfeed Conveyor (6)	$3,124		
Radial Arm Saw (3)	$2,400		
Forklift (1)	$20,000		
Sub-Total		$102,344	
WORKING CAPITAL - INVENTORY			
Raw Materials	$424,350		
Work in Process	$0		
Finish Goods	$199,091		
Sub-Total		$623,441	
TOTAL CAPITAL COSTS		$925,785	
TOTAL ANNUAL EQUIV. CAPITAL		$220,821	
ANNUAL OPERATING EXPENSES			
Production Supervision		$40,000	
EQUIPMENT LEASE			
Delivery Trucks			
Flat Beds (10)	$84,000		
Tractors (3)	$36,000		
Sub-Total		$120,000	
	$0		
	$2,000		
Sub-Total		$2,000	
UTILITIES			
Gas/oil	$0		
Electric	$25,500		
Water	$250		
Waste Disposal	$20,000		
Sub-Total		$45,750	
TOTAL ANNUAL OPERATING COSTS		$207,750	
TOTAL FIXED COST ANALYSIS			
TOTAL ANNUAL EQUIV. COSTS		$428,571	
PARAMETERS			
Plant Capacity (lineal ft. of wall)	440,000		
Length of Standard Wall (lineal ft.)	40		
COST/STD. WALL @ 33% CAPACITY		$118	
COST/STD. WALL @ 66% CAPACITY		$59	
COST/STD. WALL @ 100% CAPACITY		$39	

Appendix C
Overhead Cost Spreadsheet

	EEIH PROJECT		
	PANEL COST ANALYSIS: OVERHEAD COST		
PANEL MANUFACTURER:	Normalized Business Practice		
4" SSIC #1			
STUDY PARAMETERS			
Max. Capital Recovery Period (yr.)	10		
Minimum Attractive Rate of Return	20%		
CAPITAL COSTS			
FACILITIES			
Mfg. Space (sq.ft.)	18,327		
Capital Cost per sq.ft.	$40		
Sub-Total		$733,080	
EQUIPMENT			
Coater		$25,000	
Platen Press (small)		$26,000	
Platen Press (large)		$61,000	
Infeed conveyor		$10,000	
Outfeed Conveyor		$10,000	
Forklift		$15,000	
Sub-Total		$147,000	
WORKING CAPITAL - INVENTORY			
Raw Materials		$117,617	
Work in Process		$0	
Finish Goods		$70,000	
Sub-Total		$187,617	
TOTAL CAPITAL COSTS		$1,067,697	
TOTAL ANNUAL EQUIV. CAPITAL		$254,670.03	
ANNUAL OPERATING EXPENSES			
FACILITY LEASE			
Production supervision	36,400		
Sub-Total		$36,400	
EQUIPMENT LEASE			
Delivery Trucks (5)		$12,500	
Item 2		$0	
Item 3		$0	
Item 4		$0	
Item 5		$0	
Sub-Total		$12,500	
UTILITIES			
Water/electric/gas		$600	
Forklift operating cost		$1,200	
Coater		$1,200	
Presses		$240	
Sub-Total		$3,240	
TOTAL ANNUAL OPERATING COSTS		$52,140	
TOTAL FIXED COST ANALYSIS			
TOTAL ANNUAL EQUIV. COSTS		$306,810.03	
PARAMETERS			
Plant Capacity (lineal ft. of wall)	125,000		
Length of Standard Wall (lineal ft.)	31		
COST/PANEL @ 33% CAPACITY		$231	
COST/PANEL @ 66% CAPACITY		$114	
COST/PANEL @ 100% CAPACITY		$76	

Appendix C
Overhead Cost Spreadsheet

		EEIH PROJECT		
		PANEL COST ANALYSIS: OVERHEAD COST		
PANEL MANUFACTURER:		Normalized Business Practice		
4" SSIC #2 & 6" SSIC				
STUDY PARAMETERS				
Max. Capital Recovery Period (yr.)	10			
Minimum Attractive Rate of Return	20%			
CAPITAL COSTS				
FACILITIES				
Mfg. Space (sq.ft.)	6,000			
Capital Cost per sq.ft.	$20			
Sub-Total		$120,000		
EQUIPMENT				
Roll Coater		$26,000		
Large Vacuum Press		$8,000		
Small Vacuum Press		$3,000		
Hot wring table with jigs		$1,000		
Small forklift		$15,000		
Sub-Total		$55,000		
WORKING CAPITAL - INVENTORY				
Raw Materials		$43,379		
Work in Process		$0		
Finish Goods		$2,920		
Sub-Total		$46,299		
TOTAL CAPITAL COSTS		$221,299		
TOTAL ANNUAL EQUIV. CAPITAL		$52,784.85		
ANNUAL OPERATING EXPENSES				
Production Supervision		$40,000		
FACILITY LEASE				
Mfg. Space (sq.ft.)	6,000			
Annual lease cost per sq.ft.	$0.00			
Sub-Total		$0		
EQUIPMENT LEASE				
Delivery Trucks		$12,500		
Sub-Total		$12,500		
UTILITIES				
Utilities		$600		
Forklift		$1,200		
Vacuum Presses		$240		
Roll coater		$1,200		
Sub-Total		$3,240		
TOTAL ANNUAL OPERATING COSTS		$55,740		
TOTAL FIXED COST ANALYSIS				
TOTAL ANNUAL EQUIV. COSTS		$108,524.85		
PARAMETERS				
Plant Capacity (lineal ft. of wall)	52,000			
Length of Standard Wall (lineal ft.)	31			
COST/40 ft wall @ 33% CAPACITY		$196		
COST/40 ft wall @ 66% CAPACITY		$97		
COST/40 ft wall@ 100% CAPACITY		**$65**		