U.S. Department of Housing and Urban Development
Office of Policy Development and Research

ALTERNATIVE FRAMING MATERIALS IN RESIDENTIAL CONSTRUCTION: THREE CASE STUDIES

ALTERNATIVE FRAMING MATERIALS IN RESIDENTIAL CONSTRUCTION: THREE CASE STUDIES

Prepared for

U.S. Department of Housing and Urban Development
Office of Policy Development and Research

Prepared by

NAHB Research Center
Upper Marlboro, MD

Instrument No. DU100K000005911
July 1994

Acknowledgments

This report was prepared by the NAHB Research Center under funding from the U.S. Department of Housing and Urban Development (HUD). The principal author was Timothy J. Waite, P.E. with review by E. Lee Fisher. Technical support was provided by Mike Bruen, Bob Dewey, Eric Lund, and J. Albert van Overeem. Special appreciation is extended to William Freeborne of HUD for guidance throughout the project.

Appreciation is also extended to the builders and manufacturers who participated in the construction of demonstration homes: Mickgreen Development, Desert Hot Springs, California; Bantex Building Products, Santa Ana, California; Sunset Ridge Limited, Imperial, California; Western Metal Lath, Riverside, California; Insteel Construction Systems, Inc., Brunswick, Georgia; Del Webb California Corporation, Inc., Bermuda Dunes, California; and Bowen & Bowen Construction Company, Norcross, Georgia.

Contents

LIST OF TABLES, FIGURES, AND PHOTOS iii

EXECUTIVE SUMMARY vii

INTRODUCTION 1

BACKGROUND 3
USE OF LUMBER IN RESIDENTIAL CONSTRUCTION 3
THE COSTS OF BUILDING WITH LUMBER 4

CASE STUDY RESULTS 7

FOAM-CORE PANELS 9
Product Description 9
Demonstration Homes 12
Tools and Equipment 14
Installation 14
Observations 18
Productivity Comparisons 19
Cost Comparisons 21

LIGHT-GAUGE STEEL FRAMING 23
Product Description 23
Demonstration Homes 25
Tools and Equipment 28
Installation 28
Observations 32
Productivity Comparisons 33
Cost Comparisons 35

WELDED-WIRE SANDWICH PANELS 37
Product Description 37
Demonstration Home 38
Tools and Equipment 40
Installation 41
Observations 47
Productivity Comparisons 48
Cost Comparisons 50

CONCLUSIONS AND RECOMMENDATIONS 53

FOAM-CORE PANELS 53
Wall Framing 53

Roof Framing 53
LIGHT-GAUGE STEEL FRAMING 53
Wall Framing 53
Roof Framing 54
WELDED-WIRE SANDWICH PANELS 54
Wall Framing 54
Roof Framing 54
CONCLUSIONS 55
ENGINEERING COSTS 57
RECOMMENDATIONS 57

APPENDIX A--TIME AND MOTION STUDY DATA A-1

APPENDIX B--COST DATA B-1

APPENDIX C--SUPPORTING CALCULATIONS C-1

APPENDIX D--CONVENTIONALLY CONSTRUCTED BASELINE HOUSES D-1

APPENDIX E--CONTACTS FOR INFORMATION AND MANUFACTURERS E-1

List of Tables, Figures, and Photos

Tables

Table 1. 1990 Construction Framing Materials in New Homes 3
Table 2. Cost of Lumber in a 2,000 Square Foot Home 4
Table 3. Foam-Core Panel Strength Properties 10
Table 4. Wall Framing Productivity: Foam-Core Panels versus Conventional Wood 20
Table 5. Roof Framing Productivity: Foam-Core Panels versus Conventional Wood . . . 20
Table 6. Wall Framing Unit Costs: Foam-Core Panels versus Conventional Wood 21
Table 7. Roof Framing Unit Costs: Foam-Core Panels versus Conventional Wood 22
Table 8. Properties for Selected Gauges of Sheet Steel 24
Table 9. Wall Framing Productivity: Light-Gauge Steel versus Conventional Wood . . . 34
Table 10. Roof Framing Productivity: Light-Gauge Steel versus Conventional Wood . . . 35
Table 11. Wall Framing Unit Costs: Light-Gauge Steel versus Conventional Wood 36
Table 12. Roof Framing Unit Costs: Light-Gauge Steel versus Conventional Wood 36
Table 13. Wall Framing Productivity: Welded-Wire Sandwich Panels versus Conventional Wood 49
Table 14. Roof Framing Productivity: Welded-Wire Sandwich Panels versus Conventional Wood 50
Table 15. Wall Framing Unit Costs: Welded-Wire Sandwich Panels versus Conventional Wood 51
Table 16. Roof Framing Unit Costs: Welded-Wire Sandwich Panels versus Conventional Wood 51
Table 17. Summary of Wall Framing Unit Costs 55
Table 18. Summary of Roof Framing Unit Costs 56
Table A1.1 Foam-Core Panel Time Data: Summary for Wall, Roof, and Fascia Production Time by Component A-2
Table A1.2 Foam-Core Panel Time Data: Summary of Walls, Roof, and Fascia by Subcomponent A-3
Table A1.3 Foam-Core Panel Time Data: Summary of Wall Panels by Subcomponent . A-4
Table A1.4 Foam-Core Panel Time Data: Summary of Roof Panels by Subcomponent . A-5
Table A1.5 Foam-Core Panel Time Data: Summary of Fascia by Subcomponent A-6
Table A2.1 Light-Gauge Steel Time Data: Summary of Walls, Roof, and Fascia Production Time by Component A-7
Table A2.2 Light-Gauge Steel Time Data: Summary of Walls, Roof, and Fascia by Subcomponent A-8
Table A2.3 Light-Gauge Steel Time Data: Summary of Walls by Subcomponent A-9
Table A2.4 Light-Gauge Steel Time Data: Summary of Roof by Subcomponent A-10
Table A2.5 Light-Gauge Steel Time Data: Summary of Fascia by Subcomponent A-10
Table A3.1 Welded-Wire Sandwich Panel Time Data: Summary for Walls, Roof, and Fascia Production Time by Component A-11

Table A3.2 Welded-Wire Sandwich Panel Time Data: Summary of Walls, Roof, and Fascia by Subcomponent A-12
Table A3.3 Welded-Wire Sandwich Panel Time Data: Summary of Wall Panels by Subcomponent A-13
Table A3.4 Welded-Wire Sandwich Panel Time Data: Summary of Roof Panels by Subcomponent A-14
Table A3.5 Welded-Wire Sandwich Panel Time Data: Summary of Fascia by Subcomponent A-15
Table A4.1 California Wood-Frame Time Data: Summary of Walls, Roof, and Fascia Production Time by Component A-16
Table A4.2 California Wood-Frame Time Data: Summary of Walls, Roof, and Fascia by Subcomponent A-17
Table A4.3 California Wood-Frame Time Data: Summary of Exterior Walls by Subcomponent A-18
Table A4.4 California Wood-Frame Time Data: Summary of Interior Walls by Subcomponent A-19
Table A4.5 California Wood-Frame Time Data: Summary of Roof by Subcomponent . A-20
Table A4.6 California Wood-Frame Time Data: Summary of Fascia by Subcomponent A-20
Table A5.1 Georgia Wood-Frame Time Data: Summary of Walls, Roof, and Fascia Production Time by Component A-21
Table A5.2 Georgia Wood-Frame Time Data: Summary of Walls, Roof, and Fascia by Subcomponent A-22
Table A5.3 Georgia Wood-Frame Time Data: Summary of Walls by Subcomponent . . A-23
Table A5.4 Georgia Wood-Frame Time Data: Summary of Roof by Subcomponent . . A-24
Table A5.5 Georgia Wood-Frame Time Data: Summary of Fascia by Subcomponent . A-24

Figures

Figure 1. Framing Lumber Composite Price 4
Figure 2. Average Weekly Change--Lumber Composite Price 5
Figure 3. Foam-Core Panel Demonstration House: Floorplan 13
Figure 4. "C"-Shape 23
Figure 5. "Hat"-Shape 23
Figure 6. Light-Gauge Steel Demonstration House: Floorplan 26
Figure 7. Welded-Wire Sandwich Panel Demonstration House: Floorplan 39

Photos

Photo 1. Foam-Core Panel 10
Photo 2. Foam-Core Panel Demonstration Home 14
Photo 3. Foam-Core Panel Fastened to Sill Plate 15
Photo 4. Top of Foam-Core Panel Fitted with a Top Plate 16
Photo 5. Foam-Core Panel Gable-End Walls 17
Photo 6. Foam-Core Roof Panels Being Set in Position 18

Photo 7.	Light-Gauge Steel Demonstration Home	27
Photo 8.	Light-Gauge Steel Layout of Top and Bottom Track	29
Photo 9.	Light-Gauge Steel Walls Braced in Position	30
Photo 10.	Light-Gauge Steel Shear Walls	31
Photo 11.	"In-Line" Framing Technique	31
Photo 12.	Electrical Wiring and Plumbing Protected with Plastic Grommets	32
Photo 13.	Welded-Wire Sandwich Panel	38
Photo 14.	WWSP Demonstration Home	40
Photo 15.	Pneumatic Hog Ring Gun	41
Photo 16.	WWSPs Tied to Rebar	42
Photo 17.	WWSP Wall Bracing	43
Photo 18.	WWSP Window Framing	44
Photo 19.	Electrical Conduit Installed in WWSP	45
Photo 20.	WWSP Roof Panel Installation	46
Photo 21.	Shotcrete Application: Finish Coat	47
Photo D1.	California Wood-Frame Baseline Home	D-1
Photo D2.	Georgia Wood-Frame Baseline Home	D-2

EXECUTIVE SUMMARY

With the increase and instability in lumber prices over the last few years, alternative framing materials are becoming more cost-effective; in fact, some are even beginning to compete with dimensional lumber. Despite this impetus, it is not clear how the application of alternative materials compares with wood.

While it is relatively easy for builders to determine material costs, both the labor component and the impact of the framing alternatives on other trades and systems in the home are particularly difficult to assess. This project helps address these concerns by demonstrating some of the more promising alternative materials in the construction of homes. Specifically, it includes an evaluation of the alternatives' practical feasibility and in-place labor and material requirements as compared to wood framing in comparable homes.

The scope of this project was limited to three alternatives to lumber and plywood that are currently commercially available: foam-core structural sandwich panels, light-gauge steel framing, and welded-wire sandwich panels. A *foam-core panel* consists of a foam material sandwiched between two facings. Common facing materials include oriented strand board (OSB), waferboard, and plywood. *Steel framing* members are manufactured by a cold-forming process in which sheets of steel are put through a series of roll forming dies that form the sheet into desired widths, lengths, and shapes. Steel can be used for individual framing members in much the same way as wood. *Welded-wire sandwich panels* are composed of a polystyrene or polyurethane insulation core surrounded by a welded-wire space frame. A layer of shotcrete is spray- or trowel-applied over the wire mesh.

The Group-Timing Technique (GTT) was used to gather information for each alternative system. This technique was also used at baseline conventional wood-framed houses for comparison. The GTT is a work measurement procedure for multiple activities that allows one observer using a stop watch to make a detailed elemental time study of an entire work crew at the same time. Continuous observations were made at one-minute intervals and were recorded as tallies on a form that listed the elements of the job. Nonproductive time was identified and removed from the totals to establish a normal time for each component of work. Time values were used to calculate the productivity of the alternative systems for comparison to the baseline wood-framed houses.

In-place costs of the three alternative framing materials were determined and compared with conventional wood framing. Results indicate that certain aspects of light-gauge steel are within the range that might be expected to be cost-effective with wood. The other alternatives, foam-core and welded-wire sandwich panels, while offering structural advantages, do not appear at this time to be cost competitive with wood.

The unit costs developed in this report were based on the raw data obtained from a small sample and should not be used for estimating purposes. The three alternative material houses were located in different parts of the country. Each had unique labor rates, material costs, size, shape and style of construction. Thus, results do not reflect a definitive study but rather indicate whether builders should consider the alternative framing materials when searching for solutions to their lumber problems.

INTRODUCTION

This report is the result of a two-year study of alternative materials in residential construction conducted for the U.S. Department of Housing and Urban Development (HUD). Results from the first year are published in *Alternatives to Lumber and Plywood in Home Construction*[1] which provides introductory information on alternatives to conventional lumber and plywood, including basic properties, applicability, and available sources.

Despite the availability of numerous alternatives to lumber and plywood, considerable barriers impede their adoption. For example, the building industry is generally reluctant to adopt alternative building methods and materials unless they exhibit clear cost or quality advantages. Given the increase and instability in lumber prices over the last few years, alternative materials are becoming more cost-effective; in fact, some are even beginning to compete with dimensional lumber. Despite this impetus, it is not clear how most alternative materials compare with wood.

Little objective reporting has compared the framing costs associated with alternative material homes versus conventional wood-frame homes. The labor component and impact of the framing alternative on other trades and systems in the home are particularly difficult to assess. This project helps address these concerns by

- demonstrating some of the more promising alternative materials for use in the construction of homes;
- evaluating their practical feasibility; and
- determining their in-place labor and material requirements for comparison with wood framing.

The scope of this project was limited to three alternatives to lumber and plywood that are currently commercially available: foam-core structural sandwich panels, light-gauge steel framing, and welded-wire sandwich panels.

A *foam-core structural sandwich panel*, hereafter referred to as a foam-core panel, consists of a foam material sandwiched between two facings. The foam material is usually made from molded-bead expanded polystyrene (EPS), extruded polystyrene (XPS), urethane, or polyisocyanurate. The facing materials provide the panel's structural strength. Facing materials commonly include oriented strand board (OSB), waferboard, and plywood.

Steel framing has been used for many years as partition studs in both commercial and residential construction. Heavier-gauge members are becoming more attractive for use as bearing wall studs and floor and roof framing because of higher lumber prices. Members are manufactured by a cold-forming process in which various thicknesses of sheet steel are put through a series of roll forming

---

[1]Prepared by NAHB Research Center for the U.S. Department of Housing and Urban Development. *Alternatives to Lumber and Plywood in Home Construction.* Washington, D.C., April 1993.

dies that form the sheets into desired widths, lengths, thicknesses, and shapes. Steel can be used as individual framing members in much the same way as wood.

Welded-wire sandwich panels are composed of a polystyrene or polyurethane insulation core surrounded by a welded-wire space frame. A layer of shotcrete is spray- or trowel-applied over the wire mesh. The system's strength and rigidity is provided by diagonal truss wires welded to the wire mesh on each side. The resulting structure provides rigidity and shear transfer for full composite behavior. The panels can be used as floors, load-bearing exterior or interior walls, partitions, or roofs.

BACKGROUND

USE OF LUMBER IN RESIDENTIAL CONSTRUCTION

In most regions of the United States, wood has been the material of choice for home construction. Unlike many other regions of the world, the United States has enjoyed an abundant supply of timber products. The availability and workability of wood has enabled home builders to construct millions of residences economically and efficiently. Wood's importance is evident in Table 1, which shows that 94 percent of the exterior walls in single-family detached housing in 1990 used wood as the dominant material in new construction. At the same time, 98 percent of all interior walls for single-family detached housing were wood-framed.

Table 1
1990 CONSTRUCTION FRAMING MATERIALS IN NEW HOMES
PERCENT OF ALL MATERIALS USED

	Material	Single-Family Detached	Single-Family Attached	Multifamily Low-Rise
Exterior Wall	Wood Framing	94	92	89
	Steel Framing	0	0	1
	Concrete Block	5	8	5
	Other	1	0	5
Interior Wall	Wood Framing	98	96	84
	Steel Framing	1	3	6
	Other	1	1	10

Source: Adapted from Residential Product Demand New Construction Report, *F.W. Dodge Residential Statistics Services*, Lexington, MA, 1990.

In addition, the amount of lumber consumed by the repair and remodeling markets has increased substantially since 1982, accounting for an estimated one-third of the lumber purchased in the United States in 1991[2]. Taken together new residential construction and remodeling consumes about two-thirds of the lumber used today[3].

[2]*Alternatives to Lumber and Plywood in Home Construction.*

[3]*Ibid.*

THE COSTS OF BUILDING WITH LUMBER

Lumber prices have been increasing steadily over the past few years (see Figure 1). Between October 1992 and February 1993, the framing lumber composite price increased by approximately 100 percent. This was followed by a decrease in the composite price from March 1993 to July 1993 to within 25 percent of the October 1992 price. By December 1993, prices were back to the record levels of February 1993.

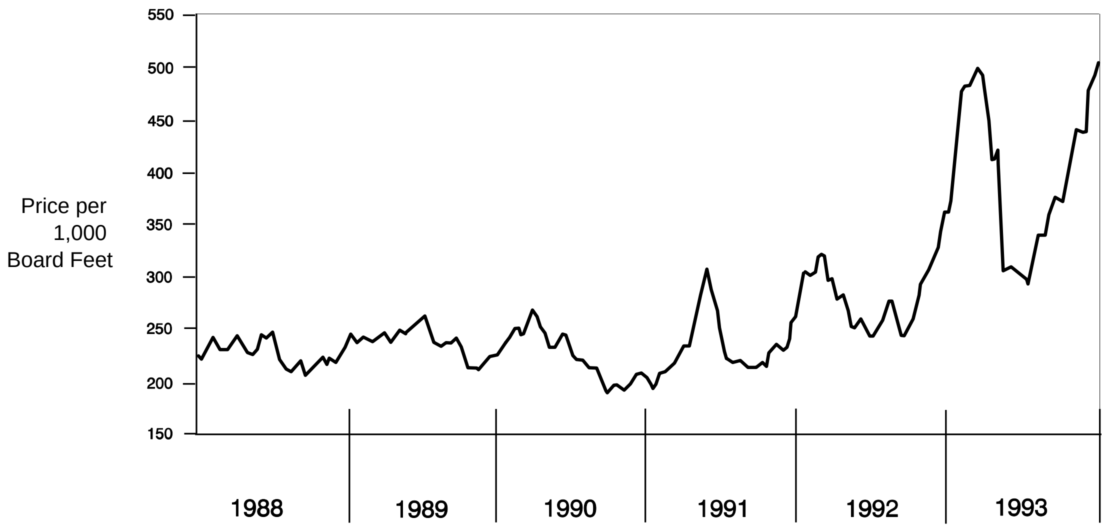


Figure 1. FRAMING LUMBER COMPOSITE PRICE
Source: Random Lengths, Eugene, OR.

Not only are the resultant price increases significant, but the sharp fluctuations have created a volatile market for timber sales. Figure 2 shows that the average weekly change in the framing lumber composite price varied in 1993 between $10 and $15 per 1,000 board feet, or about three times the rate of change experienced throughout the 1980s.

The increases in the lumber composite price translate directly into increases in lumber costs per house. Table 2 shows how the framing lumber and structural panel costs increase with the lumber composite price.

Table 2
COST OF LUMBER IN A 2,000 SQUARE FOOT HOME

Cost per 1,000 Board Feet	Framing Lumber	Structural Panel	Lumber Costs per House
$200	$3,488	$1,394	$4,882
300	5,232	2,091	7,323
400	6,976	2,788	9,764
500	8,720	3,486	12,206
600	10,464	4,183	14,647
700	12,208	4,880	17,088

Source: *Nation's Building News*, February 14, 1994.

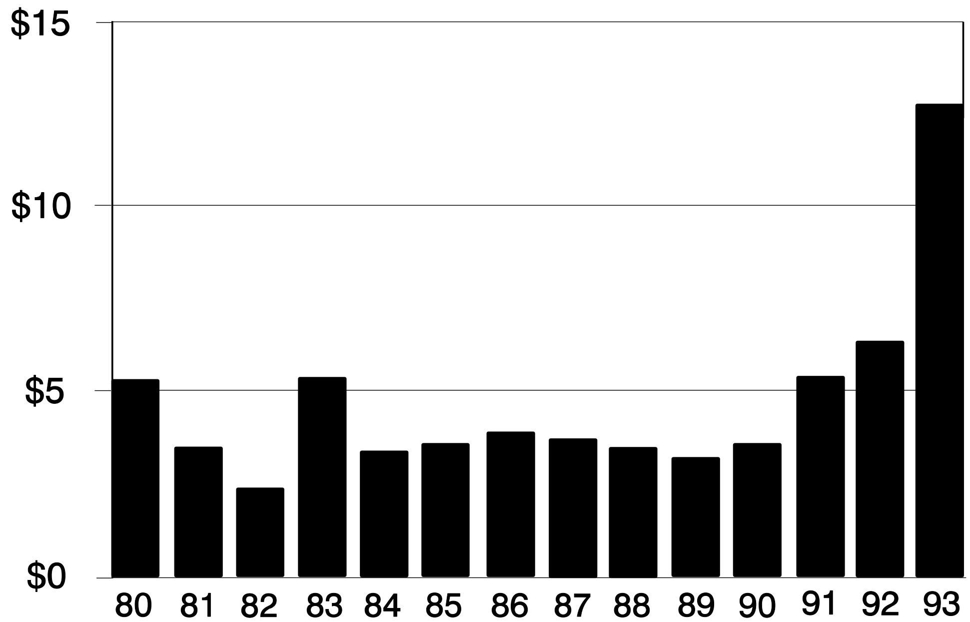


Figure 2. AVERAGE WEEKLY CHANGE--LUMBER COMPOSITE PRICE
Source: Random Lengths, Eugene, OR.

While the amount of standing timber in the United States is increasing,[4] it consists primarily of trees planted in the last few decades. Even though these trees grow quickly, they do not provide the long, large-dimensioned lumber typically used for joists and rafters. Most of the remaining old-growth forests, which are harvested to produce large-dimensioned lumber and plywood, are located on government-owned land subject to federal logging restrictions.

Other factors that affect the price of lumber are market changes in the demand for housing, duties on imported lumber, and new design values for the various grades and species of lumber.

[4]Frederick T. Kurpiel, ed., "Proceedings of Engineered Wood Products, Processing and Design Conference." Sponsored by the North Georgia Chapter of the Southeastern Section of the Forest Products Research Society. Atlanta, GA, March 26-27, 1991.

CASE STUDY RESULTS

The purpose of this report was to evaluate the practical and economic feasibility of three alternatives to conventional, residential wood-framed construction. More specifically, the intent was to determine if the costs of the alternatives were "in the same ballpark" as wood framing, realizing that local labor rates, material availability, and other factors will ultimately determine the cost in a specific area. None-the-less, results can be considered by builders when searching for solutions to their lumber problems.

The three alternative materials selected for this project based on the potential demonstrated in the housing market were: foam-core structural sandwich panels, light-gauge steel framing, and welded-wire sandwich panels. Given that use of alternative materials is not wide-spread, site selection was limited to isolated pockets of activity that coincided with the time frame of this study. The demonstration homes were located in different parts of the country. Each reflected unique labor rates, material costs, and construction size, shape, and styles.

In order to assess the alternatives, a team of observers were sent to job sites where the materials were being used to frame houses. The houses selected for observation are referred to in this report as the demonstration houses. To effectively make a comparison of the alternative framing materials in these houses, conventional wood-framed homes were selected in the general vicinity for comparison. These wood-framed homes are referred to as the baseline houses. Therefore, a total of 5 framing systems were observed: foam-core panel homes and light-gauge steel frame homes in California, a welded-wire sandwich panel home in Georgia, a conventional wood-framed home in California, and a conventional wood-framed home in Georgia. Framers, plumbers, and electricians were questioned in the field to provide input on the workability of the alternative materials and their practical applications. The in-place labor and material requirements were monitored for all homes.

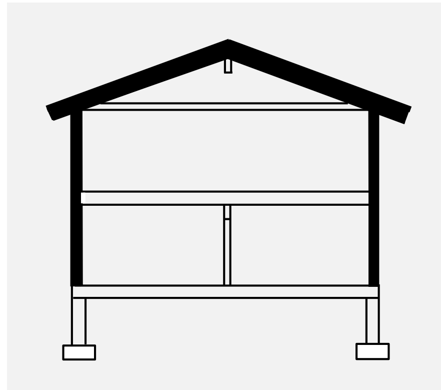
The Group-Timing Technique (GTT) was used to gather information on each alternative system. The GTT is a work measurement procedure for multiple activities that allows one observer using a stop watch to make a detailed elemental time study on an entire work crew at the same time. Each activity performed at the jobsite was broken into components (e.g., wall framing, roofs, and fascia), subcomponents (e.g., sill plate, studs, headers, etc.), and tasks (e.g., measure, cut, brace, etc.) (see list of time and motion study categories for data collection in Appendix A). Continuous observations were made at one minute intervals and recorded as tallies on a form that listed the elements of the job. Nonproductive time (e.g., breaks, lunch, etc.) was identified and removed from the totals to establish a normal time for each component of work. An allowance of 20 percent was applied to the normal time to account for personal, fatigue, and delays (PF&D). The resulting numbers provided standard time values that were used to calculate the productivity of each alternative system and the two baseline wood-framed houses that were used for comparison. This technique was designed to simulate, as close as possible, a production setting and permits a comparison of the labor required to conduct a given task.

When using the information in this report, extreme care should be taken in drawing comparisons with costs in a particular area, as local labor rates, availability of materials, and regional skill levels all influence an alternative material's final cost. The unit costs developed in this report were based on the raw data obtained from a small sample. This information includes neither nonproductive time nor builder overhead and profit. Results do not reflect a definitive study but rather indicate whether builders should consider the alternative materials when searching for solutions to lumber problems.

As with all new materials, the alternatives in this report will likely require an engineered design to obtain approval from the local building officials. Engineering costs were not included in this report. These costs typically vary depending on who provides the services. In production housing, these costs will have the tendency of being amortized throughout a large number of homes. The greatest impact of engineering costs will be on small volume and custom builders.

Results of the findings for three demonstration homes include descriptions of each alternative material and demonstration house; descriptions of installation techniques, including special tools or equipment used for each alternative; observations of problems encountered in the field or potential improvements to each system; and productivity and unit cost comparisons.

FOAM-CORE PANELS



Foam-core panels were first tested by the U.S. Forest Products Laboratory in demonstration homes between 1935 and 1937. The National Association of Home Builders (NAHB) built several prototype foam-core panel research homes in 1957 and 1958. Manufacturers of foam-core panels began marketing their product to home builders in 1959. Despite early efforts to introduce the panels, the technology did not receive much attention until the 1980s when demonstration models appeared at the Denver parade of high-end custom homes in 1987, the 1988 NAHB Convention in Dallas, and the World Expo 1992 in Barcelona, Spain.

Today, foam-core panel construction comprises less than 1 percent of all housing starts. The Natural Resources Research Institute estimated that over 3,700 foam-core panel houses were built in 1990[5]. However, over 100 foam panel manufacturers are now in business, and many have reported as much as 40 percent growth over the last few years[6].

Product Description

A foam-core panel consists of a foam material sandwiched between two facings (see Photo 1). It can be used in both residential wall and roof framing. The foam material is usually made from molded bead expanded polystyrene (EPS), extruded polystyrene (XPS), urethane, or polyisocyanurate. Typical facings include oriented strand board (OSB), waferboard, and plywood. The panels function similar to an I-beam, with the facing materials acting as the flange and the foam core acting as the web. Table 3 summarizes the typical strength properties of foam-core panels.

---

[5]T. Michael Toole and Timothy D. Tonyan. "The Adoption of Innovation Building Systems: A Case Study," *Building Research Journal*, January 1992, p. 22.

[6]Steve Andrews. "Foam-Core Panels & Building Systems: Principles, Practice, and Product Directory, 2nd Edition." *Energy Design Update*. Cutter Information Corp., Arlington, MA, 1992.

Table 3
FOAM-CORE PANEL STRENGTH PROPERTIES
(psi)

Material/Density (lbs./ft.^{3})	EPS[1] 1.0	XPS[2] 1.5	Urethane 2.0
Compressive Strength with 10% Deformation	10-14	25	25
Flexural Strength	25-30	50	40
Shear Strength	18-22	35	16
Shear Modulus	280-320	500	750

[1] expanded polystyrene
[2] extruded polystyrene
Compiled from: "Foam-Core Panels & Building Systems: Principles, Practice, and Product Directory, 2nd Edition." *Energy Design Update.* Produced by Steve Andrews for Cutter Information Corporation, Arlington, MA, 1992.

Photo 1. FOAM-CORE PANEL

Sandwich panels are usually assembled by applying a structural-grade adhesive to both sides of the foam. One side of the coated core is placed on a layer of clean facing material; the other facing is placed on top of the foam. A stack of panels is compressed under continuous pressure, set aside, and allowed to cure for approximately 24 hours. Another process uses a vacuum bag system to achieve the correct bond and cure. Typical 4-inch thick 4'x 8' wall panels weigh about 100 pounds.

Foam-core panels are available in 8'x 24' sizes for use as roof panels. Panels range in thicknesses up to 8 inches depending on the required thermal value.

Quality control during the bonding of the panels is important. In the past, delamination problems occurred when the bond between the facings and the foam failed. Moreover, laminations to special facing materials (e.g. treated lumber) can fail. Improper glue or lack of adequate pressure or cure time may cause panels to delaminate. Manufacturers should be checked to ensure they have instituted a good quality control program and that they frequently test their products. A good warranty reflects the manufacturer's confidence in the product.

As mentioned above, the foam material is usually made from either molded bead expanded polystyrene (EPS), extruded polystyrene (XPS), urethane, or polyisocyanurate. EPS is the bead-like foam used in packing material and coffee cups. The beads are injected into a mold, formed into large blocks, and cut into the sizes required for panel construction, usually 3-5/8- to 11-7/8-inch thicknesses. The density of EPS foam is usually specified at 1 lb./ft^3. For each inch of 1 lb./ft.^{3} EPS, the thermal resistance is about R-3.85.

XPS is a closed-cell foam that has a higher density and R-value than EPS. It is used in the construction industry in rigid insulation applications. XPS is manufactured by melting granules; blowing the material to make it into a foam; and dyeing, shaping, and trimming it into its final dimensions. The density for XPS foam is about 1.5 lbs./ft.^{3}, with a thermal resistance of about R-5.0 per inch of material.

Urethane and isocyanurate are both closed-cell plastic foams that contain a low-conductivity freon gas in the cells. The foam is usually manufactured on site and injected directly between two facing layers. The freon gives these foams a higher initial R-value than either EPS or XPS; however, these foams suffer from thermal drift caused by the dilution of freon in the foam cells over time. Panels covered with a facing are expected to develop a final R-value of between R- 7.1 and R-8.7 per inch of foam. The density of urethane panels is about 2 lbs./ft^3.

The water vapor permeability of a foam panel depends on the density, thickness, and type of facings. EPS panels have a perm rating ranging from 1.0 to 2.0 per inch of thickness. The permeability of XPS foam is about 1.1 per inch of thickness. The higher-density urethane has a perm rating of 1.0 or less, which technically qualifies it as a vapor retarder.

To prevent insects and rodents from damaging the foam core, the same precautions applied to conventional wood-framed structures should be applied to foam-core panel structures. Because the panels rely on the foam insulation for part of the structural integrity of the house, normal treatment around the house perimeter is especially important in areas where risks of insect and rodent activity is high.

Some panel manufacturers provide ventilation openings, expansion control joints, or thermal breaks in the splines that connect roof panels to eliminate a potential problem reported with air leakage in colder climates. Some panels contain wiring chases, although foam may need to be routed on site. Wiring can be brought up from the floor or down from the ceiling or attic space. Foam may also need to be routed for plumbing.

Some companies have received HUD, Veterans Administration (VA), Federal Housing Administration (FHA), or state government approvals for their panels. A number of them are also listed with code bodies such as the International Conference of Building Officials (ICBO) or the Building Officials Code Administrators (BOCA). The local building inspector may require an engineer's seal and/or an evaluation report to approve the use of foam-core panels.

Demonstration Homes

Mickgreen Development constructed three foam-core panel demonstration houses in Desert Hot Springs, California. Desert Hot Springs is located approximately 10 miles north of Palm Springs and 100 miles east of Los Angeles. The normal maximum temperature in Desert Hot Springs is 109°F; the normal minimum temperature is 42°F. The average annual rainfall is 5.3 inches.

The panels were manufactured by Santa Ana-based Bantex Building Products, Inc., at their nearby Yucca Valley plant. Lee Bolin Builders set the panels between August 4 and 27, 1993. The Research Center observed the construction, obtained cost information, and performed an extensive time and motion study on the labor for the panelized houses.

The 1,732-square-foot homes were built with three bedrooms, two baths, a two-car garage, and a 250-square-foot loft (see Figure 3 and Photo 2). The exterior walls were constructed of foam-core panels while the interior partitions and exterior garage walls used conventional stick framing. Approximately 190 linear feet of foam-core wall panels were tilted in place in each of the demonstration houses. The 4-inch-thick wall panels consisted of 3½ inches of MEPS and two ½-inch structural 1 grade OSB facings. The panels satisfied the design requirements for Seismic Zone 4.

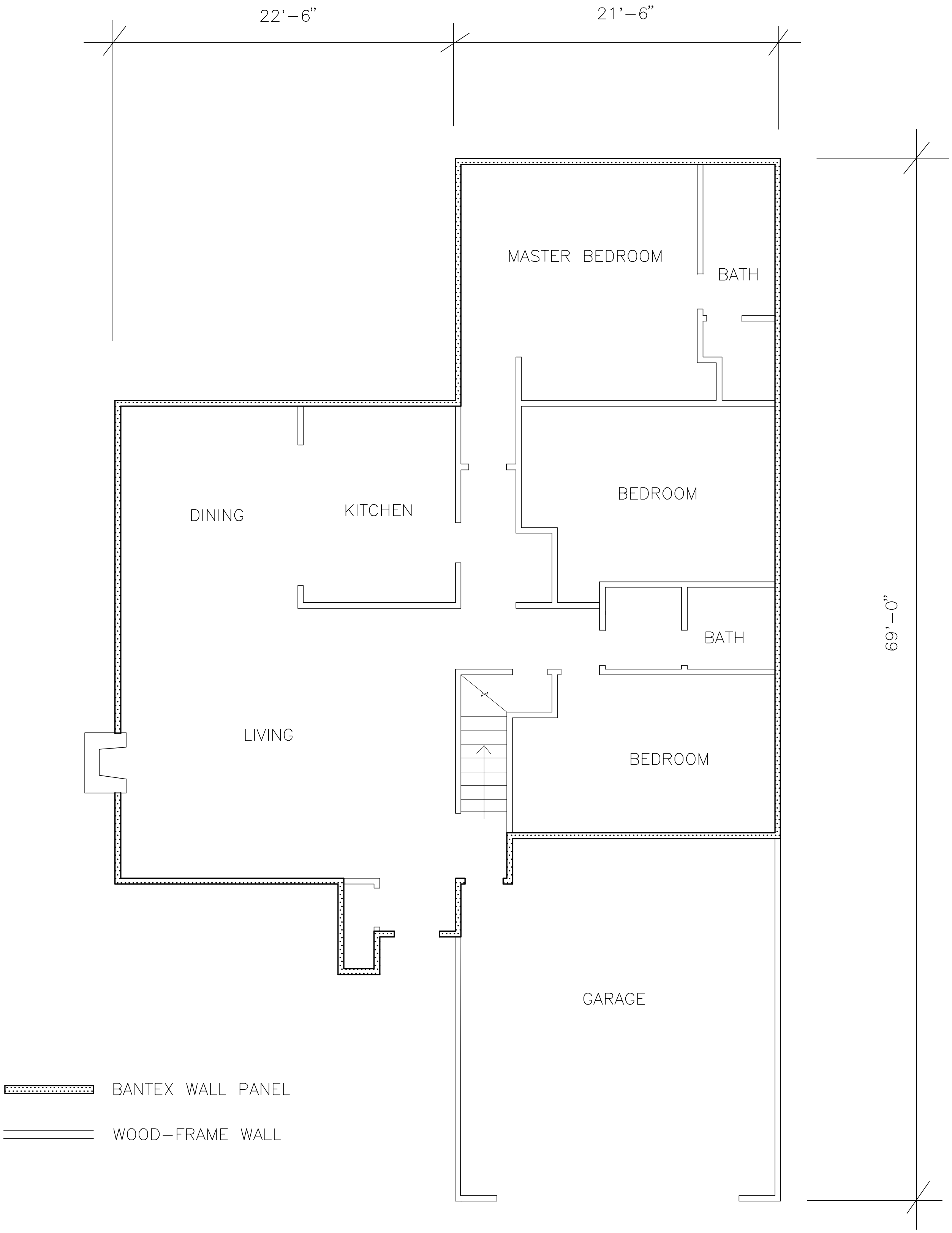


Figure 3. FOAM-CORE PANEL DEMONSTRATION HOUSE: FLOORPLAN

Photo 2. FOAM-CORE PANEL DEMONSTRATION HOME

The roof consisted of 2,365 square feet of roof panels. The panels were 6 or 8 inches thick (depending on location) and were the same material as the walls. The gable construction was assembled by resting the foam-core panels on a center ridge beam and the exterior walls. The spanning capabilities of the panels allowed a cathedral ceiling throughout the residence and accommodated the construction of a loft.

The homes were marketed for $118,000.

Tools and Equipment

In addition to the normal tools required for conventional home building, a few additional tools were needed to set the foam-core panels. A special foam-cutting tool or "hot wire" was used to cut a groove to the depth of a 2x framing member on each side of the panels when not already cut at the plant. Some builders use a "hot knife" to cut the foam; other builders use a router tool.

Due to the heavy nailing schedule, mechanical nailers, commonly used in conventional wood framing, were used to nail the panels. Sledge hammers helped position panels in place. When necessary, panels were cut by using a chain saw attachment for a worm gear saw. An oversized circular saw also could have been used. Caulk guns were required to seal the joints between panels. Because of their weight, the panels were lifted and positioned by a hydraulic lift.

Installation

The panels were delivered to the jobsite ready for erection, with the framing, sheathing, and insulation included in the foam-core panel. Wall panels were precut to the appropriate sizes and individually numbered for ease of installation. Under-slab plumbing and electrical was installed before casting the concrete foundation and stubbed up in the appropriate wall locations. A 2x4 treated sill plate was bolted down to the foundation, and wall panels with pre-routed bottoms were set on the plates. Panels were face-nailed to the plate (see Photo 3).

Photo 3. FOAM-CORE PANEL FASTENED TO SILL PLATE

The sides of the panels were also pre-routed to a depth of 3/4 inches and fitted with a 2x4 spline at the plant. The splines were fitted between the facings of the panels and nailed into place through the facings. The spline on the end of one panel was then fit into the routed edge of the adjacent panel and nailed to its facing. The joints between the panels were caulked to reduce air infiltration.

Glue was applied to the sill plate and caulk to the adjacent panel before each new panel was set in place. Where needed, cavities were provided for the 4x4 posts used to support the roof ridge beams. The tops of the wall panels were fitted with a top plate after each panel was set into position and leveled (see Photo 4). The gable-end panels were set on top of the wall panels after they were fitted with a horizontal spline (see Photo 5).

Photo 4. TOP OF FOAM-CORE PANEL FITTED WITH A TOP PLATE

Photo 5. FOAM-CORE PANEL GABLE-END WALLS

Interior walls and the exterior garage walls were constructed with conventional wood framing. Before the roof panels were set in place, the interior load bearing walls were built to support the ridge beam. Ridge beams were then set on the 4x4 posts. A 2x4 ledger was nailed to the bottom of the ridge beams to support the roof panels.

The precut roof panels were hoisted by the hydraulic lift and set into position on the roof, with one end support on the ridge beam and the other on the exterior wall (see Photo 6). The tops of the panels were screwed into the ridge beam with 10-inch bolts. Twenty-two-gauge metal straps spaced 48 inches on center were used to tie the panels together perpendicular to the ridge. The outside edges of the roof panels were cut to the proper angle with the "chain saw," the foam was routed, and a 2x8 subfascia was installed.

Photo 6. FOAM-CORE ROOF PANELS BEING SET IN POSITION

Observations

The following observations were noted during construction:

- Framers without previous foam-core panel experience quickly learned how to work with and assemble the panels.

- Roof panels allowed large spans and cathedral ceilings.

- The workers spent a considerable amount of time resorting the stack of panels received from the manufacturer as they looked for the next panel to be set in place. The resorting resulted in significant wasted time and increased the potential for damaging the panel facings.

- One site's uneven slab made it difficult to plumb the wall panels. Improper location of rough plumbing also complicated matters and required modifications during installation.

- The use of full-height gable-end wall sections would have saved time by eliminating the need to install two sections and a connecting horizontal spline for the upper panels.

- One of the houses was located near a steep slope, making it difficult for the lift operator to maneuver and position the roof panels. The topography of the jobsite should be taken into consideration in planning for foam-core panel roof construction.

- The installation of screw fasteners at the roof ridge was difficult because workers lacked the right screw gun for the job. While it is common to use screws for this installation, screws with a nut-driver head would have simplified the connection.

Productivity Comparisons

The Group Timing Technique was used to document the time required to build the walls and roof structure of both the foam-core panel homes and a conventional wood-framed home in the same region. Appendix D provides a description of the wood-framed home.

The activity of each crew member was recorded at one-minute intervals. Data were coded for each component of the building (walls, roof and fascia), subcomponent of the framing (sill plate, sheathing, etc.) and task (fasten, measure, etc.). Nonproductive time such as breaks or idle time was separated from productive time. A standard 20 percent increase for personal, fatigue, and delay was added to the productive time. Table A1.1 through A1.5 in Appendix A contain the results for the foam-core panel house. Tables A4.1 through A4.6, also in Appendix A, contain the results for the wood-framed baseline house.

Care must be taken in comparing these components in view of differences in construction and to make sure that similar components of house framing are compared. The wall and roof components of the houses were used to compare the two technologies. The foam-core panel contains the framing, insulation, and sheathing all in one structural unit. Thus, these components were also included in the total productive man-hours for the baseline home. Appendix C gives the supporting calculations for the numbers derived in this section.

Wall Framing

The unit rate for wall framing productivity was determined by dividing the time required to build the exterior wall by the horizontal length of the wall for each house. The time for the foam-core panel house was derived from the total standard time (productive time plus 20 percent) for all wall production minus the time for the gable panels (see Table A1.1). The time for the conventional wood-framed house includes all production time as summarized in Table A4.1.

Table 4 gives the results of the wall framing productivity. The wall framing productivity for the foam-core panel house was 0.21 man-hours per linear foot of wall while the productivity for the conventionally framed house was 0.24 man-hours per linear foot of wall. The difference represented a 13 percent time savings for the foam-core panel walls. One factor that contributed to a lower unit rate for the foam-core panels was the 25 percent additional time required to position the walls in the wood-framed house. It also took more time to brace the walls in the wood house. Productivity would have improved further for the foam-core panel house if workers did not have to repeatedly resort material.

Table 4
WALL FRAMING PRODUCTIVITY:
FOAM-CORE PANELS VERSUS CONVENTIONAL WOOD

	Total Productive Man-Hours	Wall Length LF of 8' High Wall	UNIT RATE Man-hours per LF of 8' High Wall
FOAM-CORE PANEL-- wall panels, plates, and posts	39.62	190	0.21
CONVENTIONAL WOOD-- studs, plates, sheathing, headers, blocking, and insulation	63.37	264	0.24

LF = linear foot

Roof Framing

The unit rate for roof framing productivity was determined by dividing the time to build the roof by the roof plan area for each house. The time for the foam-core panel house represents the total production time for the roof (see Table A1.1). The time for the conventional wood-framed house includes the components for installation of the trusses, in-fill, sheathing, and insulation (see Table A4.1).

Table 5 gives the results of the roof framing productivity. The unit rate for productivity of the foam-core panel roof was 0.030 man-hours per square foot compared to 0.020 man-hours per square foot for the conventional wood-framed roof. In other words, the roof in the foam-core panel house took 50 percent more time to construct than for the same square footage in the conventional house.

Table 5
ROOF FRAMING PRODUCTIVITY:
FOAM-CORE PANELS VERSUS CONVENTIONAL WOOD

	Total Productive Man--Hours	Roof Area SF	Unit Rate Man-hours per SF
Foam-Core Panel--roof panels and ridge beam: 4¼:12 pitch, 100% gable	70.30	2,365	0.030
Conventional Wood-- trusses, in-fill, sheathing, and insulation: 5:12 pitch, 60% gable, 40% hip	50.33	2,574	0.020

SF = square foot

Actually, it took less time to position and fasten the foam-core panels than to set the trusses in the conventional wood house; however, the production support time (e.g., obtaining/carrying materials, organizing material, jobsite cleaning, and building scaffolding) in the foam-core panel house was five times higher (see Table A1.4).

Cost Comparisons

Appendix B includes a detailed breakdown of costs to the builder (without builder overhead and profit) for all of the demonstration houses. The material costs were based on actual costs incurred. The labor and equipment costs varied from jobsite to jobsite. To standardize these costs, national average rates from *Means Residential Cost Data 1994*[7] were used. The rates were applied to the productivity values established in Tables 4 and 5 to develop labor and equipment costs for each house.

The cost data focuses on the comparable framing portions of the house. Non-productive time and engineering costs are not included. It is important to note that comparisons were based on the raw data obtained for each house. The intent was not to draw specific conclusions for future estimating purposes, but rather to see if the costs were close enough to those of conventional wood framing to foster further consideration.

Table 6 compares foam-core panel walls to conventional wood-framed walls and summarizes the unit costs for materials, labor, and equipment. Values are expressed in dollars per linear foot of an 8-foot-high wall.

Table 6
WALL FRAMING UNIT COSTS:
FOAM-CORE PANELS VERSUS CONVENTIONAL WOOD

	Material Costs[1] $/LF	Labor Costs $/LF	Equipment Costs $/LF	Total Costs $/LF
Foam-Core Panel--wall panels, plates and posts	26.17	3.26	0.70	30.13
Conventional Wood--framing, sheathing, and insulation	9.80	3.45	0.53	13.78

[1]Lumber prices are based on August 1993 purchases (framing composite price for August 1993 = $348 per 1,000 BF)
LF = linear foot

While the labor cost was slightly lower for the foam-core panels, the savings was offset by the cost of the materials. The total cost of the foam-core panel walls for the demonstration house was 2 times higher than for the conventionally framed walls. Results reflect the price of lumber at the time of

[7]R. S. Means Company, Inc. *Means Residential Cost Data, 13th Edition.* Construction Publishers & Consultants, Kingston, MA, 1993.

construction in August 1993. The material costs of the foam-core panels must be decreased in order to become cost-effective with wood-framed construction.

The cost for constructing the roof was evaluated the same way; Appendix B contains the background cost data for the demonstration houses. Table 7 compares the unit costs for the roof framing. Values are expressed in dollars per square foot of roof area.

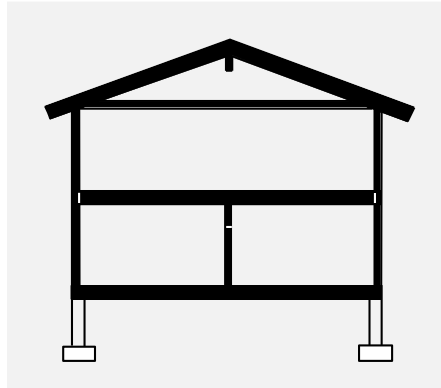
Table 7
ROOF FRAMING UNIT COSTS:
FOAM-CORE PANELS VERSUS CONVENTIONAL WOOD

	Material Costs[1] $/SF	Labor Costs $/SF	Equipment Costs $/SF	Total Costs $/SF
Foam-Core Panels--roof panels and beams: 4¼:12 pitch, 100% gable	4.07	0.47	0.29	4.83
Conventional Wood--trusses, fill, sheathing and insulation: 5:12 pitch, 60% gable, 40% hip	1.27	0.29	0.09	1.65

[1]Lumber prices are based on August 1993 purchases (framing composite price for August 1993 = $348 per 1,000 BF)
SF = square foot

Based on August 1993 lumber prices, roof framing material costs for the foam-core panel system were almost 3 times higher than conventional framing. Materials, labor, and equipment all contributed to the greater price. The panels were thicker on the roof to provide a higher R-value. The panels also had to be lifted into place with heavy equipment and set on a ridge beam. Accordingly, installation proved to be more labor-intensive than for a conventional wood trussed roof.

LIGHT-GAUGE STEEL FRAMING



Light-gauge steel framing has been used for many years in commercial buildings and in some homes for interior partitions. With the increase in and volatility of lumber prices in the 1990s, "heavier" light-gauge steel offers a framing alternative for load-bearing walls, floors, and roofs. Between 1979 and 1992, the number of steel-framed homes increased by more than 300 percent[8]. In 1993, an estimated 12,000 homes were built with steel frames, up from 500 in 1992. NAHB forecasts that 75,000 new homes will use steel framing in 1994[9].

Product Description

Light-gauge steel framing members are manufactured by a cold-forming process in which sheets of steel are put through a series of roll forming dies and formed into desired widths, lengths, thicknesses, and shapes. The strength of cold-formed sheet steel comes from the thickness of the material and how it is shaped. When a sheet is formed into a "C"-shape, its bends act as stiffeners and increase the strength of the sheet many times over (see Figure 4). Strength-to-weight ratios can be highly favorable. Other forms include the "hat"-shape shown in Figure 5.

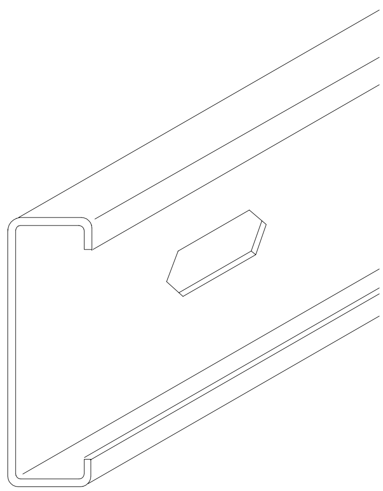


Figure 4. "C"-SHAPE

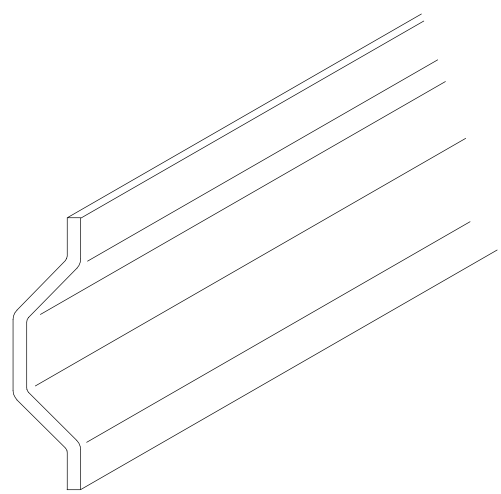


Figure 5. "HAT"-SHAPE

North American manufacturers of raw steel adhere to a number of quality codes to keep the steel components they produce up to standards. Cold-formed steel companies, while following the applicable standards and guidelines produced by ASTM (the American Society for Testing and Materials), enjoy considerable latitude in the shape of the materials they produce. Consequently,

---

[8]American Iron and Steel Institute. *Build it with Steel: An Introduction to Residential Steel Framing*. Washington, D.C., October 1993.

[9]*Engineering News Record.* "Homebuilders Seek Substitutes for Lumber." January 17, 1994, p. 3.

the shapes and sizes of light-gauge steel vary between manufacturers. Thus, an engineered design is usually required to build a home with steel as load bearing members.

Several efforts are underway to standardize typical steel sections for use in residential construction and to produce design and span tables similar to those used in conventionally framed wood construction. In the meantime, builders must work closely with manufacturers' engineers or rely on their own engineers to design steel houses.

The thickness of steel can be referred to by gauge, which typically ranges from 10 to 25. The lower the gauge, the greater the material's thickness (see Table 8). Interior partition wall studs are typically 25 gauge while load-bearing wall studs are usually 20 or 18 gauge. Some manufactured sections are identified by a printed or imprinted stamp. Some manufacturers use a color code to identify the base metal thicknesses.

Zinc galvanizing protects the steel from rusting before, during, and after construction. The proper galvanizing treatment must be specified, especially in corrosive environments near the ocean. Steel naturally conducts hotter and colder air temperatures much faster than wood does. In colder regions of the country, a thermal break usually consisting of a layer of rigid insulation is applied to the exterior side of the wall studs.

Table 8
PROPERTIES FOR SELECTED GAUGES OF SHEET STEEL

Nominal Gauge	Allowable Thickness (inches)	Weight (pounds per square foot)	Color Code (ASTM C955)
10	0.1265-0.1425	5.625	-
12	0.0966-0.1126	4.375	Red
14	0.0677-0.0817	3.125	Orange
16	0.0538-0.0658	2.500	Green
18	0.0428-0.0528	2.000	Yellow
20	0.0329-0.0389	1.500	White
22	0.0269-0.0329	1.250	-
25	0.0179-0.0239	0.875	-

Homes may be designed for traditional stick construction, whereby an almost one-for-one substitution of steel for wood is acceptable. Steel may also be used to simplify framing while providing maximum structural efficiency and ease of installation. The latter approach usually increases spacings to 4 feet or more for structural members.

Regardless of the design approach selected, the three basic residential steel framing assembly methods are

- stick-built construction;

- panelized systems; and
- pre-engineered systems.

Wood and steel stick-built construction are similar. The steel materials are delivered to the jobsite in stock lengths or, in some cases, are pre-cut to length. The layout and assembly of steel framing is the same as for wood framing except that the components are screwed together rather than nailed. Framing members are typically spaced at 16 or 24 inches on center. The studs and joists are sized by thickness and depth to handle the expected live and dead loads.

Panelized systems are fabricated in the shop or in the field. A jig is developed for each type of panel. Cut-to-length steel members are ordered for most panel work, placed in the jig, and fastened by screws or welding. If exterior sheathing is specified, it can be applied before erection. The panels are then transported from the panel shop to the jobsite. Whether or not a panelized wall system is used, steel trusses are usually pre-fabricated.

Pre-engineered systems typically space the primary load carrying members more than 24 inches on center, sometimes up to 8 feet. These systems use either secondary horizontal members to distribute wind loads to the columns or lighter-weight steel in-fill studs between the columns. Many of the pre-engineered systems provide precut-to-length framing members with holes predrilled for bolts or screws. Most of the fabrication labor may be provided by the supplier, thereby allowing a home to be framed in as little as one day.

Steel is recognized by CABO and the other model building codes, but the codes do not contain prescriptive building requirements for steel; thus, some jurisdictions may require calculations or a professional engineer's seal.

Demonstration Homes

The steel-framed demonstration homes selected for this project were located in Imperial, California. The normal maximum temperature in the Imperial Valley is 106°F; the normal minimum temperature is 42°F. The average annual rainfall is 2.8 inches.

Sunset Ridge Limited was constructing 23 new homes as part of Phase II of its Sunset Ranch Estates development. Phase I of the development, consisting of 25 units, was built with steel framing. By the time the framers started Phase II, they had conquered a good part of the learning curve. Western Metal Lath of Riverside, California, provided the steel product as well as the framing design details.

NAHB Research Center staff observed the framing of the Phase II homes from October 7 to 22, 1993. Sunset Ridge offered four different models in Phase II of the Sunset Ranch Estates development, ranging in size from 1,175 to 1,940 square feet. All models were built on a slab-on-grade foundation with an attached two-car garage. Productivity data for walls were obtained from the three-bedroom model and for the roof and fascia from the four-bedroom model. Figure 6 shows the floorplan for the three-bedroom model (also see Photo 7).

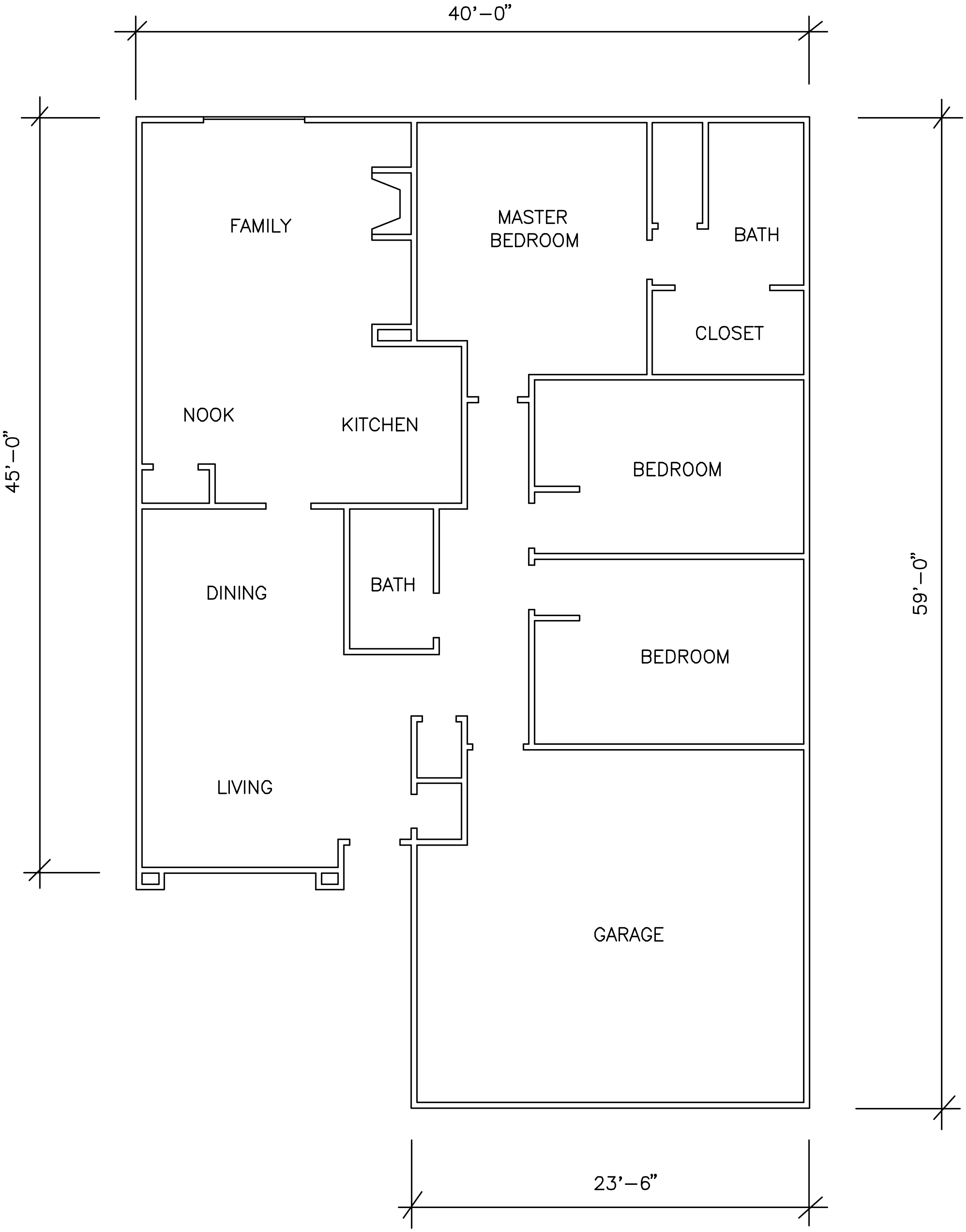


Figure 6. LIGHT-GAUGE STEEL DEMONSTRATION HOUSE: FLOORPLAN

Photo 7. LIGHT-GAUGE STEEL DEMONSTRATION HOME

All framing elements in the houses were fabricated of light-gauge steel. The stock material was shipped to the site where all panels, trusses, and headers were assembled. Wall studs were spaced 24 inches on center with load-bearing studs located directly in-line with roof trusses or floor joists. Load-bearing and interior wall studs were constructed from 20-gauge steel while built-up stud columns were made from 18-gauge material. The steel members were color-coded to distinguish between different gauges. All wall studs were delivered prepunched with holes spaced at 24-inch centers. Shear walls were made by securing 16- or 18-gauge straps diagonally to the same-gauge gusset plates at each corner of the panel. All connections were made with #10 or #12 self-tapping screws.

One-half-inch anchor bolts secured the wall panels to the floor slab. Beams and headers were made from two or more 14-, 16-, or 18-gauge "C"-shapes fastened together with track material. Floor joists consisted of 10-inch, 16-gauge "C"-shapes resting on the top track over load-bearing wall studs, intermediate beams, or headers. The trusses were built on site from 20- and 18- gauge specialty members manufactured by Western Metal Lath and secured to the top plate with truss connection anchors.

The roof sheathing consisted of OSB except at the overhang where plywood was installed to accommodate the eave detail that was left exposed underneath. The roof was covered with concrete barrel tile. The walls were finished with stucco over foamboard and were insulated with 3 inches of fiberglass batt insulation. The ceiling was insulated with 12 inches of fiberglass batt insulation. The homes were marketed for between $92,000 and $116,000 depending on the model and the options selected.

Tools and Equipment

The major difference between steel and wood framing is that the former requires variable-speed drills and screw guns in place of hammers and nails. Screws are the most common fastener used in steel framing. Zinc-plated, cadmium-plated, or phosphate-coated screws can be used in interior applications; cadmium-plated, zinc-plated, or copolymer-coated screws are recommended for exposed exterior surfaces. The screws used at the site were self-tapping, ½-, ¾-, and 1-inch zinc-plated screws with pan heads.

A metal cut-off saw and circular saw with an abrasive metal blade were used to cut the studs and other steel members. Metal snips were used for small cuts. Vise clamps often were necessary to hold members together while connections were made. A metal punch provided the occasional hole in the studs where prepunched holes were not conveniently located.

Installation

The slab foundation was cast after installation of electrical and plumbing groundworks. The walls were then laid out on the foundations with chalk marks before arrival of the framing crew. The bottom and top tracks were cut to the length of each wall and temporarily screwed together. Each track section was measured and marked to show the location of studs and columns, stud gauge, and length (see Photo 8).

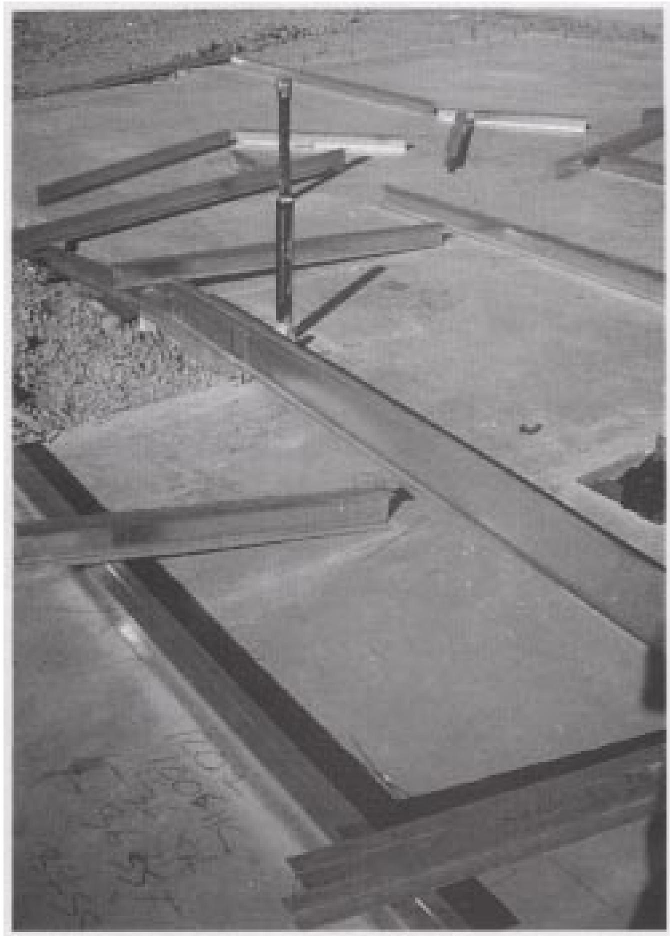


Photo 8. LIGHT-GAUGE STEEL LAYOUT OF TOP AND BOTTOM TRACK

The framing crew unscrewed the top track from the bottom and started building the walls by setting the studs in the top and bottom track. A steel stud was set in place in the top or bottom track by twisting the stud until it "snapped" into position. It was then screwed into the track.

Columns were built up by using multiple "nested" studs or two studs fitted together to form a box shape. Window framing was similar to conventional construction. Most of the headers were preassembled.

Once a wall section was completed on the floor slab, the crew tilted up the wall and temporarily braced it into position with scrap steel (see Photo 9). Adjacent walls were attached and braced in succession. The light weight of the steel walls permitted the framing crew to tilt up walls up to 40-feet-long. A truss anchor was screwed to the top plate above each load-bearing stud.

Photo 9. LIGHT-GAUGE STEEL WALLS BRACED IN POSITION

The top track in steel framing is usually not heavy enough to transfer the loads to the studs. Therefore, the load-bearing walls were framed by using "in-line" techniques so that the roof loads would be transferred directly through the load-bearing wall studs. Shear straps were screwed into gusset plates in the corners of indicated shear walls (see Photos 10 and 11).

Photo 10. LIGHT-GAUGE STEEL SHEAR WALLS

Photo 11. "IN-LINE" FRAMING TECHNIQUE

Once the interior and exterior walls were erected, plumbed, and braced, the roof was constructed using site-prefabricated steel trusses. The crew lifted each truss by hand and dragged the member across the top plates into position, seating the truss in anchors spaced 2 feet on center. The trusses were braced off one by one until all trusses were in position. OSB roof sheathing was then screwed to the trusses. A foamboard and stucco finish was applied to walls.

Plumbers and electricians ran piping and wire through the prepunched holes in the studs. Electricians installed plastic grommets in the holes to protect plastic coated wiring from scraping on the steel. Plumbers had to make sure that copper pipe did not come in contact with the steel members (see Photo 12).

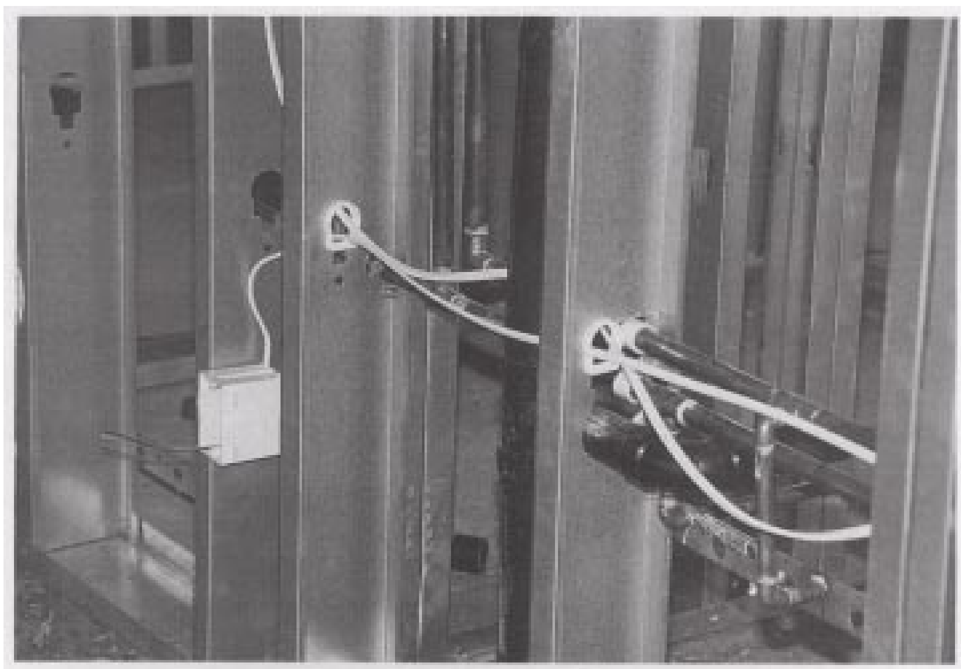


Photo 12. ELECTRICAL WIRING AND PLUMBING PROTECTED WITH PLASTIC GROMMETS

Observations

The framing crew had completed 25 Phase I homes before initiating Phase II and thus conquered a significant part of the learning curve by the time the demonstration study began. The job foreman indicated that carpenters were retrained to work with the steel and that most of them were able to shift easily to the alternative material. Other observations include the following:

- The crew easily handled all members, whether prefabricated or individual pieces. The heaviest lifts were the trusses, which were all set in place by hand.

- Most crew members wore gloves to protect their hands not only from sharp edges but also from the metal studs that were exposed to the hot desert sun. Hemmed track with bent edges could have been used to cut down on sharp edges.

- Even though studs were provided in precut lengths, some cuts were required at the site for use around windows or for cathedral wall sections. At one point, 9-foot studs were cut down to 8 feet because of a delay in shipping.

- The OSB roof sheathing was hauled up onto the roof by the crew and screwed down to the trusses. Screwing down the sheathing took considerably longer than nailing a conventional roof. Each drill was connected to the power source by an extension cord. While the framing crew seemed accustomed to this umbilical "cord," workers could be frequently seen untangling and relocating their lines as they crossed over each other in the course of their work. Cordless equipment will improve productivity.

- Prepunched holes in the studs provided rapid access for plumbing and electrical conduits. Where additional holes were necessary, hand punches were used. The electricians saved time by not having to drill holes in the steel studs, but the savings was negated by the requirement to install snap-in plastic grommets in the prepunched holes to protect the plastic wire sheathing.

- Plumbers were required to exercise care to protect copper plumbing lines from coming in contact with the metal framing.

- Steel manufacturers are set up to deliver large quantities of material to the jobsite; thus, they do not respond to smaller orders as quickly as lumber yards. When a small order was needed, the manufacturer was slow in getting the product delivered to the site, necessitating changes in the scheduling and sequencing of construction.

Productivity Comparisons

The group timing technique was used to document the time to build the walls and roof structure of the light-gauge steel homes for comparison to a conventional wood-framed home in the same region. Appendix D provides a description of the California wood-framed home.

The activity of each crew member was recorded at one-minute intervals. Data were coded for each component of the building (walls, roof and fascia), subcomponent of the framing (studs, sheathing, etc.) and task (fasten, measure, etc.). Nonproductive time such as breaks or idle time was separated from productive time. A standard 20 percent increase for personal, fatigue, and delay was added to the productive time. Tables A2.1 through A2.5 in Appendix A give the results for the light-gauge steel house. Tables A4.1 through A4.6, also in Appendix A, give the results for the wood-framed house.

The wall and roof components of the houses were used to compare the two technologies. Care had to be taken to make sure that similar components of house framing were compared. Stick framing for light-gauge steel is similar in construction to wood in a conventional stick-framed house. In this comparison, the steel home was compared directly with the wood-framed home without sheathing and insulation. The steel house was designed for Seismic Zone 4 with straps instead of sheathing while the wood-framed house used structural sheathing. The sheathing for the wood-framed house also served as the baseboard for the stucco finish while the steel-framed house had a rigid insulation board applied over the steel that served as the base for the stucco. To provide the least common denominator for a cost and productivity comparison, only the structural framing members are summarized in this section. Appendix C gives the supporting calculations for the tables that follow.

Wall Framing

The unit rate for wall framing productivity was determined by dividing the time to build all the stick-framed walls by the horizontal length of the walls for each house. The time for the light-gauge steel house was derived from the total for the production time minus the time for shear plates and insulation (see Table A2.1). The conventional wood-framed house includes production time for both interior and exterior walls, deducting the time for sheathing and insulation (see Table A4.1). The 20 percent PF&D time was included in both houses. Table 9 gives the results.

Table 9
WALL FRAMING PRODUCTIVITY:
LIGHT-GAUGE STEEL VERSUS CONVENTIONAL WOOD

	Total Productive Man-Hours	Wall Length LF of 8' Wall	Unit Rate Man-hours per LF
Light-Gauge Steel-- framing members	118.67	448	0.26
Conventional Wood-- framing members	84.60	433	0.20

LF = linear foot

The wall framing productivity for the light-gauge steel house was 0.26 man-hours per linear foot of wall while the productivity for the conventionally framed house was 0.20 man-hours per linear foot of wall, or 30 percent higher than the conventional wood-framed house. Factors that contributed to a higher unit rate for the light-gauge steel included longer times to measure and snap lines and to fasten members together.

Roof Framing

The unit rate for roof framing productivity was determined by dividing the time to build the roof by the roof plan area for each house. The time for the light-gauge steel house reflects the total production time for the roof minus the time for insulation. Roof framing productivity for the wood-framed house was calculated the same way. (see Tables A2.1 and A4.1). Table 10 shows the results.

While the trusses were fabricated at the jobsite, the time to complete this fabrication was not included in the roof framing productivity. The costs associated with the fabrication of the trusses, however, were included in the roof framing unit costs in Table 12 (see Appendix B2, B2.1).

Table 10
ROOF FRAMING PRODUCTIVITY:
LIGHT-GAUGE STEEL VERSUS CONVENTIONAL WOOD

	Total Productive Man-Hours	Roof Area SF	Unit Rate Man-hours per SF
Light-Gauge Steel--trusses, in-fill and sheathing: 5:12 pitch, 90% gable, 10% hip	98.74	3,249	0.030
Conventional Wood--trusses, in-fill, sheathing, and blocking: 5:12 pitch, 60% gable, 40% hip	47.74	2,574	0.020

SF = square foot

The unit rate for productivity of the light-gauge steel roof was 0.030 man-hours per square foot compared to 0.020 man-hours per square foot for the conventional wood-framed roof. It took almost 50 percent more time to construct the roof in the light-gauge steel house than for the same square footage in the conventional house.

The hand-erected steel trusses required a longer time to make the necessary connections. The production support time (that includes the amount of time to obtain and carry materials and the time spent waiting for and helping another person to finish a task) was also greater for the steel house (see Table A2.3).

Cost Comparisons

Appendix B includes a detailed breakdown of costs to the builder (without builder overhead and profit) for all the demonstration houses. The material costs were based on actual costs incurred. The labor and equipment costs varied from jobsite to jobsite. To standardize these costs, national average rates published in *Means Residential Cost Data 1994*[10] were used. These rates were applied to the productivity values established in Tables 9 and 10 to develop labor and equipment costs for each house.

The cost data focuses on the comparable framing portions of the house. Nonproductive time and engineering costs were not included. It is important to note that comparisons were based on the raw data obtained for each house. The intent was not to draw specific conclusions for estimating purposes, but rather to see if the costs were close enough to those of conventional wood-framed houses to foster further consideration.

Table 11 compares light-gauge steel walls to conventional wood-framed walls and summarizes the unit costs for materials, labor, and equipment. Values are expressed in dollars per linear foot of an 8-foot-high wall.

[10]R. S. Means Company, Inc.

Table 11
WALL FRAMING UNIT COSTS:
LIGHT-GAUGE STEEL VERSUS CONVENTIONAL WOOD

	Material Costs[1] $/LF	Labor Costs $/LF	Equipment Costs $/LF	Total Costs $/LF
Light-Gauge Steel-- framing materials only	6.65	3.84	0.30	10.79
Conventional Wood-- framing materials only	6.82	2.87	0.44	10.13

[1]Lumber prices are based on October 1993 purchases (framing composite price for October 1993 = $393 per 1,000 BF)
LF = linear foot

The material costs for the light-gauge steel walls were 2 percent less than for the conventional wood walls, while the total costs for the light-gauge steel walls were 7 percent more than the walls in the conventional wood-framed house. Table 11 reflects the price of lumber at the time of construction in October 1993. In January 1994, the framing composite price for lumber was 22 percent higher. When comparing unit costs for new construction, a detailed estimate should be developed to check the current cost of materials.

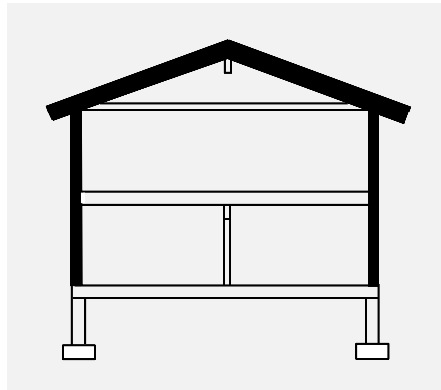
Table 12 compares the roof framing unit costs for the light-gauge steel and wood-framed houses. Values are expressed in dollars per square foot of roof area. The cost for constructing the roof was evaluated in the same way; Appendix B contains the background cost data for the demonstration houses. In the roof analysis, sheathing was included with the trusses. It took longer to fasten the sheathing to the trusses on the steel house. The steel trusses were fabricated at the jobsite before arrival of the research team. Thus, an estimated fabrication cost was based on time information provided at the jobsite (see Appendix B). As shown in the table, total roof framing costs for the light-gauge steel house were 36 percent higher than for conventional framing based on October 1993 lumber prices.

Table 12
ROOF FRAMING UNIT COSTS:
LIGHT GAUGE STEEL VERSUS CONVENTIONAL WOOD

	Material Costs[1] $/SF	Labor Costs $/SF	Equipment Costs $/SF	Total $/SF
Light Gauge Steel-- framing members, fabrication, and sheathing. 5:12 pitch, 90% gable, 10% hip	1.82	0.44	0.05	2.31
Conventional Wood-- framing members and sheathing: 5:12 pitch, 60% gable, 40% hip	1.32	0.29	0.09	1.70

[1]Lumber prices are based on October 1993 purchases (framing composite price for October 1993 = $393 per 1,000 BF)
SF = square foot

WELDED-WIRE SANDWICH PANELS



Welded-wire sandwich panels (WWSPs) are a unique approach to concrete construction that combines concrete and insulation into a single panel. WWSPs were initially patented in the United States in 1967 in Pasadena, California. Though developed in this country, the panels have been much more successful in penetrating foreign housing markets. In particular, the Far East, Middle East, and Caribbean countries that use concrete building products for residential construction have most readily adopted the WWSP technology. Until recently WWSPs were mostly used in the United States in such institutional and commercial construction as prisons, hotels, and schools. With the increase in lumber prices, however, WWSPs are attracting attention as a possible alternative in residential construction.

Today, two companies in the United States and 15 foreign companies manufacture WWSPs. Each manufacturer produces the panels in a different way that is distinguished by the steel wire gauge, the foam-core type, and the panel thickness. Each manufacturer also adheres to independent specifications and construction techniques.

WWSP structures can be built to resist high wind loads and also meet design requirements for Seismic Zone 4. The panels are termite-resistant while the double-shell configuration minimizes sound transmission. Shotcrete (concrete that is sprayed by injecting compressed air through a nozzle) makes the panels rigid and produces a monolithic structure without construction joints. The finished face can be a thin brick veneer, tile, sand texture (in several different styles), or a smooth trowel finish. U.S. manufacturers have received code evaluation reports from the Council of American Building Officials (CABO). Most building code officials, however, will likely require an engineered design.

Product Description

Welded-wire sandwich panels are composed of a three-dimensional welded-wire space frame with a polystyrene or polyurethane insulation core. The two layers of mesh are welded together with diagonal galvanized truss wires that penetrate through the foam layer (see Photo 13). The resulting structure behaves like a truss and provides rigidity and shear transfer for full composite behavior.

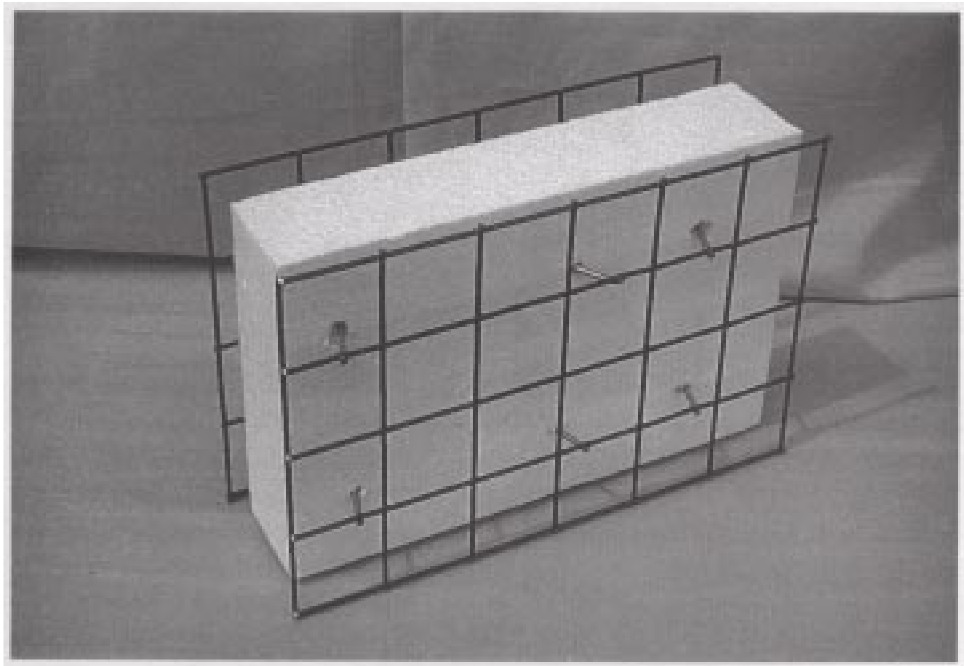


Photo 13. WELDED-WIRE SANDWICH PANEL

WWSPs are light in weight. Depending on panel use, the weight varies between 1 and 3½ pounds per square foot. A 4'x8' foot panel typically weighs less than 40 pounds and can be used for floors, load-bearing exterior or interior walls, partitions, or roofs.

A 4-inch core of expanded polystyrene covered by 2 inches of concrete on each side provides a thermal efficiency of R-18. Higher values up to R-33 may be attained by using polyurethane insulation. With 1-½ inches of concrete applied to both sides, each panel achieves a fire rating of 1-½ hours. A 2-inch application offers a 2-hour rating; a 3-1/8-inch application provides a 4-hour rating.

Demonstration Home

The welded-wire sandwich panel demonstration home was located in Brunswick, Georgia. Brunswick's normal maximum temperature is 92°F; its normal minimum temperature is 40°F. The average annual rainfall is 50 inches.

The demonstration home was designed and built by Insteel Construction Systems, Inc. (ICS), also located in Brunswick. ICS is a subsidiary of Insteel Industries, Inc., one of the nation's largest wire product manufacturers. ICS manufactures and markets welded-wire sandwich panels under the name Insteel 3-D Panel. ICS uses manufacturing equipment and a production process developed by Entwicklungs- und Verwertungs-Gesellschaft M.B.H. (EVG) of Raaba, Austria. The EVG equipment can produce a 4'x8' foot panel every 45 seconds with insulating cores ranging from 1-½ to 4 inches. Panels can be manufactured in various lengths for taller walls or roofs.

The standard Insteel 3-D Panel weighs about 1 psf and consists of two parallel sheets of 11- gauge, 2x2-inch welded-wire mesh connected by galvanized diagonal truss wires that pierce an insulating core of modified expanded polystyrene. The wall panels used on the Brunswick house consisted of 4 inches of modified expanded polystyrene insulation with 1-½ inches of concrete on each side for a total R-value of 19. The roof panels also had 4 inches of foam insulation, but polyurethane insulation was used with the same concrete dimensions to provide an R-value of 33.

NAHB Research Center staff observed the framing of the demonstration home from November 14 to December 20, 1993. The 1,925-square-foot house featured three bedrooms, two bathrooms, a breakfast room, and two-car garage. Figure 7 shows the floorplan (also see Photo 14). The living room, dining room, and kitchen all featured a cathedral ceiling. All exterior walls (including the garage), the two interior full-height load-bearing walls concealing the bedrooms, and the kitchen partition wall were made from Insteel 3-D Panels. A total of 360 linear feet of walls in the demonstration house were WWSPs.

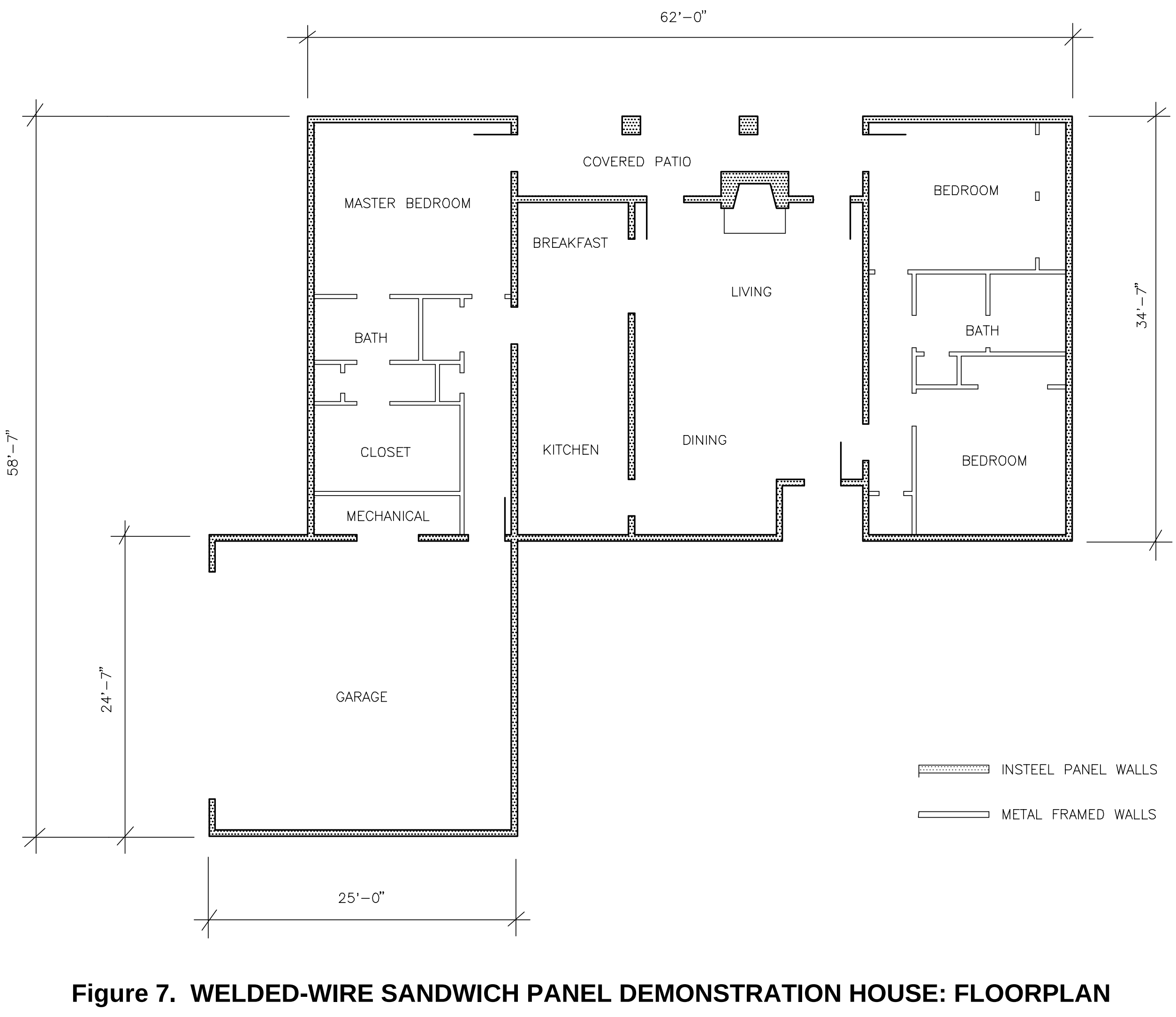


Figure 7. WELDED-WIRE SANDWICH PANEL DEMONSTRATION HOUSE: FLOORPLAN

Photo 14. WWSP DEMONSTRATION HOME

The interior bedroom walls at the bathrooms were framed with light-gauge steel. Beams and headers were made from panels spliced together with cover mesh. Block-outs for roof ventilation were provided to ventilate the attic space. The walls were treated with a textured sand finish after application of the finish coat of shotcrete.

The complex hip roof consisted of 3,265 square feet of Insteel 3-D Panels, including a 2-foot overhang. The roof finish was clay tile over the concrete.

The house was located on an attractive lot on a small lake. ICS was building the house as a demonstration home and at the time of this report had not set a sales price.

Tools and Equipment

Welded-wire sandwich panels require dramatically different tools and equipment than conventional wood framing. The panels were anchored to the floor slab with reinforcing bar, which was doweled into the floor slab. Holes for the bars were drilled using a concrete hammer drill.

While panels can be tied together by hand with tie wire, the preferred method of securing the panels is with the use of a pneumatic hog ring gun (see Photo 15). The hog ring gun requires an air compressor for operation but saves considerable time both in fastening panels to each other and tying the cover and corner mesh to the panels. The hog ring gun originated in the furniture industry.

Photo 15. PNEUMATIC HOG RING GUN

The panels were cut to size at the plant; however, when modifications or additional cuts were needed, a portable gas circular saw was used. Window and door openings required bolt cutters to cut the mesh and a small hand saw to cut the polystyrene.

The window and door framing was fastened using a pneumatic stapler to staple the wire mesh in the panels to 2x framing material. Top plates were fastened the same way. Propane torches and acetylene oxygen were used to melt the polystyrene to accommodate electrical conduit, plumbing, or reinforcement.

A concrete mixer and pump pumped the shotcrete to a special nozzle that mixed air and concrete to the proper consistency for application. A mason's broom was used to spread the "brown coat" (first layer) of shotcrete uniformly between the polystyrene and the mesh, and a small rake roughened the surface to provide a good bond with the finish coat. After the finish coat was applied, it was trowelled and worked with a mason's screed. Scrapers and shovels were used to clean the concrete overspray.

Installation

Once the slab was cast, wall panels were laid out and dowels epoxyed in place. The welded-wire sandwich panels were then positioned between the dowels. The panels were tied to the dowels and were freestanding without additional support (see Photo 16). Each successive panel was tied to the previous panel using the hog ring gun until all wall panels were in place. Cover mesh was tied over the joints between panels and at the panel corners. Doors and windows were measured, marked, and cut out of the panel sections. The walls were then braced with 2x4s and plumbed into position. The windows were installed and caulked in the framing (see Photos 17 and 18).

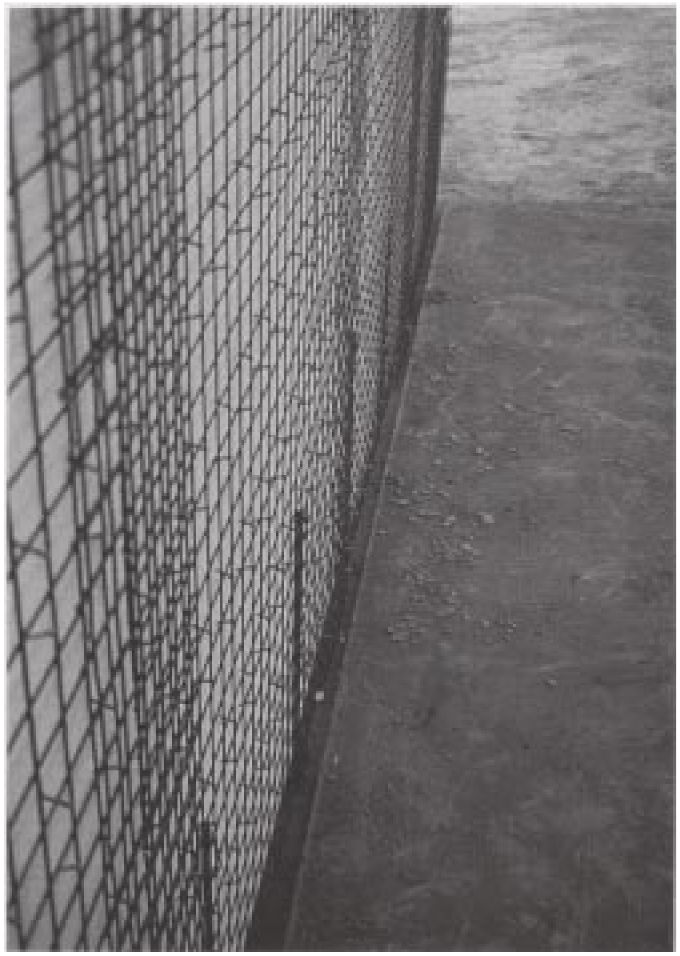


Photo 16. WWSPs TIED TO REBAR

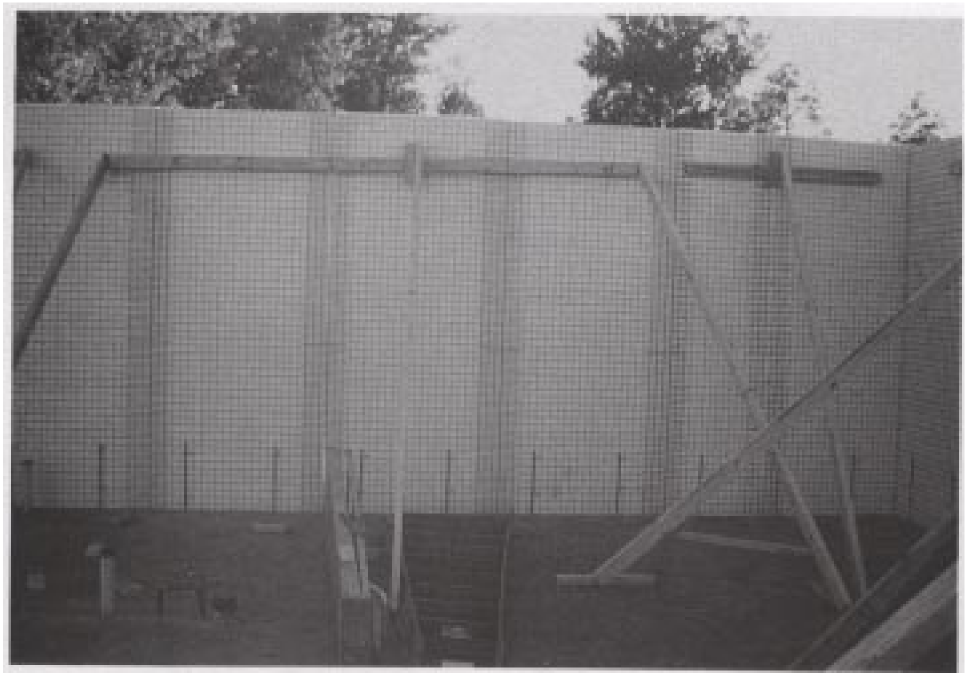


Photo 17. WWSP WALL BRACING

Photo 18. WWSP WINDOW FRAMING

The electricians and plumbers ran conduit and piping in the walls behind the mesh. To fit the conduit in the allowable space, the polystyrene was melted back with a blow torch by about ½ inch (see Photo 19). Electrical boxes were tied to the mesh and taped off to prevent their filling up with shotcrete. Ductwork for the kitchen hood exhaust fan was run through an interior wall panel and vented outside.

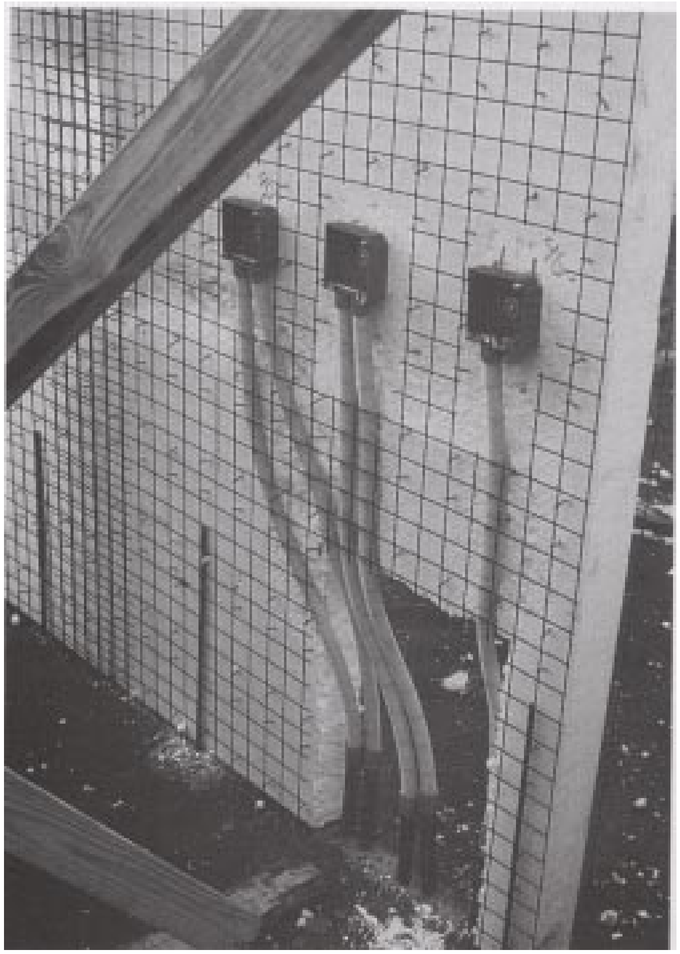


Photo 19. ELECTRICAL CONDUIT INSTALLED IN WWSP

A temporary ridge beam and parallel intermediate beams were constructed in each section of the house and garage. Given the weight of the wet concrete, the roof panels were temporarily supported by shoring posts, scaffolding, and 2x4s. With the shoring in place, the roof panels were lifted up by hand and tied in place (see Photo 20). Reinforcing bars were added to the ridge of the roof where the panels met as well as to the roof/wall connections. After routing back the foam, a fascia board was stapled to the end of the roof panels. The fascia was leveled and braced to provide a straight roof edge. Attic soffit vents — required only in the bedrooms where there were no cathedral ceilings — were made by cutting the mesh and polystyrene and inserting PVC pipe through the panels on 1-foot centers. Holes for roof fans and plumbing vents were cut and blocked out.

Wire and plastic screed material were fastened to the wall corners and the roof. The floor was cleaned and covered with sand to protect it from shotcrete overspray that could bond to the floor. Shoring posts and windows were protected with polyethylene wrap.

Photo 20. WWSP ROOF PANEL INSTALLATION

A mixing and pumping station was set up with pallets of cement, sand, and a supply of water all within easy reach of the concrete mixer. The concrete and air hoses were outfitted with a spray nozzle. A remote control switch was hooked up to the concrete pump. The concrete mixer and pump operator used a two-way radio to communicate with the switch operator. The shotcrete was prepared from a 6-bag mix.

The shotcrete operation moved quickly. After application of the brown coat, the crew broomed the surface even and raked it to create a rough surface. The roof was sprayed in one layer and screed finished. It then cured for seven days. When the crew returned, they removed the shoring and bracing from the interior and exterior of the house and tied string lines on the walls in preparation for the final coat of shotcrete. The final coat was applied in the same way as the brown coat (see Photo 21). The masons trowelled and screed the shotcrete into a smooth, level surface on the walls and ceiling and allowed it to cure overnight. A sand texture applied to the exterior walls gave the appearance of stucco.

Photo 21. SHOTCRETE APPLICATION: FINISH COAT

Observations

The following observations were noted during field operations:

- When precut panels are used, they must be cut properly. Some of the roof panels were not cut to the right size and had to be re-cut or replaced.

- The electricians made two visits to the jobsite. The first visit was to run the conduit behind the mesh before application of the shotcrete; the second visit was to pull the wire and install the fixtures.

- Plumbers need to bring their stub-ups into the panel walls specified for water or sewer connections. Most stub-ups were located in interior partition walls that were not made of panels. With some stub-ups located in panel walls, however, the plumber needed to return to the jobsite a second time to finish making connections.

- While panel erection requires little skill, the shotcrete operation requires a crew that is experienced with WWSPs. It is important to get the right mix consistency and strength to prevent the shotcrete from slumping down the walls and to help prevent shrinkage cracks.

- Shotcreting of the walls and ceilings went quickly but was delayed when the hoses were moved around the scaffolding on the interior and when the concrete pump broke down.

- The masons must have knowledge of concrete and be skilled in troweling and screeding concrete on vertical surfaces. Working with the screeds and string lines required some experience.

- Welded-wire sandwich roof panels, while easy to erect, are difficult to support. The panels alone cannot support the wet weight of the shotcrete. Consequently, the required shoring is an extra step that takes a long time to complete and delays the schedule. The roof required a seven-day period for curing. Perhaps, the schedule can be improved in production housing that makes use of a pre-engineered, reusable set of shoring materials.

Productivity Comparisons

The Group Timing Technique was used to compare the time required to build the walls and roof structure of both the welded-wire sandwich panel house and a conventional wood-framed home in the same region. Appendix D provides a description of the Georgia wood-framed house.

The activity of each crew member was recorded at one-minute intervals. Data were coded for each component of the building (walls, roof and fascia), subcomponent of the framing (dowels, panels, etc.) and task (fasten, measure, etc.). Nonproductive time such as breaks or idle time was separated from productive time. A standard 20 percent increase for personal, fatigue, and delay was added to the productive time. Tables A3.1 through A3.5 in Appendix A provide the results for the welded-wire sandwich panel house. Tables A5.1 through A5.5, also in Appendix A, provide the results for the wood-framed house.

The wall and roof components of the houses were used to compare the two technologies. For welded-wire sandwich panels, an equivalent component for the wood-framed house was used. Understanding that these are different technologies, care must be taken in evaluating these components because of differences in construction and to make sure that similar components of house framing are compared. For welded-wire sandwich panels, the structural framing, sheathing, insulation, and architectural finish are integral to the panel. In this comparison, the wood-framed house includes let-in bracing, insulation, and a stucco finish. To provide the least common denominator for a cost and productivity comparison, all the costs for the wood-framed house were included, although, insulation and exterior finish productivity was not monitored for the wood-framed house. An estimated time to complete the insulation, stucco, and brick work was added to the time for the wood-framed house to provide a better evaluation of the two systems (see Appendix B). Appendix C gives the supporting calculations for the tables that follow.

Wall Framing

The unit rate for wall framing productivity was determined by dividing the time to build the walls by the horizontal length of the walls for each house. The time for the welded-wire sandwich panels was derived from the total for the production time (see Table A3.1). The wood-framed house used all the production time subcomponents for the walls plus estimated man-hours for insulation and exterior wall finishes. The walls in the conventional house were 8 feet high while the welded-wire sandwich panels were 9 feet high. Eleven percent was deducted from the WWSP time to correct for the height difference. The 20 percent PF&D time was included in both houses. Table 13 gives the results.

Table 13
WALL FRAMING PRODUCTIVITY:
WELDED-WIRE SANDWICH PANELS VERSUS CONVENTIONAL WOOD

	Total Productive Man-Hours[1]	Wall Length LF of 8' Wall	Unit Rate Man-hours per LF of 8' Wall
Welded-Wire Sandwich Panels-- completed panels normalized for 8' wall	504.68	378	1.34
Conventional Wood-- framing members, insulation, bracing, stucco finish for 8' wall	190.00	237	0.80

[1]Includes estimated hours for conventionally framed house for insulation and exterior finishes (see Appendix B)
LF = linear foot

The wall framing productivity for the welded-wire sandwich panels was 1.34 man-hours per linear foot of wall while the productivity for the conventionally framed house was 0.80 man-hours per linear foot of wall. Productivity for the former was 68 percent higher than for the conventional wood-framed house.

The difference in production support time is perhaps most pronounced in the detailed summaries in Appendix A. A total of 15,330 minutes in support time elapsed for the panel system while only 554 minutes elapsed for the conventional house. The most significant production support time came from such tasks as mixing the shotcrete, obtaining and carrying materials, jobsite cleaning, erecting and dismantling scaffolding, working on the equipment, assisting other crew members with various tasks, and considerable time attributed to discussing business.

In this comparison, it is important to recognize the differences in the construction of the two homes. The conventional wood house was finished with a brick and vinyl siding. While this type of construction was typical of the area, it does not resemble the finish installed on the welded-wire sandwich panel house. Even if a stucco finished home had been selected as the best approximation of the finish, the strength of the wood-framed wall would not compare with the strength of the completed welded-wire sandwich panel wall. Future research should compare WWSPs with concrete masonry houses. For the walls, the major impact on cost was the labor. While it was easy to erect the panels, the shotcrete operation added considerable man-hours to the project.

Roof Framing

The unit rate for roof framing productivity was determined by dividing the time required to build the roof by the roof plan area for each house. The time for the welded-wire sandwich panels represents the total production time for the roof (see Table A3.1). The time for the wood-framed house was calculated by using the total for the production time plus an estimated time for the insulation (see Table A5.1 for time data and Appendix B for the costs). Table 14 gives the results.

Table 14
ROOF FRAMING PRODUCTIVITY:
WELDED-WIRE SANDWICH PANELS VERSUS CONVENTIONAL WOOD

	Total Productive Man--Hours	Roof Area SF	Unit Rate Man-hours per SF
Welded-Wire Sandwich Panels-- roof panels, shoring, reinforcing, attic vents, and shotcrete: 6:12 pitch, 32% gable, 68% hip	784.90	3,263	0.241
Conventional Wood-- trusses, in-fill, sheathing, and insulation: 9&10:12 pitch, 100% gable	72.47	2,551	0.028

SF = square foot

The unit rate for productivity of the welded-wire sandwich panel roof was 0.241 man-hours per square foot compared to 0.028 man-hours per square foot for the conventional wood-framed roof. Productivity for the WWSP roof was about eight times higher than for the conventional house.
A closer look at the breakdown of the tasks for the roof framing in Appendix A shows that several of the tasks associated with the welded-wire sandwich panel roof took considerable time. For example, 15 percent of the time to construct the roof is attributed to building the shoring, with another 56 percent dedicated to production support. Out of this production support time, 21 percent was dedicated to cleaning the jobsite, including removing the bracing material and shotcrete overspray. About 49 percent of the production support time was used to obtain and carry materials, help other crew members, adjust or repair equipment, and organize or plan for shoring and roof panel erection.

Cost Comparisons

Appendix B includes a detailed breakdown of costs to the builder (without overhead and profit) for all the demonstration houses. The material costs were based on actual costs incurred; the labor and equipment costs varied from one jobsite to the next. To standardize the costs, national average rates taken from *Means Residential Cost Data 1994*[11] were used. The rates were applied to the productivity values established in Tables 13 and 14 to develop labor and equipment costs for each house.

The cost data focus on the comparable framing portions of the house. Nonproduction time and engineering costs are not included. It is important to note that comparisons based on the raw data were obtained for each house. The intent was not to draw specific conclusions for future estimating purposes, but rather to see if the costs were close enough to those of conventional wood framing to foster further consideration.

[11] R. S. Means Company, Inc.

Table 15 compares welded-wire sandwich panel walls to conventional wood-framed walls and summarizes the unit costs for materials, labor, and equipment. Values are expressed in dollars per linear feet of an 8-foot-high wall.

Table 15
WALL FRAMING UNIT COSTS:
WELDED-WIRE SANDWICH PANELS VERSUS CONVENTIONAL WOOD

	Material Costs[1] $/LF	Labor Costs $/LF	Equipment Costs $/LF	Total $/LF
Welded-Wire Sandwich Panels-- wall panels, shotcrete, bracing, reinforcing, screed, scaffolding, and equipment (normalized to 8')	28.28	21.78	2.61	52.67
Conventional Wood-- framing, foamboard, insulation, siding, and brick (8' wall)	17.90	12.27	2.21	32.38

[1]Lumber prices are based on December 1993 purchases (framing composite price for December 1993 = $492 per 1000 BF)
LF = linear foot

The cost of welded wire sandwich panel walls for the demonstration house was about 63 percent higher than the cost of walls for the conventionally framed house based on the price of lumber at the time of construction in December 1993. The comparison includes the wall finishes for both houses. Note that the conventional house was finished with brick and vinyl siding.

The cost for constructing the roof was evaluated the same way; Appendix B contains the background information for the demonstration houses. Table 16 compares the unit costs for the roof framing. Values are expressed in dollars per square foot of roof area.

Table 16
ROOF FRAMING UNIT COSTS:
WELDED-WIRE SANDWICH PANELS VERSUS CONVENTIONAL WOOD

	Material Costs[1] $/SF	Labor Costs $/SF	Equipment Costs $/SF	Total $/SF
Welded-Wire Sandwich Panels-- roof panels, shoring, scaffolding, reinforcing, screed, attic vents, and shotcrete: 6:12 pitch, 32% gable, 68% hip	5.68	3.50	0.42	9.60
Conventional Wood-- trusses, in-fill, sheathing and insulation: 9&10:12 pitch, 100% gable	1.44	0.41	0.07	1.92

[1]Lumber prices are based on December 1993 purchases (framing composite price for December 1993 = $492 per 1000 BF)
SF = square foot

Total roof framing costs for the welded-wire sandwich panels were about five times higher than total costs for conventional framing based on December 1993 lumber prices. The cost differential was largely attributable to the intensity of labor dedicated to shoring the roof.

CONCLUSIONS AND RECOMMENDATIONS

The intent of this study was to determine how three alternative framing materials compare with conventional wood framing in residential construction. Results indicate that certain aspects of light-gauge steel are within the range that might be expected to be cost-effective when compared with wood. Foam-core panels and welded-wire sandwich panels offer some thermal and structural advantages but do not appear to be cost-competitive with wood at this time.

FOAM-CORE PANELS

Foam-core panel framing offers a composite panel construction that is easy to erect and can provide large spans and cathedral ceilings. R-values up to 8.7 per inch of foam can be attained depending on the type of foam used in the panel.

Wall Framing

The material costs of foam-core panels are the most significant factor contributing to the systems high cost compared with conventional wood framing. If the material costs could be lowered, foam-core panels would be in a better position to compete because of their time savings; it took 13 percent less time to build the composite exterior wall framing than to complete an equivalent frame for the conventional house. Productivity of the foam-core sites would have improved if the time to obtain materials were reduced, more attention were devoted to providing a level slab to build on, and full-height wall sections were used on the gable ends. The labor cost savings was offset by the extra cost of materials, resulting in overall costs for the foam-core panel walls 2 times higher than for the conventionally framed walls.

Roof Framing

While it took less time to construct the foam-core panel walls, it took 50 percent more time to construct the roof in the foam-core panel house than for the same square footage in the conventional house. The production support time was much higher in this type of construction, contributing to a tripling of total costs to install these panels for roofing. The total cost difference was $3.18 per square foot of roofing.

LIGHT-GAUGE STEEL FRAMING

Wall Framing

The light-gauge steel framed house compared favorably with the conventional wood-framed home in wall construction. It took 30 percent more time to construct the wall framing in the steel demonstration home. While the cost of the steel material was 2 percent less than the cost of the wood, the overall steel framing costs were 7 percent higher. Labor costs accounted for the higher cost of the steel framed house. The time to build the wall sections could be reduced if fastening times could be reduced. Prescriptive methods for building light-gauge steel houses need to be developed so that the extra engineering costs associated with steel framing may be eliminated.

Roof Framing

In the demonstration home, steel roof framing did not compare well with conventional manufactured wood trusses. It took 50 percent longer to frame and sheath a roof in the steel house. Both labor and material cost contributed to the higher overall cost of the roof framing resulting in a 36 percent higher cost than for the wood-framed house.

WELDED-WIRE SANDWICH PANELS

The welded-wire sandwich panel house is a new approach to home construction. WWSPs may be desired for upscale housing, coastal structures, or buildings in Seismic Zone 4; however, for affordable wood-framed housing, the cost of WWSPs is too high at this time.

Wall Framing

Based on the demonstration home observed in this study, some refinement of the WWSP construction methods or further increases in the price of lumber are necessary before this technology can compete in the wood-framed housing market. Welded-wire sandwich panel walls took 68 percent more time to build and were 63 percent more expensive than the walls in the wood-framed home. This type of construction offers better potential for upscale housing or coastal structures that need to resist high wind loads.

Roof Framing

The welded-wire sandwich panel roof framing product was the most expensive component. It took eight times longer to build than the wood-framed house and was five times more expensive. Shoring techniques need to be improved to cut down on the construction time for the roof panels. The total cost difference was $7.68 per square foot of roofing.

CONCLUSIONS

Table 17 summarizes the unit costs for the wall framing for all three alternative framing materials. The total costs of the light-gauge steel walls are shown to be the most cost-effective when compared with the baseline conventional wood house.

Table 17
SUMMARY OF WALL FRAMING UNIT COSTS

FOAM-CORE PANELS	Material Costs[1] $/LF	Labor Costs $/LF	Equipment Costs $/LF	Total Costs $/LF
Foam-Core Panel--wall panels, plates and posts	26.17	3.26	0.70	30.13
Conventional Wood--framing, sheathing, and insulation for exterior walls	9.80	3.45	0.53	13.78
LIGHT-GAUGE STEEL	**Material Costs[2] $/LF**	**Labor Costs $/LF**	**Equipment Costs $/LF**	**Total Costs $/LF**
Light-Gauge Steel--framing materials only	6.65	3.84	0.30	10.79
Conventional Wood--framing materials only	6.82	2.87	0.44	10.13
WELDED-WIRE SANDWICH PANELS	**Material Costs[3] $/LF**	**Labor Costs $/LF**	**Equipment Costs $/LF**	**Total Costs $/LF**
Welded-Wire Sandwich Panels--wall panels, shotcrete, bracing, reinforcing, screed, scaffolding, and equipment (normalized to 8')	28.28	21.78	2.61	52.67
Conventional Wood--framing, foamboard, insulation, siding, and brick (8' wall) for exterior walls	17.90	12.27	2.21	32.38

[1] Lumber prices are based on August 1993 purchases (framing composite price for August 1993 = $348 per 1,000 BF)
[2] Lumber prices are based on October 1993 purchases (framing composite price for October 1993 = $393 per 1,000 BF)
[3] Lumber prices are based on December 1993 purchases (framing composite price for December 1993 = $492 per 1,000 BF
LF = linear foot

None of the alternative framing materials were cost-competitive with conventional wood in the baseline houses for roof framing. Table 18 summarizes the unit costs for the roof framing. The manufactured roof trusses in the baseline houses studied were more cost-effective in both labor and material costs. If a builder is considering to use an alternative framing material for the wall construction, it would be advisable at the present time to use the alternative material up to the top plate, and build the roof framing out of conventional wood trusses.

Table 18
SUMMARY OF ROOF FRAMING UNIT COSTS

FOAM-CORE PANELS	Material Costs[1] $/SF	Labor Costs $/SF	Equipment Costs $/SF	Total Costs $/SF
Foam-Core Panels--roof panels and beams: 4¼:12 pitch, 100% gable	4.07	0.47	0.29	4.83
Conventional Wood--trusses, fill, sheathing and insulation: 5:12 pitch, 60% gable, 40% hip	1.27	0.29	0.09	1.65
LIGHT-GAUGE STEEL	**Material Costs[2] $/SF**	**Labor Costs $/SF**	**Equipment Costs $/SF**	**Total Costs $/SF**
Light-Gauge Steel--framing members, fabrication, and sheathing. 5:12 pitch, 90% gable, 10% hip	1.82	0.44	0.05	2.31
Conventional Wood--framing members and sheathing: 5:12 pitch, 60% gable, 40% hip	1.32	0.29	0.09	1.70
WELDED-WIRE SANDWICH PANELS	**Material Costs[3] $/SF**	**Labor Costs $/SF**	**Equipment Costs $/SF**	**Total Costs $/SF**
Welded-Wire Sandwich Panels--roof panels, shoring, scaffolding, reinforcing, screed, attic vents, and shotcrete: 6:12 pitch, 32% gable, 68% hip	5.68	3.50	0.42	9.60
Conventional Wood-- trusses, in-fill, sheathing and insulation: 9&10:12 pitch, 100% gable	1.44	0.41	0.07	1.92

[1] Lumber prices are based on August 1993 purchases (framing composite price for August 1993 = $348 per 1,000 BF)
[2] Lumber prices are based on October 1993 purchases (framing composite price for October 1993 = $393 per 1,000 BF)
[3] Lumber prices are based on December 1993 purchases (framing composite price for December 1993 = $492 per 1,000 BF
SF = square foot

ENGINEERING COSTS

As with all new materials, the alternatives in this study will likely require an engineered design to obtain approval from local building officials. The model building codes do not address prescriptive methods for these materials at this time. Engineering costs vary depending on who provides the services. These costs were not included in the cost summaries for each alternative material in this report.

For foam-core panels, the roof panel spans and ridge beams will need to be engineered. The walls are straightforward and test results are usually available from the manufacturer for the rated wind and axial loads.

All load bearing light-gauge steel members will need to be designed by an engineer. Manufacturers and design professionals currently charge rates between $0.75 to 1.50 per square-foot of living area depending on the complexity of the house.

Similar to the foam-core panels, WWSP walls are rated for specific wind and axial loads and information is available from the manufacturers. WWSP roofs, however, do require engineering design for the panel spans, concrete reinforcement, and shoring requirements to support the wet concrete roof before curing.

RECOMMENDATIONS

It is important to recognize that the comparisons made in this study are directly related to the unique characteristics of the demonstration homes. The results of this study should not be extrapolated for widespread use without a careful feasibility study. While light-gauge steel framing may be cost-effective in one area of the country, it may not compare as favorably in another region. Foam-core panels and WWSPs were not found to be cost-effective at this time although some benefits of foam-core panels and WWSPs may make them desirable in other locations.

Switching completely to an alternative material may not be a solution to the lumber problem. In fact, the results showed that certain components of an alternative may be competitive with wood even though the entire system is not. The use of one of these alternatives for integration into a wood-framed home may be more practical at this time. For instance, light-gauge steel framed walls may be used with wood roof trusses. Non-load bearing interior studs may be framed using light-gauge steel, while the load bearing members may be framed out of wood.

Additional observations regarding the alternative framing materials include the need to improve supplier response time to builders and the need to provide prescriptive specifications to reduce the reliance on engineers to approve house plans.

With the continuing volatility of lumber prices, further research is needed in the area of alternative framing materials in residential construction. Some of these needs are

- working with material manufacturers to improve productivity at the jobsite;

- continuing to demonstrate alternative materials and establishing a database for labor productivity and cost information on a national scale;

- working on gaining alternative material acceptance at the national level through adoption by the model building code bodies;

- reducing engineering costs by standardizing materials and providing design tables and span charts for builders and code officials;

- finding ways to integrate cost-effective alternative materials into conventional wood-framed construction; and

- translating local availability of a manufacturing plant or process into a national system to provide widespread distribution of material.

APPENDIX A
TIME AND MOTION STUDY DATA

Appendix A contains the results of the time and motion study performed on all of the demonstration and baseline houses. Tables A1.1 through A1.5 summarize the results for the foam-core panel house. Tables A2.1 through A2.5 summarize the results for the light-gauge steel house, etc.

Detailed field observations were made using the Group-Timing Technique that allowed the observers to perform a time analysis for all of the houses studied in this report. The one-minute observations were recorded as tallies and later summarized into the tables found in this appendix. The categories that were used for data collection are listed below.

TIME AND MOTION STUDY CATEGORIES FOR DATA COLLECTION

COMPONENTS

- Wall--stick-frame
- Wall--panel
- Floor
- Roof--stick-frame
- Roof--truss
- Roof--panel
- Fascia
- Plumbing
- Electrical

SUBCOMPONENTS

- Layout
- Sill plate
- Dowels
- Rebar
- Wall stud
- Posts
- Shear plates
- Sheathing
- Top plate
- Screed/corner bead
- Blocking
- Doors/windows
- Insulation
- Panel
- Gable panel
- Joists
- Rim joist
- Ridge beam
- Rafters
- Trusses
- Nail strip/base
- Chamfer strip
- Ledger
- Eave/rake end
- Attic vents
- Route foam
- Fascia backer
- Headers
- Shoring/bracing
- Production--support
- Nonproduction
- Plumbing/HVAC
- Electrical

TASKS

- Layout
- Measure
- Cut
- Cut/extend tails
- Melt polyethylene
- Position
- Remove
- Stand wall
- Fasten
- Cover/protect
- Sill sealer
- Bond agent
- Drill
- Mark
- Brace
- Caulk
- Spray shotcrete
- Brush/rake
- Trowel/screed
- Finish/rub
- Spray texture
- Finish texture
- Mix texture
- Mix shotcrete
- Move hose
- Route foam
- Obtain tools/equipment
- Read plans
- Talk business
- Obtain/carry materials
- Organize material
- Jobsite cleaning
- Wait mate
- Build/take down scaffold
- Help mate
- Adjust/repair equipment
- Man hose
- Idle
- Rework
- Delay
- Lunch/break
- Personal
- Untangle extension cords
- Control switch
- Snap lines

Time was separated into production support and non-production support categories. The non-production support time was set aside from the total, leaving a normal time, (a time that a competent, trained worker should be able to match without extreme effort.) A residential construction allowance of 20 percent was applied for personal, fatigue, and delays (PFD). When applied to normal time, the result is standard time. This provided a uniform allowance for breaks, personal hygiene job interruptions, delays caused by the process, etc.

TABLE A1.1
FOAM-CORE PANEL TIME DATA:
SUMMARY FOR WALL, ROOF, AND FASCIA PRODUCTION TIME BY COMPONENT
MAN-MINUTES

Subcomponent	Component			
	Exterior Wall-Panel	Roof-Panel	Fascia	Total
Layout	17	25		42
Sill Plate	159			159
Posts	186			186
Top Plate	108			108
Blocking	4			4
Panel	810	1,577		2,387
Gable Panel	341			341
Ridge Beam		141		141
Ledger		16		16
Eave/Rake End		90		90
Route Foam			19	19
Fascia Board			431	431
Production Support	697	1,666	97	2,460
Total	2,322	3,515	547	6,384
Total w/PF&D (20%)	2,786	4,218	656	7,661

TABLE A1.2
FOAM-CORE PANEL TIME DATA:
SUMMARY OF WALLS, ROOF, AND FASCIA BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent														
	Layout	Sill Plate	Posts	Top Plate	Blocking	Panel	Gable Panel	Ridge Beam	Ledger	Eave/ Rake End	Route Foam	Fascia Backer	Prod. Support	Non-Prod.	Total
Layout	42														42
Measure		9		21		129	19	17		12		67			274
Cut		14	49		4	281	19	8	1	78		73			527
Position		117	128	6		1,026	181	55	7			41			1,561
Fasten			9	81		872	119	42	8			250			1,381
Sill Sealer		19													19
Drill						76	3	6							85
Brace						3		13							16
Route Foam											19				19
Read Plans													77		77
Talk Business													367		367
Obt. Materials													1,330		1,330
Org. Material													128		128
Job Cleaning													245		245
Wait Mate													94		94
Build Scaffold													219		219
Idle														297	297
Rework														296	296
Delay														281	281
Lunch/Break														757	757
Personal														3	3
Total	42	159	186	108	4	2,387	341	141	16	90	19	431	2,460	1,634	8,018

TABLE A1.3
FOAM-CORE PANEL TIME DATA:
SUMMARY OF WALL PANELS BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent									
	Layout	Sill Plate	Posts	Top Plate	Blocking	Panel	Gable Panel	Prod. Support	Non-Prod.	Total
Layout	17									17
Measure		9		21		74	19			123
Cut		14	49		4	83	19			169
Position		117	128	6		367	181			799
Fasten			9	81		283	119			492
Sill Sealer		19								19
Drill							3			3
Brace						3				3
Read Plans								32		32
Talk Business								72		72
Obtain Materials								503		503
Org. Materials								40		40
Job Site Cleaning								47		47
Wait Mate								3		3
Idle									56	56
Rework									97	97
Delay									224	224
Lunch/Break									251	251
Total	17	159	186	108	4	810	341	697	628	2,950

TABLE A1.4
FOAM-CORE PANEL TIME DATA:
SUMMARY OF ROOF PANELS BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent							
	Layout	Panel	Ridge Beam	Ledger	Eave-Rake End	Production Support	Non-Product.	Total
Layout	25							25
Measure		55	17		12			84
Cut		198	8	1	78			285
Position		659	55	7				721
Fasten		589	42	8				639
Drill		76	6					82
Brace			13					13
Read Plans						45		45
Talk Business						290		290
Obtain/Carry Materials						750		750
Organize Materials						85		85
Jobsite Cleaning						196		196
Wait Mate						81		81
Build/Take Down Scaffold						219		219
Idle							179	179
Rework							189	189
Delay							57	57
Lunch/Break							332	332
Total	25	1,577	141	16	90	1,666	757	4,272

TABLE A1.5
FOAM-CORE PANEL TIME DATA:
SUMMARY OF FASCIA BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent				
	Route Foam	Fascia Backer	Production Support	Non-Production	Total
Measure		67			67
Cut		73			73
Position		41			41
Fasten		250			250
Route Foam	19				19
Talk Business			5		5
Obtain/Carry Materials			77		77
Organize Materials			3		3
Jobsite Cleaning			2		2
Wait Mate			10		10
Idle				62	62
Rework				10	10
Lunch/Break				174	174
Personal				3	3
Total	19	431	97	249	796

TABLE A2.1
LIGHT-GAUGE STEEL TIME DATA:
SUMMARY OF WALLS, ROOF, AND FASCIA PRODUCTION TIME BY COMPONENT
MAN-MINUTES

Subcomponent	Component			
	Walls	Roof Trusses	Fascia	Total
Layout	450			450
Sill Plate	434			434
Wall Stud	3,186			3,186
Shear Plates	47			47
Sheathing		1,034		1,034
Top Plate	94			94
Headers	739			739
Insulation	246	184		430
Rafters/Trusses		1,461		1,461
Nail Strip/Base		149		149
Fascia Board			175	175
Production Support	1,030	2,293	119	3,442
Total	6,226	5,121	294	11,641
Total w/ PF&D (20%)	7,471	6,145	353	13,969

TABLE A2.2
LIGHT-GAUGE STEEL TIME DATA:
SUMMARY OF WALLS, ROOF, AND FASCIA BY SUBCOMPONENT
MAN-MINUTES

Tasks	Subcomponent													
	Layout	Sill Plate	Wall Studs	Shear Plates	Sheath -ing	Top Plate	Head- ers	Insula- tion	Truss	Nail Strip	Fascia Backer	Prod. Support	Non- Product.	Total
Layout	240													240
Snap Lines	210													210
Measure		62	73		56	48	195		71	4	12			521
Cut		116	52	5	55	41	202	70	27	34	10			612
Position		32	1,145	16	11		67	360	542	12	32			2,217
Fasten		224	1,799	26	912	5	275		677	99	121			4,138
Brace			117						144					261
Read Plans												31		31
Talk Business												129		129
Obtain Materials												1,562		1,562
Organize Material												31		31
Jobsite Cleaning												86		86
Wait Mate												966		966
Build Scaffold												10		10
Help Mate												590		590
Adjust Equipment												37		37
Untangle Cords													10	10
Idle													1,227	1,227
Rework													38	38
Lunch/Break													1,610	1,610
Personal													219	219
Total	450	434	3,186	47	1,034	94	739	430	1,461	149	175	3,442	3,104	14,745

TABLE A2.3
LIGHT-GAUGE STEEL TIME DATA:
SUMMARY OF WALLS BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent									
	Layout	Sill Plate	Wall Studs	Shear Plates	Top Plate	Headers	Insulation	Product. Support	Non-Product.	Total
Layout	240									240
Measure		62	73		48	195				378
Snap Lines	210									210
Cut		116	52	5	41	202	40			456
Position		32	1,145	16		67	206			1,466
Fasten		224	1,799	26	5	275				2,329
Brace			117							117
Read Plans								31		31
Talk Business								75		75
Obtain Materials								690		690
Organize Material								16		16
Jobsite Cleaning								45		45
Wait Mate								36		36
Help Mate								100		100
Adjust Equipment								37		37
Untangle Cords									10	10
Idle									324	324
Rework									1	1
Lunch/Break									778	778
Personal									123	123
Total	450	434	3,186	47	94	739	246	1,030	1,236	7,462

TABLE A2.4
LIGHT-GAUGE STEEL TIME DATA:
SUMMARY OF ROOF BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent						
	Sheathing	Insulation	Trusses	Nail Strip/Base	Production-support	Non-Production	Total
Measure	56		71	4			131
Cut	55	30	27	34			146
Position	11	154	542	12			719
Fasten	912		677	99			1,688
Brace			144				144
Talk Business					53		53
Obtain Materials					849		849
Organize Materials					15		15
Jobsite Cleaning					41		41
Wait Mate					930		930
Build Scaffold					10		10
Help Mate					395		395
Idle						903	903
Rework						26	26
Lunch/Break						832	832
Personal						94	94
Total	1,034	184	1,461	149	2,293	1,855	6,976

TABLE A2.5
LIGHT-GAUGE STEEL TIME DATA:
SUMMARY OF FASCIA BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent			
	Fascia Backer	Production Support	Non-Production	Total
Measure	12			12
Cut	10			10
Position	32			32
Fasten	121			121
Talk Business		1		1
Obtain Materials		23		23
Help Mate		95		95
Rework			11	11
Personal			2	2
Total	175	119	13	307

TABLE A3.1
WELDED-WIRE SANDWICH PANEL TIME DATA:
SUMMARY FOR WALLS, ROOF, AND FASCIA PRODUCTION TIME BY COMPONENT
MAN-MINUTES

Subcomponent	Component			
	Wall Panel	Roof Panel	Fascia	Total
Layout	98			98
Dowels	131			131
Rebar	281	1,394		1,675
Top Plate	134			134
Screed/Corner Bead	1,971	740		2,711
Shoring/Bracing	527	5,790	183	6,500
Panel	9,916	8,195	594	18,705
Attic Vents		960		960
Fascia Backer			1,726	1,726
Production Support	15,330	22,166	1,112	38,608
Total	28,388	39,245	3,615	71,248
Total w/ PF&D (20%)	34,066	47,094	4,338	85,498
Other Prod Subcomponents				
Plumbing/HVAC	416	97		513
Doors/Windows	2,705			2,705

TABLE A3.2
WELDED-WIRE SANDWICH PANEL TIME DATA:
SUMMARY OF WALLS, ROOF, AND FASCIA BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent													
	Layout	Dowels	Rebar	Top Plate	Screed/ Corner Bead	Shoring Bracing	Doors/ Wind's	Panel	Attic Vents	Fascia Backer	Plumb./ HVAC	Prod. Sup-port	Non-Prod-uction	Total
Layout	98													98
Measure			42			318	395	267		329	51			1,402
Cut			112	3	1	436	623	2,018	445	94	102			3,834
Melt Polyethylene							197	358	51		100			706
Position		16	880	71	2,279	2,446	632	2,537	424	925	246			10,456
Remove						2,329								2,329
Fasten			391		431	843	370	5,065	34	378	14			7,526
Cover/Protect						128	205							333
Bond Agent								63						63
Drill		115		60					6					181
Route Foam			250											250
Caulk							283							283
Spray Shotcrete								1,269						1,269
Brush/Rake								187						187
Trowel/Screed								5,388						5,388
Finish/Rub								358						358
Finish Texture								1,195						1,195
Mix Texture												1,050		1,050
Mix Shotcrete												3,696		3,696
Move Hose												526		526
Obtain Tool/Equip												1,218		1,218
Read Plans												386		386
Talk Business												7,362		7,362
Obtain Materials												3,314		3,314
Organize Material												71		71
Jobsite Cleaning												6,207		6,207
Wait Mate												2,502		2,502
Scaffold												2,189		2,189
Help Mate												3,904		3,904
Adjust Equipment												3,790		3,790
Man Hose												1,325		1,325
Control Switch												1,068		1,068
Untangle Cords													2	2
Idle													8,664	8,664
Rework													318	318
Delay													184	184
Lunch/Break													9,021	9,021
Personal													588	588
Total	98	131	1,675	134	2,711	6,500	2,705	18,705	960	1,726	513	38,608	18,777	93,243

TABLE A3.3
WELDED-WIRE SANDWICH PANEL TIME DATA: SUMMARY OF WALL PANELS BY SUBCOMPONENT

MAN-MINUTES

Task	Subcomponent											
	Layout	Dowels	Rebar	Top Plate	Screed/ Corner Bead	Shoring/ Bracing	Doors/ Wind's	Panel	Plumb./ HVAC	Prod-uction Support	Non-Prod-uction	Total
Layout	98											98
Measure			22			12	395	235	51			715
Cut			46	3	1	50	623	603	5			1,331
Melt Polyethylene							197	119	100			416
Position		16	161	71	1,864	129	632	1,149	246			4,268
Fasten			52		106	336	370	2,514	14			3,392
Cover/Protect							205					205
Drill		115		60								175
Caulk							283					283
Spray Shotcrete								649				649
Brush/Rake								187				187
Trowel/Screed								3,083				3,083
Finish/Rub								182				182
Finish Texture								1,195				1,195
Mix Texture										1,050		1,050
Mix Shotcrete										1,925		1,925
Move Hose										254		254
Obtain Tools/Equip.										749		749
Read Plans										64		64
Talk Business										2,792		2,792
Obtain Materials										1,025		1,025
Organize Materials										13		13
Jobsite Cleaning										1,592		1,592
Wait Mate										784		784
Build Scaffold										888		888
Help Mate										1,233		1,233
Adjust Equipment										1,607		1,607
Man Hose										761		761
Control Switch										593		593
Untangle Cords											2	2
Idle											3,197	3,197
Rework											151	151
Delay											80	80
Lunch/Break											3,645	3,645
Personal											233	233
Total	98	131	281	134	1,971	527	2,705	9,916	416	15,330	7,308	38,817

TABLE A3.4
WELDED-WIRE SANDWICH PANEL TIME DATA: SUMMARY OF ROOF PANELS BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent								
	Rebar	Screed/ Corner Bead	Shoring/ Bracing	Panel	Attic Vents	Plumbing /HVAC	Production Support	Non-Production	Total
Measure	20		306	32					358
Cut	66		386	821	445	9			1,815
Melt Polyethylene				239	51				290
Position	719	415	2,134	1,388	424				5,080
Remove			2,329						2,329
Fasten	339	325	507	2,551	34				3,756
Cover/Protect			128						128
Bond Agent				63					63
Drill					6				6
Route Foam	250								250
Spray Shotcrete				620					620
Trowel/Screed				2,305					2,305
Finish/Rub				176					176
Mix Shotcrete							1,771		1,771
Move Hose							272		272
Obtain Tools/Equip.							372		372
Read Plans							322		322
Talk Business							4,149		4,149
Obtain/Carry Materials							2,215		2,215
Organize Materials							58		58
Jobsite Cleaning							4,598		4,598
Wait Mate							1,628		1,628
Scaffold							1,282		1,282
Help Mate							2,304		2,304
Adjust/Repair Equip.							2,156		2,156
Man Hose							564		564
Control Switch							475		475
Idle								5,200	5,200
Rework								112	112
Delay								104	104
Lunch/Break								4,946	4,946
Personal								327	327
Total	1,394	740	5,790	8,195	960	97	22,166	10,689	50,031

TABLE A3.5
WELDED-WIRE SANDWICH PANEL TIME DATA:
SUMMARY OF FASCIA BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent					
	Shoring/ Bracing	Panel	Fascia Backer	Production Support	Non-Product.	Total
Measure			329			329
Cut		594	94			688
Position	183		925			1,108
Fasten			378			378
Obtain Tools/Equipment				97		97
Talk Business				421		421
Obtain/Carry Materials				74		74
Jobsite Cleaning				17		17
Wait Mate				90		90
Build/Take Down Scaffold				19		19
Help Mate				367		367
Adjust/Repair Equipment				27		27
Idle					267	267
Rework					55	55
Lunch/Break					430	430
Personal					28	28
Total	183	594	1,726	1,112	780	4,395

TABLE A4.1
CALIFORNIA WOOD-FRAME TIME DATA:
SUMMARY OF WALLS, ROOF, AND FASCIA PRODUCTION TIME BY COMPONENT
MAN-MINUTES

Subcomponent	Component				
	Exterior Wall Stick	Interior Wall Stick	Roof Trusses	Fascia	Total
Layout	152	174	38		364
Sill Plate	204	114			318
Wall Stud	458	1,103			1,561
Sheathing	1,271		1,100		2,371
Top Plate	79	131			210
Headers	109	17			126
Blocking	165	278	489		932
Insulation	120		130		250
Trusses			406		406
Fascia Board				241	241
Production Support	610	636	354	38	1,638
Total	3,168	2,453	2,517	279	8,417
Total w/ PF&D (20%)	3,802	2,944	3,020	335	10,100

TABLE A4.2
CALIFORNIA WOOD-FRAME TIME DATA:
SUMMARY OF WALLS, ROOF, AND FASCIA BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent												
	Layout	Sill Plate	Wall Stud	Sheath-ing	Top Plate	Headers	Blocking	Insula-tion	Trusses	Fascia Backer	Product. Support	Non-Product.	Total
Layout	191												191
Snap Lines	77												77
Measure			42		11		64		8				125
Cut		65	63		107	32	385			85			737
Cut Tails									42				42
Position		43	146	2,371	3	21		250	127				2,961
Stand Wall			389										389
Fasten		24	712		89	73	483		221	156			1,758
Sill Sealer		24							8				32
Drill		38											38
Mark	96	124											220
Brace			209										209
Read Plans											37		37
Talk Business											151		151
Obtain Materials											749		749
Organize Material											223		223
Jobsite Cleaning											229		229
Wait Mate											249		249
Idle												396	396
Rework												144	144
Delay												7	7
Lunch/Break												1,088	1,088
Personal												128	128
Total	364	318	1,561	2,371	210	126	932	250	406	241	1,638	1,763	10,180

TABLE A4.3
CALIFORNIA WOOD-FRAME TIME DATA:
SUMMARY OF EXTERIOR WALLS BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent										
	Layout	Sill Plate	Wall Stud	Sheath-ing	Top Plate	Headers	Blocking	Insulation	Product. Support	Non-Product.	Total
Layout	74										74
Snap Lines	35										35
Measure			3		11						14
Cut		40	30		38	16	80				204
Position		26	44	1,271	2	21		120			1,484
Stand Wall			54								54
Fasten		17	207		28	72	85				409
Sill Sealer		24									24
Drill		23									23
Mark	43	74									117
Brace			120								120
Read Plans									31		31
Talk Business									62		62
Obtain/Carry Materials									153		153
Organize Material									194		194
Jobsite Cleaning									105		105
Wait Mate									65		65
Idle										137	137
Rework										50	50
Delay										7	7
Lunch/Break										381	381
Personal										63	63
Total	152	204	458	1,271	79	109	165	120	610	638	3,806

TABLE A4.4
CALIFORNIA WOOD-FRAME TIME DATA:
SUMMARY OF INTERIOR WALLS BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent								
	Layout	Sill Plate	Wall Stud	Top Plate	Headers	Blocking	Production Support	Non-Product.	Total
Layout	117								117
Snap Lines	28								28
Measure			39						39
Cut		25	33	69	16	204			347
Position		17	102	1					120
Stand Wall			335						335
Fasten		7	505	61	1	74			648
Drill		15							15
Mark	29	50							79
Brace			89						89
Read Plans							6		6
Talk Business							32		32
Obtain/Carry Materials							409		409
Organize Materials							14		14
Jobsite Cleaning							95		95
Wait Mate							80		80
Idle								120	120
Rework								94	94
Lunch/Break								236	236
Personal								41	41
Total	174	114	1,103	131	17	278	636	491	2,944

TABLE A4.5
CALIFORNIA WOOD-FRAME TIME DATA: SUMMARY OF ROOF BY SUBCOMPONENT
MAN-MINUTES

Tasks	Subcomponents							
	Layout	Sheathing	Blocking	Insulation	Trusses	Production-Support	Non-Production	Total
Measure			64		8			72
Snap Lines	14							14
Cut			101					101
Cut Tails					42			42
Position		1,100		130	127			1,357
Fasten			324		221			545
Sill Sealer					8			8
Mark	24							24
Talk Business						40		40
Obtain Materials						168		168
Organize Materials						15		15
Jobsite Cleaning						29		29
Wait Mate						102		102
Idle							111	111
Lunch/Break							471	471
Total	38	1,100	489	130	406	354	582	3,099

TABLE A4.6
CALIFORNIA WOOD-FRAME TIME DATA: SUMMARY OF FASCIA BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent			
	Fascia Backer	Production Support	Non-Production	Total
Cut	85			85
Fasten	156			156
Talk Business		17		17
Obtain/Carry Materials		19		19
Wait Mate		2		2
Idle			28	28
Personal			24	24
Total	241	38	52	331

TABLE A5.1
GEORGIA WOOD-FRAME TIME DATA:
SUMMARY OF WALLS, ROOF, AND FASCIA PRODUCTION TIME BY COMPONENT
MAN-MINUTES

Subcomponent	Component			
	Walls Stick	Roof Trusses	Fascia	Total
Layout	615	35		650
Sill Plate	153			153
Wall Stud	1,027			1,027
Sheathing	493	859		1,352
Top Plate	46			46
Headers	74			74
Blocking	40	24		64
Rafters		236		236
Trusses		560		560
Fascia Board			123	123
Production Support	554	1,017	50	1,621
Total	3,002	2,731	173	5,906
Total w/PF&D (20%)	3,602	3,277	208	7,087

TABLE A5.2
GEORGIA WOOD-FRAME TIME DATA:
SUMMARY OF WALLS, ROOF, AND FASCIA BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent												
	Layout	Sill Plate	Wall Stud	Sheath-ing	Top Plate	Head-ers	Block-ing	Rafters	Trusses	Fascia Backer	Product. Support	Non-Product	Total
Layout	464												464
Snap Lines	152			5					26				183
Measure			3	160		12		56	11	9			251
Cut		83	82	256		32	35	59	4	30			581
Extend Rafter Tails									20				20
Position			394	331				47	354	41			1,167
Stand Wall			140										140
Fasten		70	327	600	46	30	29	57	124	43			1,326
Mark	34							17					51
Brace			81						21				102
Obtain Tools/Equip.											13		13
Read Plans											70		70
Talk Business											92		92
Obtain/Carry Materials											1,038		1,038
Organize Materials											7		7
Jobsite Cleaning											24		24
Wait Mate											293		293
Help Mate											5		5
Adjust/Repair Equip.											79		79
Idle												410	410
Rework												228	228
Delay												20	20
Lunch/Break												1,089	1,089
Personal												21	21
Total	650	153	1,027	1,352	46	74	64	236	560	123	1,621	1,768	7,674

TABLE A5.3
GEORGIA WOOD-FRAME TIME DATA:
SUMMARY OF WALLS BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent									
	Layout	Sill Plate	Wall Stud	Sheathing	Top Plate	Headers	Blocking	Production Support	Non-Product.	Total
Layout	456									456
Snap Lines	132									132
Measure			3	25		12				40
Cut		83	82	74		32	13			284
Position			394	107						501
Stand Wall			140							140
Fasten		70	327	287	46	30	27			787
Mark	27									27
Brace			81							81
Obtain Tools/Equip.								9		9
Read Plans								52		52
Talk Business								43		43
Obtain/Carry Materials								342		342
Jobsite Cleaning								24		24
Wait Mate								5		5
Adjust/Repair Equip.								79		79
Idle									127	127
Rework									84	84
Delay									20	20
Lunch/Break									398	398
Total	615	153	1,027	493	46	74	40	554	629	3,631

TABLE A5.4
GEORGIA WOOD-FRAME TIME DATA:
SUMMARY OF ROOF BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent							
	Layout	Sheathing	Blocking	Rafters	Trusses	Production Support	Non-Product.	Total
Layout	8							8
Snap Lines	20	5			26			51
Measure		135		56	11			202
Cut		182	22	59	4			267
Extend Rafter Tails					20			20
Position		224		47	354			625
Fasten		313	2	57	124			496
Mark	7			17				24
Brace					21			21
Obtain Tools/Equip.						4		4
Read Plans						18		18
Talk Business						24		24
Obtain/Carry Materials						687		687
Organize Materials						7		7
Wait Mate						272		272
Help Mate						5		5
Idle							283	283
Rework							140	140
Lunch/Break							691	691
Personal							21	21
Total	35	859	24	236	560	1,017	1,135	3,866

TABLE A5.5
GEORGIA WOOD-FRAME TIME DATA:
SUMMARY OF FASCIA BY SUBCOMPONENT
MAN-MINUTES

Task	Subcomponent			
	Fascia Backer	Production Support	Non-Production	Total
Measure	9			9
Cut	30			30
Position	41			41
Fasten	43			43
Talk Business		25		25
Obtain/Carry Materials		9		9
Wait Mate		16		16
Rework			4	4
Total	123	50	4	177

APPENDIX B
COST DATA[1]

Appendix B pulls together all of the cost data for the demonstration and baseline homes. Section B1 is the foam-core panel house, B2, the light-gauge steel house, etc. Included in each section are the material, and standardized labor and equipment costs. The California wood-framed house is broken into two sections, B4A and B4B, to break out the exterior walls for comparison with the foam-core panels.

The material costs were derived either from the builder, or from drawing take-offs and supplier quotes, depending on availability of information. Standardized labor costs were derived from *Means Residential Cost Data 1994* in an effort to provide uniform labor rates. Wage rates varied too much from jobsite to jobsite so that the field data was not a good source to use for comparison. Standardized equipment rates were determined also using *Means*.

Section B5.4 is an estimated labor time for activities that we were not able to actually observe.

B1. FOAM-CORE PANEL HOUSE
1,732 SF Living Area

B1.1 MATERIAL COSTS
(Source: Bantex Building Products, Santa Ana, CA)

Wall Framing (exterior)	
Foam-core panels, 4" thick (excluding gables)	$4,973
Roof Framing	
Foam-core panels, 6&8" thick	$8,224
Miscellaneous lumber (beams, sheathing)	1,410
Total roof framing	$9,634
Exterior Finish	
Stucco and accessories	$1,750

B1.2 STANDARDIZED LABOR COSTS
(source: *Means Residential Cost Data 1994*)

Wall Framing

		Hourly	Daily
1	carpenter foreman	$17.95	$143.60
2	carpenters	15.95	255.20
1	carpenter's helper	12.25	98.00
32 MH			$496.80
	Weighted Average Rate		$15.53/MH

[1]Costs are expressed as "costs to the builder."

Roof Framing

	Hourly	Daily
1 carpenter foreman	$17.95	$143.60
2 carpenters	15.95	255.20
1 carpenters helper	12.25	98.00
0.5 equipment operator	16.75	67.00
36 MH		$563.80
Weighted Average Rate		$15.66/MH

B1.3 STANDARDIZED EQUIPMENT COSTS

(source: *Means Residential Cost Data 1994*)

Wall Framing

	Daily
1 air compressor	$69.60
4 power tools	36.80
32 MH	$106.40
Weighted Average Rate	$3.33/MH

Roof Framing

		Daily
0.5 hydraulic lift		$245.90
1 air compressor		69.60
4 power tools	36.80	
36 MH		$352.30
Weighted Average Rate		$9.79/MH

B2. LIGHT-GAUGE STEEL HOUSES

1,635 SF and 1,839 SF Living Area

B2.1 MATERIAL COSTS (Source: Quantities were taken from drawings; unit costs are from the cold-formed steel manufacturer)

Wall Framing (interior and exterior - 1,635 SF house)	
Exterior Walls	
200 LF ÷ 2 LF(spacing) x 1.50(percent) =	
150 studs (20 GA)	
150 studs x 8 LF(length) x $0.48/LF(20 GA) =	$576
Exterior Track (Top and Bottom)	
200 LF x 2 each x 1.50 (percent) = 600 LF	
600 LF x $0.48/LF(20GA) =	288
Headers	
12 openings x 6 LF x 2 ea = 144 LF	
Studs: 144 LF x $1.28/LF(16 GA) =	184
Track: 144 LF x $0.48/LF(18 GA) =	69
Garage	
Studs: 40 LF x $1.58/LF (14 GA) =	63
Track: 40 LF x $0.62/LF (16 GA) =	25
Shear Plates	
24 Straps x 12 LF = 300 LF	
300 LF x $0.66/LF (20 GA) =	198
Plates =	100
Interior Walls	
248 LF ÷ 2 LF (Spacing) x 1.25 (Percent) =	
155 studs (20 GA)	
155 studs x 10 LF (Length) x $0.48/LF (20 GA) =	744
Interior Track	
248 LF x 2 EA x 1.50 (Percent) = 744 LF	
744 LF x $0.48/LF (20 GA) =	357
Miscellaneous Angle	75
Break Shapes	300
Total Wall Framing	$2,979
Roof Framing (1,839 SF house)	
Roof Trusses - Material	
Typical Truss	
46 LF x 3 EA x 1.05 (Percent) = 145 LF	
145 LF x $0.79/LF (16 GA) = $115	
$115/Truss ÷ 46 LF = 2.50/LF	
46 LF Truss: 12 EA x $115 =	$1,380
36 LF Truss: 15 EA x 36 LF x $2.50/LF =	1,350
23 LF Truss: 10 EA x 23 LF x $2.50/LF =	575
Fill Framing	200
Fascia, Gable Framing, Overhang	150
Total Roof Trusses	$3,655
Sheathing (Lumber-OSB and Plywood)	$1,000
Roof Trusses - Fabrication (from on-site framer)	
85 MH/house x $14.80/MH =	1,258
Total Roof Framing =	$5,913

B2.2 STANDARDIZED LABOR COSTS

(source: *Means Residential Cost Data 1994*)

Wall Framing

		Hourly	Daily
1	carpenter foreman	$17.95	$143.60
2	carpenters	15.95	255.20
1	carpenters helper	12.25	98.00
1	laborer	11.80	94.40
40 MH			$591.20
	Weighted Average Rate		$14.78/MH

Roof Framing

		Hourly	Daily
1	carpenter foreman	$17.95	$143.60
2	carpenters	15.95	255.20
1	carpenter's helper	12.25	98.00
1	laborer	11.80	94.40
0.125	forklift operator	15.45	15.45
41 MH			$606.65
	Weighted Average Rate		$14.80/MH

B2.3 STANDARDIZED EQUIPMENT COSTS

(source: *Means Residential Cost Data 1994*)

Wall Framing

		Daily
5	power tools	$46.00
40 MH		$46.00
	Weighted Average Rate	$1.15/MH

Roof Framing

		Daily
0.125	forklift	$24.95
5	power tools	46.00
41 MH		$70.95
	Weighted Average Rate	$1.73/MH

B3. WELDED WIRE SANDWICH PANEL HOUSE
1925 SF Living Area

B3.1 MATERIAL COSTS
(Source: Insteel Construction System, Inc., Brunswick, GA)

Wall Framing (exterior and load-bearing walls and exterior finish)

Welded-wire sandwich panels	$6,224
Cover mesh	748
Rebar	80
Screed	131
Cement	2,695
Sand	589
Admixture	450
Hog rings	50
Scaffold	382
Miscellaneous lumber (bracing, etc.)	678
Total Wall Framing	$12,027

Roof Framing

Panels	$9,034
Cover mesh	1,530
Rebar	160
Screed	131
Cement	3,302
Sand	720
Admixture	550
Hog rings	150
Miscellaneous lumber (bracing, shoring, etc.)	2,200
Scaffold	763
	$18,540

B3.2 STANDARDIZED LABOR COSTS
(Source: *Means Residential Cost Data 1994*)

Wall and Roof Panel Erection (82% of work)

		Hourly	Daily
1	skilled worker foreman	$18.20	$145.60
2	skilled workers	16.20	259.20
2	carpenters	15.95	255.20
1	carpenter helper	12.25	98.00
3	laborers	11.80	283.20
72 MH			$1,041.20
	Weighted Average Rate		$14.46/MH

Wall and Roof Shotcrete Operation (18% of work)

		Hourly	Daily
1	skilled worker foreman	$18.20	$145.60
2	cement finishers	15.60	249.60
2	carpenters	15.95	255.20
1	carpenter's helper	12.25	98.00
1	equipment operator	16.05	128.40
2	laborers	11.80	188.80
72 MH			$1,065.60
	Weighted Average Rate		$14.80/MH

B3.3 STANDARDIZED EQUIPMENT COSTS
(source: *Means Residential Cost Data 1994*)

Wall and Roof Panel Erection (82% of work)

		Daily
1	air compressor	$69.60
4	power tools	36.80
72 MH		$106.40
	Weighted Average Rate	$1.48/MH

Wall and Roof Shotcrete Operation (18% of work)

		Daily
1	grout pump	$105.40
1	air compressor	69.60
1	mixer and hoses	25.20
1	accessories	10.40
72 MH		$210.60
	Weighted Average Rate	$2.93/MH

B4A. WOOD FRAME HOUSE- CALIFORNIA (exterior walls only)

1,170 SF Living Area

B4A.1 MATERIAL COSTS (Source: Material costs were gathered from take-offs and local suppliers).

Quotes from Home Builder Co., San Bernardino, CA (May 1994)

2x4 wall studs 92¼ = $2.61	
2.61 ÷ 92.25in. x 12in./LF ÷ 0.667 BF/LF=	$0.51/BF
Miscellaneous lumber $1.16/LF ÷ 1.50 BF/LF=	0.77/BF
3/8in. structural plywood $10.37/4 x 8 sheet ÷ 32 SF =	0.32/SF
15/32in. OSB $13.25/4x8 sheet ÷ 32 SF =	0.41/SF

Adjustment Factors for August 1993

Framing lumber composite price August 1993 = $348	
Framing lumber composite price May 1994 = $403	
Adjustment factor = 348 ÷ 403 = 0.86	
2 x 4 studs $0.51 x 0.86 =	$0.44/BF
Miscellaneous lumber $0.77 x 0.86 =	0.66/BF
3/8 in. plywood $0.32 x 0.86 =	0.28/SF
15/32 in. OSB $0.41 x 0.86 =	0.35/SF

Wall Framing

Lumber	
264 LF x 9.0 BF/LF = 2,376BF	
2,376 B.F. x $0.44/B.F. =	$1,045
Miscellaneous Lumber	
3,376 B.F. x 0.25 (Percent) x $0.66/BF =	557
Total Lumber	$1,602
Miscellaneous (nails, etc.)	140
Insulation	215
Sheathing	
(264 LF x 8 FT Walls) + 140 SF (Gable Ends) = 2,252SF	
2,252 SF x $0.28/SF (Plywood) =	631
Total Wall Framing	$2,588

Roof Framing

Trusses and Fill Framing	
21 each x 1.20 (Fill) x $85/Truss(Means) =	$2,150
Sheathing	
2,574 SF x $0.35/SF (OSB) =	901
Insulation	215
Total Roof Framing	$3,266

B4A.2 STANDARDIZED LABOR COSTS

(Source: *Means Residential Cost Data 1994*)

Wall Framing

		Hourly	Daily
1	carpenter foreman	$17.95	$143.60
2	carpenters	15.95	255.20
2	carpenter's helpers	12.25	196.00
1	laborer	11.80	94.40
48 MH			$689.20
	Weighted Average Rate		$14.36/MH

Roof Framing

		Hourly	Daily
1	carpenter foreman	$17.95	$143.60
2	carpenters	15.95	255.20
2	carpenter helpers	12.25	196.00
1	laborer	11.80	94.40
0.25	equipment operator	16.75	33.50
50 MH			$722.70
	Weighted Average Rate		$14.45/MH

B4A.3 STANDARDIZED EQUIPMENT COSTS

(Source: *Means Residential Cost Data 1994*)

Wall Framing

		Daily
1	air compressor	$69.60
4	power tools	36.80
48 MH		$106.40
	Weighted Average Rate	$2.22/MH

Roof Framing

		Daily
0.25	hydraulic lift	$122.95
1	air compressor	69.60
4	power tools	36.80
50 MH		$229.35
	Weighted Average Rate	$4.59/MH

B4B. WOOD FRAME HOUSE - CALIFORNIA
(Interior and Exterior Walls)
1,170 SF Living Area

B4B.1 MATERIAL COSTS (Source: Material costs were gathered from take-offs and local suppliers.)

Quotes from Home Lumber Co., San Bernardino, CA (May 1994)

2 x 4 wall studs 92¼in. = $2.61		
$2.61 ÷ 92.25in. x 12 in/LF ÷ 0.667 BF/LF =		$0.51/BF
Miscellaneous lumber	$1.16/LF ÷ 1.50 BF/LF =	0.77/BF
3/8in. structural plywood	$10.37/4 x 8 sheet ÷ 32SF =	0.32/SF
15/32 OSB	$13.25/4x8 sheet ÷ 32 SF =	0.41/SF

Adjustment Factors for October 1993

Framing lumber composite price October 1993 = $393	
Framing lumber composite price May 1994 = $403	
Adjustment Factor = 393 ÷ 403 = 0.98	
2 x 4 studs $0.51 x 0.98 =	$0.50 BF
Miscellaneous lumber $0.77 x 0.98 =	0.75/BF
3/8in. plywood $0.32 x 0.98 =	0.31/SF
15/32in. OSB $0.41 x 0.98 =	0.40/SF

Wall Framing	
Lumber	
Studs	
433LF x 9.0 board feet(B.F.)/L.F. = 3,897 B.F.	
3,897 B.F. x $0.50 B.F. =	$1,949
Miscellaneous lumber	
3,897 B.F. x 0.25 (percent) x $0.75/BF =	731
Total Lumber	2,680
Miscellaneous (Nails, etc.)	275
Total Wall Framing	$2,955

Roof Framing	
Trusses and fill framing	
21 each x 1.20(fill) x $85/truss(*Means*) =	$2,150
Sheathing	
2,574SF x $0.40/SF (OSB) =	1,030
Insulation	215
Total Roof Framing	$3,395

B4B.2 STANDARDIZED LABOR COSTS

(Source: *Means Residential Cost Data 1994*)

Wall Framing

		Hourly	Daily
1	carpenter foreman	$17.95	$143.60
2	carpenters	15.95	255.20
2	carpenter's helpers	12.25	196.00
1	laborer	11.80	94.40
48 MH			$689.20
	Weighted Average Rate		$14.36/MH

Roof Framing

		Hourly	Daily
1	carpenter foreman	$17.95	$143.60
2	carpenters	15.95	255.20
2	carpenter helpers	12.25	196.00
1	laborer	11.80	94.40
0.25	equipment operator	16.75	33.50
50 MH			$722.70
	Weighted Average Rate		$14.45/MH

B4B.3 STANDARDIZED EQUIPMENT COSTS

(Source: *Means Residential Cost Data 1994*)

Wall Framing

		Daily
1	air compressor	$69.60
4	power tools	36.80
48 MH		106.40
	Weighted Average Rate	$2.22/MH

Roof Framing

		Daily
0.25	hydraulic lift	$122.95
1	air compressor	69.60
4	power tools	36.80
50 MH		229.35
	Weighted Average Rate	

B5. WOOD FRAME HOUSE--GEORGIA

1,546 SF Living Area

B5.1 MATERIAL COSTS

(Source: Bowen & Bowen Construction Company, Norcross, GA)

Wall Framing (exterior)	
Lumber	$1,077
Miscellaneous (nails, etc.)	10
Insulation	361
Exterior Finish	
Foamboard	168
Vinyl siding	2,400
Brick	200
Miscellaneous (fasteners)	27
Total Wall Costs	$4,243
Roof Framing	
Trusses	$2,331
Fill framing	128
Sheathing	838
Miscellaneous clips, etc.	12
Insulation	361
Total Roof Framing	$3,670

B5.2 STANDARDIZED LABOR COSTS

(source: *Means Residential Cost Data 1994*)

Wall and Roof Framing

		Hourly	Daily
1	carpenter foreman	$17.95	$143.60
2	carpenters	15.95	255.20
1	carpenter's helper	12.25	98.00
1	laborer	11.80	94.40
40 MH			$591.20
	Weighted Average Rate		$14.78/MH

B5.3 STANDARDIZED EQUIPMENT COSTS

includes subcontractor overhead and profit
(source: *Means Residential Cost Data 1994*)

Wall and Roof Framing

		Daily
1	air compressor	$69.60
4	power tools	36.80
40 MH		$106.40
	Weighted Average Rate	$2.66/MH

B5.4 ESTIMATED LABOR TIME

man-hours taken from *Means Residential Cost Data 1994*

Exterior Wall Finish

Brick	90 SF x 0.176 M.H./SF =	15.84 MH
Vinyl	2358 SF x 0.034 MH/SF =	80.17 MH
Foamboard	2448 SF x 0.01 MH/SF =	24.48 MH
Insulation	1896 SF x 0.005 MH/SF =	9.48 MH
		129.97 MH
		x 60 = 7798 MM
		(includes 20% PF&D)

Roof Framing

Insulation	2551 SF x 0.007 =	17.86 MH
		x 60 = 1071 MM
		(includes 20% PF&D)

APPENDIX C
SUPPORTING CALCULATIONS

C1. FOAM-CORE PANELS VERSUS CONVENTIONAL WOOD

TABLE 4 - WALL FRAMING PRODUCTIVITY

Foam-Core Panel
Total Productive Man-Hours
(2,322 MM - 341 MM [Table A1.1] x 1.20 [PF&D] ÷ 60 MM/MH 39.62 MH
Unit Rate
39.62 MH ÷ 190 LF = 0.21 MH/LF
Conventional Wood
Total Productive Man-Hours
3,802 MM [Table A4.1-including PF&D] ÷ 60 MM/MH = 63.37 MH
Unit Rate
63.37 MH ÷ 264 LF = 0.24MH/LF

TABLE 5 - ROOF FRAMING PRODUCTIVITY

Foam-Core Panel
Total Productive Man-Hours
4,218 MM [Table A1.1] ÷ 60 MM/MH = 70.30 MH
Unit Rate
70.30 MH ÷ 2,365 SF = 0.030 MH/SF

Conventional Wood
Total Productive Man-Hours
3,020 MM [Table A4.1] ÷ 60 MM/MH = 50.33 MH
Unit Rate
50.33 MH ÷ 2,574 SF = 0.020 MH/SF

TABLE 6- EXTERIOR WALL FRAMING UNIT COSTS

Foam-Core Panel
Material Costs
$4,973 [Appendix B, B1.1] ÷ 190 LF [Table 4] = $26.17/LF
Labor Costs
$15.53/MH [Appendix B, B1.2] x 0.21 MH/LF [Table 4] = $3.26/LF
Equipment Costs
$3.33/MH [Appendix B, B1.3] x 0.21 MH/LF [Table 4] = $0.70/LF
Total Costs
$26.17 + 3.26 + 0.70 = $30.13/LF

Conventional Wood
Material Costs
$2,588 [Appendix B, B4A.1] ÷ 264 LF [Table 4] = $9.80/LF
Labor Costs
$14.36/MH [Appendix B, B4A.2] x 0.24 MH/LF [Table 4] = $3.45/LF
Equipment Costs
$2.22/MH [Appendix B, B4A.3] x 0.24 MH/LF [Table 4] = $0.53/LF
Total Costs
$9.80 + 3.45 + 0.53 = $13.78

TABLE 7 - ROOF FRAMING UNIT COSTS

Foam-Core Panel
Material Costs
$9,634 [Appendix B, B1.1] ÷ 2,365 SF [Table 5] = $4.07/SF
Labor Costs
$15.66/MH [Appendix B, B1.2] x 0.030 MH/SF [Table 5] = $0.47/SF
Equipment Costs
$9.79/MH [Appendix B, B1.3] x 0.030 MH/SF [Table 5] = $0.29/SF
Total Costs
$4.07 + 0.47 + 0.29 = $4.83/SF

Conventional Wood
Material Costs
$3,266 [Appendix B, B4A.1] ÷ 2,574 [Table 5] = $1.27/SF
Labor Costs
$14.45/MH [Appendix B, B4A.2] x 0.020 MH/SF [Table 5] = $0.29/SF
Equipment Costs
$4.59/MH [Appendix B, B4A.3] x 0.020MH/SF [Table 5] = $0.09/SF
Total Costs
$1.27 + 0.29 + 0.09 = $1.65/SF

C2. LIGHT-GAUGE STEEL VERSUS CONVENTIONAL WOOD

TABLE 9 - WALL FRAMING PRODUCTIVITY

Light-Gauge Steel
Total Productive Man-Hours
(6,226 - 47 - 246MM) [Table A2.1] x 1.20 [PF&D] ÷ 60 MM/MH = 118.67 MH
Unit Rate
118.67 MH ÷ 448 LF = 0.26 MH/LF

Conventional Wood
Total Productive Man-Hours
(3,168 + 2,453 - 1,271 - 120MM) [Table A4.1] x 1.20 [PF&D] ÷ 60 MM/MH = 84.60MH
Unit Rate
84.60 MH ÷ 433 L.F. = 0.20 MH/LF

TABLE 10 - ROOF FRAMING PRODUCTIVITY

Light-Gauge Steel
Total Productive Man-Hours
(5,121 - 184 MM) [Table A2.1] x 1.20 [PF&D] ÷ 60 MM/MH = 98.74 MH
Unit Rate
98.74 MH ÷ 3,249 SF= 0.030 MH/SF

Conventional Wood
Total Productive Man-Hours
(2,517 - 130 MM) [Table A4.1] x 1.20 [PF&D] ÷ 60 MM/MH = 47.74 MH
Unit Rate
47.74 MH ÷ 2,574 SF = 0.020 MH/SF

TABLE 11 - WALL FRAMING UNIT COSTS

Light-Gauge Steel
Material Costs
$2,979 [Appendix B, B2.1] ÷ 448 LF [Table 9] = $6.65/LF
Labor Costs
$14.78 [Appendix B, B2.2] x 0.26 MH/LF [Table 9] = $3.84/LF
Equipment Costs
$1.15 [Appendix B, B2.3] x 0.26 MH/LF [Table 9] = $0.30/LF
Total Costs
$6.65 + 3.84 + 0.30 = $10.79/LF

Conventional Wood
Material Costs
$2,955 [Appendix B, B4B.1] ÷ 433 LF [Table 9] = $6.82/LF
Labor Costs
$14.36 [Appendix B, B4B.2] x 0.20 MH/LF [Table 9] = $2.87/LF
Equipment Costs
$2.22 [Appendix B, B4B.3] x 0.20 MH/LF [Table 9] = $0.44/LF
Total Costs
$6.82 + 2.87 + 0.44 = $10.13/LF

TABLE 12 - ROOF FRAMING UNIT COSTS

Light-Gauge Steel
Material Costs
$5,913 [Appendix B, B2.1] ÷ 3,249 SF [Table 10] = $1.82/SF
Labor Costs
$14.80 [Appendix B, B2.2] x 0.030 MH/SF [Table 10] = $0.44/SF
Equipment Costs
$1.73 [Appendix B, B2.3] x 0.030 MH/SF [Table 10] = $0.05/SF
Total Costs
$1.82 + 0.44 + 0.05 = $2.31/SF

Conventional Wood
Material Costs
$3,395 [Appendix B, B4B.1] ÷ 2,574 SF [Table 10] = $1.32/SF
Labor Costs
$14.45 [Appendix B, B4B.2] x 0.020 [Table 10] = $0.29/SF
Equipment Costs
$4.59 [Appendix B, B4B.3] x 0.020 [Table 10] = $0.09/SF
Total Costs
$1.32 + 0.29 + 0.09 = $1.70/SF

C3. WELDED-WIRE SANDWICH PANELS VERSUS CONVENTIONAL WOOD

TABLE 13 - WALL FRAMING PRODUCTIVITY

Welded-Wire Sandwich Panels
Total Productive Man-Hours
34,066 MM [Table A3.1] x 8/9 [8LF wall] ÷ 60 MM/MH = 504.68MH
Unit Rate
504.68 MH ÷ 378 LF = 1.34 MH/LF

Conventional Wood
Total Productive Man-Hours
3,602 MM [Table A5.1] + 7798 MM [Appendix B, B5.4] = 11,400 MM
11,400 MM ÷ 60 MM/MH = 190.00MH
Unit Rate
190.00 MH ÷ 237 LF = 0.80 MH/LF

TABLE 14 - ROOF FRAMING PRODUCTIVITY

Welded-Wire Sandwich Panels
Total Productive Man-Hours
47,094 MM [Table A3.1] ÷ 60 MM/MH = 784.90 MH
Unit Rate
784.90 MH ÷ 3,263 SF = 0.241 MH/SF

Conventional Wood
Total Productive Man-Hours
3,277 MM [Table A5.1] + 1,071 [Appendix B, B5.4] = 4,348 MM
4.348 MM ÷ 60MM/MH = 72.47MH
Unit Price
72.47 MH ÷ 2,551 SF = 0.028 MH/SF

TABLE 15 - EXTERIOR WALL FRAMING UNIT COSTS

Welded-Wire Sandwich Panels
Material Costs
$12,027 [Appendix B, B3.1] x 8/9 [8LF wall] ÷ 378 LF [Table 13] = $28.28/LF
Labor Costs
0.82 x $14.46/MH [Appendix B, B3.2] + 0.18 x $14.80/MH [Appendix B, B3.2] = $14.52/MH
$14.52/MH x 1.34 MH/LF [Table 13] = $21.78/LF
Equipment Costs
0.82 x $1.48/MH [Appendix B, B3.3] + 0.18 x $2.93/MH [Appendix B, B3.3] = $1.74/MH
$1.74/MH x 1.34 MH/LF [Table 13] = $2.61/LF
Total Costs
$28.28 + 21.78 + 2.61 = $52.67/LF

Conventional Wood
Material Costs
$4,243 [Appendix B, B5.1] ÷ 237 LF [Table 13] = $17.90/LF
Labor Costs
$14.78 [Appendix B, B5.2] x 0.80 MH/LF [Table 13] = $12.27/LF
Equipment Costs
$2.66 [Appendix B, B5.3] x 0.80 MH/LF [Table 13] = $2.21/LF
Total Costs
$17.90 + 12.27 + 2.21 = $32.38/LF

TABLE 16 - ROOF FRAMING UNIT COSTS

Welded-Wire Sandwich Panels

Material Costs

$18,540 [Appendix B, B3.1] ÷ 3,263 SF [Table 14] = $5.68/SF

Labor Costs

$14.52/MH [Table 15 calculation above] x 0.241 MH/SF [Table 14] = $3.50/SF

Equipment Costs

$1.74/MH [Table 15 calculation above] x 0.241 MH/SF [Table 14] = $0.42/SF

Total Costs

$5.68 + 3.50 + 0.42 = $9.60/SF

Conventional Wood

Material Costs

$3,670 [Appendix B, B5.1] ÷ 2,551SF [Table 14] = $1.44/SF

Labor Costs

$14.78/MH [Appendix B, B5.2] x 0.028 MH/SF [Table 14] = $0.41/SF

Equipment Costs

$2.66/MH [Appendix B, B5.3] x 0.028 MH/SF [Table 14] = $0.07/SF

Total Costs

$1.44 + 0.41 + 0.07 = $1.92/SF

APPENDIX D
CONVENTIONALLY CONSTRUCTED BASELINE HOUSES

Two locations were selected to monitor the construction of wood-framed houses and provide a baseline to compare the alternative houses selected in this study. An attempt was made to approximate the size and complexity of the alternative demonstration houses. Because of the variations in construction methods and materials on the East and West coasts, one wood-framed house was selected in California and another in Georgia.

CALIFORNIA WOOD-FRAMED BASELINE HOUSE

The West Coast wood-framed baseline house selected for this project was located in the Sun City Palm Springs Development near Indio, California, approximately 25 miles southeast of the foam-core panel house and 80 miles north of the light-gauge steel house. The normal maximum temperature in Indio is 109°F; the normal minimum temperature is 42°F. The average annual rainfall is 5.3 inches.

A total of 5,800 lots have been approved for construction in this development by Del Webb California Corporation, Inc., of Bermuda Dunes, California. Del Webb allowed the Research Center staff to observe the framing of one of these homes from September 28 to October 5, 1993.

The NAHB Research Center studied the framing for the 1,170-square-foot Model 161B, which features two bedrooms, two bathrooms, and a two-car garage (see Photo 22). The house was designed by Iverson Associates of Irvine, California.

Photo D1. CALIFORNIA WOOD-FRAMED BASELINE HOME

All framing elements in the house were made of conventional lumber. Load-bearing and partition walls were constructed of 2x4 studs 16 inches on center. Full blocking was installed in the walls to prevent twisting of the studs. Shear walls were made by using 3/8-inch plywood sheathing; stucco was used on 1-inch rigid foam for the exterior finish. Headers were made from dimensional lumber. The roof was framed with manufactured wood trusses at 24-inch centers with blocking installed between the trusses. One-half inch plywood sheathing was used on the roof, that was covered with concrete tile roofing over 30-pound felt. The walls and ceiling were insulated with R-13 and R-30 fiberglass insulation, respectively.

The houses were marketed at prices ranging from $127,000 to $138,000 depending on the extra options.

GEORGIA WOOD-FRAMED BASELINE HOUSE

The East Coast wood-framed baseline house selected for this project was located in Atlanta, Georgia. The normal maximum temperature for Atlanta is 88°F; the minimum temperature is 32°F. The average annual rainfall is 51 inches.

Some 200 lots were approved for construction in the subject development by Bowen & Bowen Construction Company of Norcross, Georgia. NAHB Research Center staff observed the framing of one home from December 9 to 13, 1993.

The model under study was 1,546 square feet and featured three bedrooms, two bathrooms and a two car garage (see Photo 23). The house was designed by Frank O. Battle & Associates Creative Home Designs of Buford, Georgia.

Photo D2. GEORGIA WOOD-FRAMED BASELINE HOME

All framing elements in the house were made of conventional lumber. Both load-bearing and interior nonload-bearing walls were constructed with 2x4 studs spaced 16 inches on center. Shear walls were made by using let-in bracing and plywood corners. A combination of vinyl siding and brick were applied over foamboard for the exterior finish. Headers were made from dimensional lumber. The roof was framed by using wood manufactured trusses at 24-inch centers, sheathed with ½-inch nominal OSB, and covered with asphalt shingle roofing over 15- pound felt. The walls and ceiling were insulated with R-13 and R-30 fiberglass batt insulation, respectively.

The house was marketed for about $99,500 depending on the options selected.

APPENDIX E
CONTACTS FOR INFORMATION AND MANUFACTURERS
(PARTIAL LIST)
FOAM-CORE PANELS

Advanced Energy Technologies, Inc.
P.O. Box 387
Clifton Park, NY 12065
518/371-2140

Advanced Foam Plastics, Inc.
5250 North Sherman Street
Denver, CO 80216
303/297-3844

AFM Corporation
R-Control Division
24000 W. Hwy. 7, Ste. 201
Shorewood, MN 55331
612/474-0809

Alchem, Inc.
3617 Strawberry Road
Anchorage, AK 99502
907/243-2144

Amotex Plastics
P.O. Box 120427
Nashville, TN 37212
615/254-1381

APC International
2280 Grandview Road
Ferndale, WA 98248
206/366-3400

ARCO Chemical Company
3801 West Chester Pike
Newtown Square, PA 19073
215/359-2769

Ashland Chemical
ISOSET Adhesives
P.O. Box 2219
Columbus, OH 43216
614/889-4664

Associated Foam Manufacturers
Box 246
Excelsior, MN 55331
612/474-0809

Atlas Industries
6 Willows Road
Ayer, MA 01432
800/343-1437

Bantex Building Products, Inc.
1040 Santa Ana Blvd., Ste. 200
Santa Ana, CA 92703
714/569-0064

The Beamery, Inc.
P.O. Box 9
Heiskell, TN 37754-0009
615/947-3308

Branch River Foam Plastics, Inc.
15 Thurber Blvd.
Smithfield, RI 02917
401/232-0270

Building Systems Company
522 Third Street
Hanover, PA 17331
717/633-7750

Carpenter Insulation Co.
5016 Monument Ave.
Richmond, VA 23230
804/359-0800

Cheney Homes, Inc.
P.O. Box 58
Delafield, WI 53018-0058
414/784-8500

Concept 2000 Homes
3003 N. Highway 94
St. Charles, MO 63301
314/947-7414

Cornell Corp.
P.O. Box 338
Cornell, WI 54732
715/239-6411

Crane Core Tec Company
2351 Kenskill Ave.
Washington Ct. House, OH 43160
614/335-9400

Dow Chemical
2020 Willard H. Dow Center
Midland, MI 48674
517/636-6919

Dreaming Creek Timberframing
2487 Judes Ferry Road
Powhatan, VA 23139
804/598-4328

Enercept, Inc.
3100 Ninth Ave. SE
Watertown, SD 57201
605/882-2222

Falcon Manufacturing, Inc.
8240 Byron Center Road
Byron Center, MI 49315
616/878-1568

Fischer Corporation
1843 Northwestern Pkwy.
Louisville, KY 40203
502/778-5577

Foam Laminates of Vermont
P.O. Box 102
Hinesburg, VT 05461
802/453-4438

Foam Products Corporation
2525 Adie Road
P.O. Box 2217
Maryland Heights, MO 63043
800/824-2211

Georgia Pacific Corp.
133 Peachtree Street, NE
P.O. Box 105605
Atlanta, GA 30348-5605
404/527-0480

Harmony Exchange
Rt. #2, Box 843
Boone, NC 28607
704/264-2314

Insul-Kor, Inc.
P.O. Box 116
Elkhart, IN 46514
219/262-3472

Jacobs Plastics, Inc.
381 Miles Road
Adrian, MI 49221
517/263-3890

J-Deck Building Systems
2587 Harrison Road
Columbus, OH 43204
614/274-7755

Korwall Industries, Inc.
326 North Bowen Road
Arlington, TX 76012
817/277-6741

Marne Industries, Inc.
P.O. Box 465
Grand Rapids, MI 49588
616/698-2001

Metal Construction Association
1101 14th St., NW, Ste. 1100
Washington, DC 20005
202/371-1243

Midwest Panel Systems, Inc.
9012 East US 223
Blissfield, MI 49228
517/486-4844

Modular Energy Systems
311 East Glen Cove
Mesa, AZ 85201
602/898-7283

Morton International
100 N. Riverside Drive
Chicago, IL 60606
312/807-3136

The Murus Company
P.O. Box 220
Mansfield, PA 16933
717/549-2100

North American Panel Systems
RD 1, Box 56B
Westmoreland, NH 03467
603/352-9994

Opco, Inc.
P.O. Box 101
Latrobe, PA 15650
412/537-9300

Panel Building Systems
431 Second Street
Reynolds Industrial Park
Greenville, PA 16125
412/646-2400

Perma "R" Products, Inc.
P.O. Box 5235 EKS
109 Perma "R" Road
Johnson City, TN 37603
615/929-8007

PFS Corporation
2402 Daniel Street
Madison, WI 53704
608/221-3361

Polyfoam Packers Corp.
2320 S. Foster Ave.
Wheeling, IL 60090-6572
708/398-0110

Pond Hill Homes
RD 3, Box 467
Blairsville, PA 15717
412/459-5404

RADCO
P.O. Box 2768
LaGrange, GA 30241
404/884-9011

RADVA Corp.
P.O. Box 2900, FSS
Radford, VA 24143
703/639-2458

Ray-Core, Inc.
P.O. Box 395
111 Woodward Ave.
Lock Haven, PA 17745
717/748-6032/626

Remarc, Inc.
P.O. Box 174
Holderness, NH 03245
603/968-9678

Soli-Cor, Inc.
1073 Merchants Lane
Oilville, VA 23129-2210
804/784-6054

Structural Panels, Inc.
350 Burbank Road
Oldsmar, FL 34677

Sunlight Homes
P.O. Box 1569
Bernalillo, NM 87004

Swift Adhesives, Inc.
3100 Woodcreek Drive
P.O. Box 1546
Downers Grove, IL 60515
708/971-6776

Tectum, Inc.
P.O. Box 920
Newark, OH 43055
614/345-9691

Thermal Shell Homes
5835 W. Rochelle, Ste. 201
Las Vegas, NV 89103
702/222-0681

Therm-L-Tec Systems, Inc.
119 Osage Avenue
Kansas City, KN 66105
913/621-1916

U.C. Industries, Inc.
Technology Center
P.O. Box 423
Tallmadge, OH 44278
216/633-6735/219

Upperloft Design
Rt. #1, Box 2901
Lakemont, GA 30552
404/782-5246

Vermont Stresskin Panels
RR1, Box 2794
Cambridge, VT 05444
802/644-8885

Vinyl Tech
P.O. Box 749
Venice, FL 34284-0749
813/493-4858

Weyerhaeuser Company
209 Diana Drive
Poland, OH 44514
216/757-8105

W.H. Porter, Inc.
4240 136th Avenue
Holland, MI 49424
616/399-1963

Wing Manufacturing
1638 Clearview Drive
Latrobe, PA 15650
412/537-7755

Winter Panel Corporation
RR5, Box 168B
Glen Orne Drive
Brattleboro, VT 05301
802/254-3435

LIGHT-GAUGE STEEL FRAMING

A&H Building Materials Co., Inc.
3361 East 36th Street
P.O. Box 42227
Tucson, AZ 85733
602/622-4741

The Adonis Group, Inc.
14483 62nd Street North
Clearwater, FL 34620
813/536-2228

Advanced Building Concepts
4370 NE Halsey Street
Portland, OR 97213
503/288-6936

Advanced Framing Systems, Inc.
1118 West Spring Street
P.O. Box 1796
Monroe, GA 30655
404/267-2520

Alabama Metal Industries
P.O. Box 3928
Birmingham, AL 35206
205/787-2611

All American Design Build, Inc.
220 Lake Avenue
St. James, NY 11780
516/826-1000

Allsteel Rolled Products, Inc.
2251 S.W. 66th Terrace
Davie, FL 33317
305/475-9771

American Iron and Steel Institute
Cold-Formed Steel Construction
1101 17th St., NW, #1300
Washington, DC 20036
202/452-7100

American Steel Home Building Industries
P.O. Box 2887
Worburn, MA 01888
617/932-6943

American Steel Tube Co.
1400 Baron Steel Ave.
Box 3216
Toledo, OH 43607
419/531-4653

American Studco, Inc.
P.O. Box 6633
Phoenix, AZ 85005
800/877-8823

Angeles Metal Systems
Corporate Office
4817 E. Sheila Street
P.O. Box 911031
Los Angeles, CA 90091
213/268-1777

California Building Systems
4815 E. Sheila Street
Los Angeles, CA 90040
213/260-5380

CEMCO
263 Covina Lane
City of Industry, CA 91744
818/369-3564

Clark-Cincinnati
5310 Duff Drive
Cincinnati, OH 45246
513/874-9631

Component Housing System USA
1707 W. Compton Blvd.
Compton, CA 90220
310/635-8263

Consolidated Systems, Inc.
650 Rosewood Drive
Columbia, SC 29202
800/654-1912

Dale/Incor
6455 Kingsley
Dearborn, MI 48126
313/846-9400

Dale of Florida
1001 NW 58th Court
Ft. Lauderdale, FL 33309
305/772-6300

Dietrich Industries, Inc.
Corporate Headquarters
500 Grant St., Ste. 2226
Pittsburgh, PA 15219
412/281-2805

Dura-Frame, Inc.
9039 Junita Drive, NE
No. 302
Kirkland, WA 98034
206/821-0895

Excalibur Structures, Inc.
3730 E. McKinney, Ste. 102
Denton, TX 76201
817/383-8067

Fenestra Corp.
P.O. Box 8189
Erie, PA 16505
814/838-2001

The Formetal Co., Inc.
239 Third Street
Forest Park, GA 30050
404/361-0524

G.E.I. Development
17165 Horace Street
Granada Hills, CA 91344
818/368-4293

HONSADOR, Inc.
91-151 Malakale Road
Ewa Beach, HI 96707
808/682-2011

Incor Division of Dale Industries
4601 N. Point Blvd.
Baltimore, MD 21219
410/477-4100

Janco Homes
P.O. Box 908
Glenpol, OK 74033
918/322-3439

Jewell Building Systems, Inc.
P.O. Box 397
Dallas, NC 28034
704/922-8652

Knorr Steel Framing Systems
5073 Salem-Dallas Hwy.
Box 5267
Salem, OR 97304
503/371-8033

Madray Steel Building Systems
P.O. Box 712
Okeechobee, FL 34973
813/763-8856

Marino Industries Corp.
400 Metuchen Road
P.O. Box 358
South Plainfield, NJ 07078
908/757-9000

Novatech International, Inc.
1340 Neptune Drive
Boyton Beach, FL 33426
407/736-6659

NU-STEEL
Engineered Home Kits
Box 279
Suwanee, GA 30174
404/271-7363

Nu-Tech Homes, Inc.
9678 Main Street
P.O. Box 424
Clarence, NY 14031-0424
716/759-2077

Pacific Steel Housing
Corp.
1600 W. Galer Street
Seattle, WA 98119
206/282-3055

Patren Corporation
933 Lee Road, Ste. 250
Orlando, FL 32810
407/628-8044

Pioneer Housing Systems, Inc.
Industrial Park
P.O. Box 5129
Fitzgerald, GA 31750
912/423-6630

Pioneer Steel Framing Systems
c/o Vanport Steel & Supply, Inc.
609 NE Repass Road
Vancouver, WA 98665
206/696-4682

Residential Steel Framing
10340 Denton Drive
Dallas, TX 75220
214/350-8150

Southeastern Metals Manufacturing
Co., Inc.
11801 Industry Drive
P.O. Box 26347
Jacksonville, FL 33218
800/342-1279 (in state)
800/874-0335 (out of state)

Steel Benders, Inc.
15550 West 108th Street
Lenexa, KS 66219
913/492-7274

Steel Framing Systems
P.O. Box 6133
Wauconda, IL 60084
708/987-5588

Steel Framing Systems, Inc.
34889 Oak Knoll Circle
Gurnee, IL 60031
708/336-1413

Steeler, Inc.
Corporate Office
10023 Martin Luther King Hwy.
Seattle, WA 98178

Studco of Hawaii, Inc.
P.O. Box 30446
Honolulu, HI 96820
808/845-9311

Super Stud Building Products
8-01 26th Avenue
Astoria, NY 11102
718/545-5700

Total American, Inc.
5470 Oakbrook Pkwy.
Suite B
Norcross, GA 30093
404/840-9038

Tri-Steel Structures, Inc.
Corporate Office
5400 South Stemmons (1-35E)
Denton, TX 76205
1/800-TRI-STEEL

Unimast, Inc.
100 Fulton Street
Boonton, NJ 07005
800/334/0665 (in state)
800/524-0712 (out of state)

U.S. Gypsum Company
101 South Wacker, Dept. 147-5
Chicago, IL 60606
312/606-4065

Visionary Homes, Inc.
12745 SE 222 Avenue
Boring, OR 97009
503/658-6114

Ware Industries Corp.
61 Avenue K
Newark, NJ 07105
201/589-3511

Western Metal Lath Co.
6510 General Drive
Box 39998-92519
Riverside, CA 92509
714/360-3500

WELDED-WIRE SANDWICH PANELS

Insteel Construction Systems, Inc.
2610 Sidney Lanier Drive
Brunswick, GA 31520
912/264-3772

Truss Panel Systems
Estate Pastory #7
St. John, U.S. Virgin Islands 00830
809/776-6237