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

Steel vs. Wood
Cost and Short Term Energy Comparison
Valparaiso Demonstration Homes

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Prepared for

The U.S. Department of Housing and Urban Development
Office of Policy Development and Research
Washington, DC

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Washington, DC 20036

and

The National Association of Home Builders
Washington, DC

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EXECUTIVE SUMMARY

Steel framing has been used for many years for interior non-load bearing and curtain walls in commercial construction. However, cold-formed steel members have only recently attracted attention for use in load bearing wall, floor, and roof framing applications in residential construction.

Despite the availability of cold-formed steel framing, there are still basic barriers that impede its adoption in the residential market. Probably the primary barrier is that the building industry is generally reluctant to adopt alternative building methods and materials unless they exhibit clear cost or quality advantages. A second barrier is how the high thermal conductivity of steel affects energy use in homes. Given improvements in the technology over the past few years, it is not clear how steel compares with wood framing in terms of overall cost to the builder.

The scope of this project was limited to constructing two identical side-by-side homes at three different locations in the U.S. Each location had unique labor rates, material costs, size, shape and style of construction. The sites include Indiana, South Carolina, and North Dakota. Each site has a house framed with conventional dimensional lumber and a second one framed with cold-formed steel. Blower door tests were conducted for both houses to determine the levels of air infiltration for each house. Similarly, co-heat tests were performed to compare short-term energy consumption between the two houses.

A modified version of the Group–Timing Technique (GTT) was used to gather information for these houses. The GTT is a work measurement procedure for multiple activities that allows one observer using a stopwatch to make a detailed time study of an entire work crew at the same time. Continuous observations were made on a 15- minute interval and were recorded as tallies on a form that listed the elements of the job. Nonproductive time was also 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 each of the houses for comparison.

Installed costs of the steel framing material were determined and compared with that of conventional wood framing. Results indicate that certain aspects of cold-formed steel (such as floor framing and interior non-load bearing walls) are within the range that might be expected to be cost–effective with wood. An infiltration test and short-term energy test (i.e., co-heat test) were also conducted for each home. Results indicated that both steel and wood-framed homes have approximately the same leakage (infiltration) rate and tested UA (thermal resistance) value of the wood house was 4% better than that of an identical steel house.

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 a particular material's final cost. The unit costs developed in this report were based on the data obtained from a small sample. This information does not include nonproductive time, builder overhead or profit. Results do not reflect a definitive study but rather indicate whether builders should consider cold-formed steel framing when searching for solutions to lumber problems and concerns. The reader should also be careful when using the cost data shown in Appendix B for a specific activity, as the data provided may not be representative of the true cost for that specific activity in another project, location, or circumstances.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

PAGE

1. INTRODUCTION

This report is the first of three reports of a multi–year study of cost and energy comparisons of steel and wood houses conducted for the U.S. Department of Housing and Urban Development (HUD), the North American Steel Framing Alliance (NASFA), and the National Association of Home Builders (NAHB). This study is conducted by the NAHB Research Center, Inc.

Steel framing has been used for many years for interior non-load bearing and curtain walls in commercial construction. However, cold-formed steel members are only recently attracting attention for use in load bearing wall, floor, and roof framing applications in residential construction.

Despite the availability of cold-formed steel framing, there are still basic barriers that impede its adoption in the residential market. Probably the largest barrier is that the building industry is generally reluctant to adopt alternative building methods and materials unless they exhibit clear cost or quality advantages. A second large barrier is the question of how the higher thermal conductivity of steel affects energy use in homes. Given improvements in the technology over the past few years, it is not clear how steel compares with wood framing in terms of overall cost for builders.

Little objective reporting exists comparing the total costs associated with framing with cold-formed steel versus conventional wood-frame homes. In addition, the labor component and impact of steel framing on other trades and systems in the home are particularly difficult to assess. This project helps address these concerns by:

- determining the in-place labor and material cost for components of nearly identical homes built with steel and wood framing;
- determining the impact of cold-formed steel framing on other trades; and,
- determining the short-term energy consumption for nearly identical wood and steel homes.

The scope of this project was limited to three sites. The three sites are located as follows:

- Valparaiso, Indiana;
- Beaufort, South Carolina; and,
- Fargo, North Dakota.

This report is limited to the findings of the demonstration homes in Valparaiso, Indiana.

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2. OBJECTIVE

The purpose of this report was to compare the labor and material cost and energy performance (i.e., energy consumption) of steel-framed homes to those of nearly identical wood-framed homes. More specifically, the intent was to determine if the costs of steel-framed homes were "in the same ballpark" as wood-framed homes, 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 assessing the potential use of steel in their homes.

In order to assess the costs, an observer was sent to the job site where the materials were being used to frame the houses. The houses selected for observation are referred to in this report as the demonstration houses. To effectively make a comparison, both steel and wood houses were erected side-by-side in Valparaiso, Indiana. Framers, plumbers, and electricians were questioned in the field to provide input on the workability of each of the two materials and their practical applications. The in-place labor and material requirements and costs were monitored for both homes. Co-heat and infiltration tests were also conducted to compare and contrast the energy performance and consumption of steel and wood-framed homes.

Each set of houses, to the extent possible, had nearly identical floor plan, dimensions, orientation, exposure, HVAC equipment. The demonstration homes were erected side-by-side.

3. COLLECTION OF LABOR HOURS

A modified version of the Group- Timing Technique (GTT) was used to gather information on each demonstration home. The GTT is a work measurement procedure for multiple activities that allows one observer using a stopwatch to make a detailed elemental time study on an entire work crew at the same time. Each activity performed at the job site was broken into components (e.g., floor framing, wall framing, and roofs), subcomponents (e.g., studs, headers, etc.), and tasks (e.g., measure, cut, brace, etc.) (see list of time and motion study categories for data collection in Appendix B). Continuous observations were made at fifteen-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. The resulting numbers provided standard time values that were used to calculate the productivity of each of the two framing systems 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.

To the extent possible, all phases of construction that are directly or indirectly impacted by the framing materials were monitored and time and motion data were collected[1]. The data collection concentrated on the following components and subcomponents: Framing, Insulation, Sheathing, HVAC, Electrical, Plumbing, Drywall & Paint, Carpentry, Windows, Doors, Siding, Front Porch, Deck and Floor Covering.

[1] The cost of engineering, building permits, blueprints, rough and final stake, water lines, sewer lines, excavation, backfill, foundations, basement construction, sand and stone, damp proofing, footing drains, structural steel (I-beam and lolly columns), interior concrete, LVL/glulam beams, interior and exterior lights, appliances, mirrors, monthly utility bills, general site cleanup, driveways, sidewalks, exterior concrete, landscaping, and interest on loan were not documented in this report.

4. SITE LOCATION

<u>Valparaiso, Indiana:</u> **Carriage Crossing (Keystone Commons)**

Generation Homes constructed the wood and steel demonstration homes in the Carriage Crossing development of 57 home sites nestled in the northwest corner of Keystone Commons, in the heart of Valparaiso, Indiana. The average annual maximum temperature in Valparaiso is 96°F (36°C); the average annual minimum temperature is -12°F (-24°C)[2].

The approximately 2,200-square-foot (204 m^2) homes were built with four bedrooms, two and a half baths, two-car garage, unfinished basement and a bonus room (see Appendix A for plans). Both exterior and interior walls were built with conventional stick framing techniques.

<u>Builder: Generation Homes</u>: An EPA "Energy Star" builder that builds single-family homes, town-homes, and condominiums in Northwest Indiana. Generation Homes offers the option of either steel or wood frame houses. Generation Homes is a "turn key cost" builder meaning the final price of the home includes all the items necessary to complete the home.

5. CHARACTERISTICS OF DEMONSTRATION HOMES

All framing elements in the wood and steel demonstration homes were fabricated of conventional lumber or cold-formed steel members using local common practices. All framing materials were shipped to each site where all floors, walls, headers, and roofs were constructed. A 2x6 treated wood sill plate was secured to the top of foundation walls for both houses. One-half inch (12.7 mm) anchor bolts secured the sill plates to the top of foundation walls. The roofs were framed using ceiling joists and rafters, and sheathed with ½ inch (12.7 mm) nominal OSB, and covered with asphalt fiberglass roofing shingles over 15-pound felt underlayment. The walls, ceilings and basement walls were insulated with R-19, R-40 and R13 fiberglass batt insulation, respectively. A combination of vinyl siding and brick was applied over oriented-strand-board (OSB) sheathing for the exterior finish of the wood house. Vinyl siding was used as the exterior finish for the steel house.

Steel Demonstration Home:

Wall studs were spaced at 24 inches (610 mm) on center with load bearing studs located directly in-line with roof rafters and floor joists. The 24-inches (610 mm) on center represent local practice in the Valparaiso area for steel framing. All structural steel studs were 550S-162-33 mil (0.84 mm) (2x6x33 mil). Non-structural steel studs were 350S162-27 (2x4x27 mil). All steel-framed members were designed using the *Prescriptive Method for Residential Cold-Formed Steel-Framing*[3]. All steel studs were delivered pre-punched with holes spaced at 24 inches (610 mm) on center. All steel members were precut by the steel supplier to the lengths required by the builder[4]. Exterior walls were sheathed with 7/16 inch (11 mm) APA rated oriented-strand-board (OSB) to the studs (fully sheathed walls). The exterior walls of the steel house were covered with ¾ inch (19 mm) rigid foam

[2] National Oceanic & Atmospheric Administration.

[3] *Prescriptive Method for Residential Cold-Formed Steel Framing*, Second Edition. U.S. Department of Housing and Urban Development (HUD), Washington, DC. September 1997.

[4] It is not common practice for steel suppliers to deliver pre-cut (to length) steel members. Typically, Steel studs come in lengths with 2-foot increments. Steel suppliers can deliver cut-to-length members at a premium cost.

panels secured to the exterior side of the OSB with plastic cap nails. The front porch of the steel house was designed to be larger than that of the wood house to provide a slightly different appearance.

Wood Demonstration Home:

Wall studs were spaced at 16 inches (406 mm) on center with load bearing studs located directly in-line with roof rafters and floor joists. The 16-inches (406 mm) on center represent local practice in the Valparaiso area for wood framing. All structural wood studs were 2x6 Douglas Fir. The 2x6 in-lieu of the 2x4 size was used in order to install the thicker insulation to meet the energy requirements. Non-structural wood studs were 2x4 Douglas Fir. Exterior were sheathed with 7/16 inch (11 mm) APA rated oriented-strand-board (OSB) to the studs (fully sheathed walls). The wood house has an additional dormer installed on top of the garage (attached to the bonus room). This was done to have different architectural looks for the houses. The wood house also had the front of the house faced with brick veneer.

The homes were marketed for between $180,000 and $200,000 depending on the options selected. Table 5.1 summarizes the characteristics and geometry of each of the demonstration homes built at the Valparaiso site.

Table 5.1 – Characteristics of Each Valparaiso Demonstration Home[1]

Characteristic	Steel House	Wood House
House Orientation	Front Door Faces East	Front Door Faces East
House Type	Colonial w/ Attached Garage	Colonial w/ Attached Garage
Number of Stories	2	2
Foundation Type	Concrete Basement & Crawl Space	Concrete Basement & Crawl Space
Roof Type	Steel Ceiling Joists and Rafters	Wood Ceiling Joists and Rafters
Roof Covering	Asphalt Fiberglass Shingles	Asphalt Fiberglass Shingles
Roof Pitch	7:12	7:12
House Width	40 ft.	40 ft.
House Length	52 ft.	52 ft.
1st Floor Wall Height	8 ft.	8 ft.
2nd Floor Wall Height	8 ft.	8 ft.
No. of Bedrooms	4	4
Basement	Unfinished	Unfinished
A/C Unit	10 SEER Central Air Conditioning	10 SEER Central Air Conditioning
Furnace	80% A.F.U.E. Gas Forced Air	80% A.F.U.E. Gas Forced Air

For SI: 1 ft. = 305 mm
[1] Refer to Appendix A for house dimensions.

6. TOOLS AND EQUIPMENT

Common tools were used in the construction of both demonstration homes.

Screws for the steel-framed home were installed using variable speed screw guns, provided by Black and Decker, with a clutch to prevent operator-induced fastening problems such as overdriving. Pneumatic pin drivers were used to fasten wood sheathing to steel wall studs. A chop saw with an abrasive aluminum oxide blade was used to cut steel members including studs, joists, and tracks. A standard circular saw with an abrasive blade and a hand-held power shears were also used to cut steel members. Other tools for the steel house were used such as drywall screw guns, vise clamps, metal hole puncher, tape measure, felt pencil, etc.

Common tools for the wood house were used such as hammers, nail guns, air compressor, circular saw, drywall screw gun, tape measure, etc.

7. HOUSE CONSTRUCTION

Table 7.1 provides a summary of framing details for each component of the two demonstration homes. Detailed floor plans are shown in Appendix A to this report.

Table 7.1 – Valparaiso Demonstration Homes Framing Details

Component	Steel House	Wood House
Basement	Unfinished Concrete Foundation Walls and Crawl Space	Unfinished Concrete Foundation Walls and Crawl Space
Insulation	R11 Fiberglass Batts	R11 Fiberglass Batts
Crawl Space Insulation	R13 Fiberglass Batts on Walls	R13 Fiberglass Batts on Walls
Floors	Cold-Formed Steel	Framing Lumber
Sill Plate	2x6 Treated SYP #1	2x6 Treated SYP #1
First Floor Joist Size & Spacing	1000S162-54 @ 16” and 24” o.c.	2x10 Doug Fir @ 16” o.c.
Second Floor Joist Size & Spacing	1000S162-54 @ 24”o.c.	2x10 Doug Fir @ 16” o.c.
Joist Fasteners	No. 10 x 3/4” Hex Head Screws	16d Nails – Senco Power Sinkers
Rim Track	1000T162-33	2x10 Doug Fir
Floor Sheathing	¾” x 4’x8’ Advantech Flooring	3/4” x 4’x8’ Advantech Flooring
Sheathing Fasteners	No. 10 x 1-1/4” Hex Head Screws	8d Nails-Senco Power/Sinkers
Floor Headers	1000S162-54	2x10 Doug Fir
Structural Walls	Cold-Formed Steel	Framing Lumber
Stud Size and Spacing	550S162-33 @ 24” o.c.	2x6 Doug Fir @ 16” o.c.
Stud Fasteners	No. 8 x 1/2” Pan Head Screws	16d Senco Power Nails
Top Plate/Track	550T162-33	2x6 Doug Fir
Wall Sheathing	7/16”x4’x8’ Oxboard (OSB)	7/16” x4’x8’ Oxboard (OSB)
Sheathing Fasteners	ET&F Pins	8d Senco Power Nails
Drywall Size	1/2”x4’x8’/12’	1/2”x4’x8’/12’
Drywall Fasteners	No. 6x1-1/4” Drywall Screws	No. 6x1-1/4” Drywall Screws
Rigid Foam Material & Thickness	3/4” Tenneco Extruded Polystyrene R-3.8 Rigid Foam Panels	N/A
Rigid Foam Fastening	Plastic Cap Nails	N/A
Siding Material	Vinyl Siding	Vinyl Siding, Brick Front
Wall Cavity Insulation Type	R19, Fiberglass Batts	R19, Fiberglass Batts
Non-Structural Walls	Cold-Formed Steel	Framing Lumber
Stud Size and Spacing	350S162-27 @ 24” o.c.	2x4 Doug Fir @ 24” o.c.
Stud Fasteners	No. 8 x 1/2” Pan Head Screws	16d Senco Power Nails
Drywall Size and Fasteners	1/2”x4’x8’/12’ with Drywall screws	1/2”x4’x8’/12’ with Drywall screws
Ceiling Joists and Roof Rafters	Cold-Formed Steel	Framing Lumber
Joist Size and Spacing	1000S162-43 @ 24”o.c.	2x10 Doug Fir @ 16” o.c.
Joist Fasteners	No. 10 x 1-1/4” Hex Head Screws	16d Nails-Senco Power/Sinkers
Drywall Size and Fastening	1/2”x4’x8’/12’ w/Drywall screws	1/2”x4’x8’/12’ w/Drywall screws
Rafter Size and Spacing	800S162-54 @ 24” o.c	2x8 Doug Fir @ 16” o.c.
Rafter Fasteners	No. 10 x 1-1/4” Hex Head Screws	Senco Power 16d Nails
Roof Sheathing	7/16”x4’x8’ Oxboard	7/16” x4’x8’ Oxboard
Roof Insulation Type and Thickness	R40 Cellulose, Blown in	R40 Cellulose, Blown in
Cathedral Ceiling Insulation	R30 Fiberglass Batts	R30 Fiberglass Batts

For SI: 1 ft. = 305 mm, 1 inch = 25.4 mm.

8. AIR LEAKAGE AND SHORT-TERM ENERGY TESTS

Each of the demonstration homes was tested for tightness, duct leakage, and short-term energy consumption. A brief description of each of the above-mentioned tests is shown below.

Air Leakage Test (Blower Door Test)

Natural air infiltration into and out of a house is a critical component in a home's energy performance and durability. Air infiltration comprises a large portion of the overall heating and cooling load in a home.

Blower door testing is used to quantify how much fresh air enters a building with all exterior openings closed. The results of a blower door test indicate how leaky a house is, where the major sources of air leakage are located, and how the house compares to other homes of similar size and type.

Test Method

A blower door test is performed in accordance with ASTM E779[5].

Results of blower door testing are presented in several ways, including Air Changes per Hour (ACH) value. An Air Change occurs when a building has its entire volume of air replaced with new air. The length of time required for this to take place is the infiltration rate of a building.

An ACH50 value is often used to relate a home's blower door results because the value is directly obtainable from the test and does not require any assumptions about the building's performance under natural (i.e. not under artificially elevated pressures) conditions. Results may also be presented in terms of airflow at a pressure differential of 50 Pascals, or CFM50.

Interpretation of blower door results usually involves a reference to some allowable leakage level. Many energy programs specify a maximum allowable ACH50 value. Others approximate a natural infiltration rate by dividing the ACH50 value by a factor that typically ranges from 17 – 20. These natural infiltration estimations are often criticized for being inaccurate. Other performance criteria may relate leakage to the square footage of the house, like CFM50 per square foot of living area.

Duct-Blaster Test

A similar diagnostic test is a duct blaster test. Like a blower door test, duct blaster testing quantifies the air leakage from a duct system by pressurizing the system with a fan. Duct leakage can waste large amounts of heating and cooling energy, especially when the ducts are located outside of the conditioned space of the building.

Test Method

A duct blaster test is performed in accordance with ASTM E1554-94[6]. It is conducted in a very similar manner to blower door testing. The duct system is pressurized using an auxiliary fan, and

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[5] ASTM E779-99 *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*. American Society for Testing and Materials, West Conshohocken PA.
[6] ASTM E1554-94 *Standard Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization*. American Society for Testing and Materials, West Conshohocken PA.

flow and pressure data points are recorded. Duct blaster results are usually referenced to a duct pressure of 25 Pascals relative to the house. Typical results are airflow at 25 Pa (cfm @ 25 Pa) and air leakage at 25 Pa normalized by house square footage (cfm/ft^2 @ 25 Pa).

Short-Term Energy Test (Co-heat Test)

The thermal performance of a building without significant mass can be reasonably obtained through the use of a Co-Heat Test. A co-heat test is conducted to determine the building load coefficient (UA) of a building. The building load coefficient represents the thermal conductivity of the conditioned building envelope. The UA can be divided by the surface area of the entire envelope to determine the average U value (1/R) for the house.

Test Method

During the test, thermostatically controlled portable electric heaters placed throughout the living area of the building maintain a constant indoor temperature. This is done to provide a steady state indoor temperature that will be compared to the outdoor conditions and building energy consumption to determine the thermal performance of the building. All energy and temperature data needs to be gathered by a data logger that can monitor the parameters and control the indoor temperatures.

To avoid the effects of solar gains, the test must be conducted during the nighttime hours. The test duration should be a minimum of one hour; this must follow achievement of thermal steady-state conditions. Temperature drifting within the living area should be minimized; ideally equipment will be designed to keep all areas within ±2°F.

It must be assumed that all electricity consumed during the test is converted into useable heat. The UA is determined as follows:

$$UA = Q/(\Delta T)t$$

Q = Energy consumed by the building for the test period (BTU)
ΔT = Average difference in indoor and outdoor temperatures for the test period (°F)
UA = Thermal resistance for the test building (BTU/hr-°F)
t = Test interval (hours)

It should also be noted that air infiltration could also account for a significant amount of heat loss as infiltration, or more accurately exfiltration, is a major source of energy loss in houses. To accurately determine the true "Thermal Performance" of a building, the exfiltration component should be eliminated from the co-heat test. This is commonly done through either a tracer gas dilution test or applying tested characteristics of the building with environmental conditions during the test. The primary drivers for infiltration are the wind speed and the difference between the indoor and outdoor temperatures. The effects of infiltration ($UA_{infiltration}$) can be estimated using the ASHRAE[7] recognized LBNL (Lawerence Berkley National Laboratory) model. The result is a function of the characteristics of the house (e.g. number of stories, shielding around house, etc.), conditions at time of testing (such as temperature and wind speed) and the Estimated Leakage Area (ELA) of the house which can be obtained by conducting a rigorous Blower Door test. The thermal performance ($UA_{thermal}$) of each house can be accurately estimated using the following equation:

[7] 2001 ASHRAE Handbook of Fundamentals Chapter 26.21, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

$UA_{thermal} = UA_{co\text{-}heat} - UA_{infiltration}$

The infiltration characteristics can be estimated through the use of a blower door test. This test can determine the air leakage from a house (CFM) given a variety of pressures (Pascal) applied by a fan. From established equations, an estimated leakage area (ELA) can be calculated.

The Lawrence Berkley Laboratories (LBL) developed a single-zone approach to calculating air infiltration rates in houses[8]. This method is illustrated in the following equation:

$$Q = ELA\,(A\Delta t + Bv^2)^{0.5}$$

Q = airflow rate, CFM
ELA = effective leakage area, in^2
A = stack coefficient
Δt = temperature difference, °F
B = wind coefficient
V = wind speed, mph

The result is a function of the characteristics of the house (e.g. number of stories, shielding around house,) conditions at time of testing (e.g. temperature, wind speed) and the Estimated Leakage Area (ELA) of the house. For an accurate ELA measurement, rigorous Blower Door test should be performed on each house. Even though the LBL model is widely accepted for measuring infiltration, there are numerous studies that indicate the stack effect component of the model is "known to have a bias and, therefore, requires compensation to improve accuracy."[9,10].

Test Apparatus and Procedure for the Valparaiso Demonstration Homes

Co-heat testing requires equipping the subject house with extensive monitoring and control equipment. Ambient air temperatures were taken at sixty-four different points throughout the house. Forty-eight of the temperatures were assigned to twelve zones with the average of four sensors associated with a heater determining whether the heater is on or off. The remaining sixteen sensors were placed in unconditioned areas such as the attic, garage and crawl space. Outside, a mini-weather station was located between 50-75 feet (15,240 to 22,860 mm) from the house. The station monitors, temperature, humidity, wind speed and direction.

At the center of all the equipment is a programmable data logger and electric relay box. The data logger records all the readings from the instruments and is able to calculate area temperatures and control the zone heaters as necessary. The relay box takes the low voltage signals from the data logger and controls the 240V heaters (up to 16). The power to the relay box is run directly from the main panel on a 100-amp circuit breaker.

The intention for testing the homes in Valparaiso was to determine a UA value for the entire house (including the basement) and the finished living space (excluding the basement). The energy used in the basement would be backed out of the total based upon run time and a calibrated power

[8] ASHRAE Handbook of Fundamentals (2001), American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, GA, p. 26.21.
[9] EPRI, Electric Power Research Institute, Uncertainty Analysis of the Measured Performance Rating Method, Research Project 2417-16, Palo Alto, CA (June 1994).
[10] Judkoff, R., J.D. Balcomb, C.E. Hancock, G. Barber, and K. Subbarao, Side-by-Side Thermal Tests of Modular Offices: A Validation Study of the STEM Method. NREL DE-AC36-99-GO10337 (December 2000).

consumption rate. Tests were conducted on three different nights, the first in the wood house and the second and third night in the steel house. The tests were run overnight with the data being used to calculate UA values gathered one hour prior to dawn when the previous day's solar gains are at their minimum.

9. FACTORS IMPACTING CONSTRUCTION AND COLLECTED DATA

It is important to address the factors that may have significant impact on the data collected. These factors include weather, trained supervision, availability of labor, and variability in home sizes.

Weather

Construction on the steel house began in December 1999. The weather was extremely cold during the first two months of construction, where temperatures dropped into the negative low teens. Construction on the wood house began in late January 2000. The cold weather resulted in a slower than usual construction for the steel floors, walls, and roof framing.

Significant time was spent in clearing snow from the material and for handling the materials during extreme weather conditions. This time was not captured in the time and motion study, as it was difficult to separate this time from the actual framing time.

Since construction on the wood house started later in the winter season, it faced a similar problem at the beginning of construction. However, the extreme weather conditions were not as big of a factor for the wood house as for the steel house. Therefore, it is our belief that adjustment factors to normalize the collected labor hours should be used given the direct impact of the severe weather conditions on the framing of these houses. An adjustment factor of 0.85 is recommended for the floor, bearing walls, and roof framing of the steel house while an adjustment factor of 0.95 is recommended for the floor, wall, and roof framing of the wood house as well as the interior non-bearing steel walls of the steel house. Since use of these factors will significantly impact the total results by skewing the labor cost of the steel house, two set of tables will be presented for the labor hours: One without any factors (Table 10.5) and one with adjustment factors (Table 10.6). Table 10.6 is provided only to show the potential impact of the weather adjustment factors on the workers' productivity based on the observed data, but will not be used in subsequent tables or to estimate the labor cost for each of the houses.

Trained Supervision

Construction on the steel house began with an experienced lead framer. This framer left shortly after the roof was framed. This caused some delays and nonproductive times in framing the rest of the house because the remaining crew was left without direct supervision for a few days. This issue was not a factor at all in the construction of the wood house. Availability of trained supervision is an issue that must be considered when using an alternative material such as steel, as such, no adjustment factors will be used on the steel house.

Availability of Trained Labor

The framing crew for the steel house suffered a high turn over rate during the construction period. New laborers (with less experience than the departing ones) were brought in to work on the house during the time and motion study data collection. This caused slight increases in the cost of framing especially in the interior non-structural walls and roof sheathing. The wood framing crew on the other hand was relatively stable throughout the construction period. No adjustment factors for the steel house will be used here also, as lack of trained labor is another issue that must be considered when using an alternative material such as steel.

Variability in Demonstration Homes Sizes

To the extent possible, both homes were identical. The variations in the completed homes were mainly due to construction tolerances and practices. The results of this study will be presented on the basis of the actual square or linear footage of each house, so that the difference in sizes will have negligible impact on the results. The difference in construction (such as vinyl vs. brick or the additional dormer) will be addressed by backing out the times for these activities.

Stud Size and Spacing

The wood house uses 2x6 exterior wood studs spaced at 16" (406 mm) on center while the steel house uses 550S162 exterior steel studs spaced at 24" (610 mm) on center. This difference could have a significant impact on the material cost of the steel house. Local practice in Valparaiso is to place wood studs at 16" (410 mm) on center. This is done because of dimensional stability of the wood studs, the difficulty in drywall installation for 24" (610 mm) on center stud spacing, and the need for deeper cavity for insulation. Although the practice is to place wood studs at 16" (406 mm) on center, it can be shown that a 24" (610 mm) on center stud spacing can be structurally satisfactory. The impact of the stud spacing will be discussed in the conclusion of this report. On the other hand, the steel house could have easily used 350S162 steel studs in lieu of the 550S162 used as *the Prescriptive Method*[11] allows both stud sizes to be used for the given site location and environmental loads. However, for this report, no adjustment factors will be used for these differences.

Labor Cost

The builder reported that his framers (full time employees) are being paid significantly higher wages than their wood framer counterparts because of competition with local commercial work. Valparaiso (in Northern Indiana) has a high demand for commercial steel framers who typically earn higher wages. To stay competitive and retain the experienced framers, builders are expected to pay higher wages. However, for this report, no adjustment factors will be used for labor cost (i.e., actual cost paid by builder will be used).

10. PRODUCTIVITY COMPARISONS

The wood and steel demonstration homes were approximately 2200 square-foot (205 m^2) each, two-story custom homes with full unfinished basements in Valparaiso, Indiana. Floor plans for the demonstration homes are shown in Appendix A. The Valparaiso site presented several regional conditions that make steel framing a particularly attractive alternative:

- a fast growing area that is receptive to new and advanced technologies;
- well trained wood and steel residential framers;
- abundant suppliers of steel framing materials;
- existing steel builders;

[11] *Prescriptive Method for Residential Cold-Formed Steel Framing*, Second Edition. U.S. Department of Housing and Urban Development (HUD), Washington, DC. September 1997.

- steel framing is accepted by the local building officials;
- steel prescriptive standards are widely used;
- engineering is not required for either steel- or wood-framed homes, and,
- local code requires steel homes to have exterior foam sheathing that provides a good candidate for long-term energy monitoring of both houses in a relatively cold climate.

Framing the steel house began in mid December 1999. Framing the wood house began in late January 2000. Both houses were completed in late April 2000. The framing crew for both houses include (see Table 10.1):

- three steel framers with combined experience of more than 20 years using cold-formed steel framing for residential construction. The framers are full time employees for the builder;
- a steel framing foreman for the builder who exclusively frames with steel, but previously framed with wood.
- three wood framers with combined experience of more than 30 years using conventional wood framing construction. The framers worked for a subcontractor who was hired to frame the wood house; and,
- a wood framing foreman (contractor) who exclusively frames with wood.

A NAHB Research Center engineer monitored the construction process for both wood and steel homes from start to finish. The site engineer was present during every aspect of the construction process. A modified version of the group timing technique was used to document the time to build each of the two demonstration homes. The activity of each crewmember was recorded at 15-minute intervals. Data were collected and coded for each component of the house (walls, floors, roofs, etc.) and sub-component of the framing (studs, sheathing, etc.). Nonproductive time such as breaks or idle time was separated from productive time. Increases in time for personnel, fatigue, and delays were not added to productive time.

Summary of Data Collected

Appendix B contains a detailed breakdown by component and sub-component of the labor man-minutes from the time and motion study conducted at each site. Appendix C contains normalized labor man-minutes for each component of the house. The normalization was done based on the size (such as square footage of floor, walls, roofs, etc) for each of the framing components and based on the living area square footage for the sub trades. The normalization procedure assumed that all activities not involving the framing material should be the same (e.g., cutting OSB for the floor framing or installing furnace in the basement). This way, the activity that has a direct impact on the framing material or that is directly impacted by the framing material is identified. It is to be noted also that a weather adjustment factor will be used on the times reported in Appendix C. Appendix D contains detailed material take off and costs for each of the two houses.

Table 10.2 describes the contractors and sub-contractors for each of the demonstration homes. Table 10.3 summarizes the dimensions of the different components for each of the demonstration homes as obtained (measured) from each site. Table 10.4 provides a detailed summary of the total man-hours for each component of each of the demonstration homes, based on actual man-minutes from Appendix B (with no adjustments). Table 10.5 summarizes the normalized man-hours for each activity. Table 10.6 provides normalized man-hours for each activity with the weather adjustment factor applied. The times in Tables 10.5 and 10.6 have been adjusted for the larger porch for the steel house and the dormer for the wood house.

Table 10.1 – Crew Composition for Valparaiso Demonstration Homes

Component	Steel House	Wood House
Floor, Structural Walls, Non-Structural Walls and Roof Framing and Decking	Foreman, 2 Framers, 1 Helper	Foreman, 2 Framers, 1 Helper
Structural Wall Sheathing Installation	Foreman, 3 Framers, 1 Helper	Foreman, 3 Framers, 1 Helper
Roofing	2 Roofers	2 Roofers
Rigid Foam Installation	2 Framers	N/A
Blown in Insulation	2 Workers	2 Workers
HVAC	2 Installers	2 Installers
Electrical	Foreman & 2 Electricians	Foreman & 2 Electricians
Plumbing	Foreman & 2 Plumbers	Foreman & 2 Plumbers
Batt Insulation	4 Installers	4 Installers
Vinyl Siding	Foreman & Helper	Foreman & Helper
Brick Installation	N/A	Foreman, 1 Installers, 2 Helper
Drywall Installation	Foreman & 2 Installers	Foreman & 3 Installers
Trim Carpentry	2 Installers	2 Installers
Drywall Finishing	2 Installers	2 Installers
Painting	1 Painter	1 Painter
Windows, Doors & Kitchen Cabinets	2 Framers	2 Framers
Vinyl and Hardwood Floors	2 Installers	2 Installers
Carpet	Foreman, Installer, & Helper	Foreman, Installer, & Helper
Front Porch Framing	Foreman, 2 Framers, 1 Helper	Foreman, 1 Framer, 1 Helper
Deck Framing	2 Installers	2 Installers
Stairs	1 Framer & 1 Helper	1 Framer & 1 Helper
Garage/ Door Opener Installation	1 Installer	1 Installer
Fire Place Installation	1 Installer	1 Installer

Table 10.2 – Contractors for Valparaiso Demonstration Homes

Component	Steel House	Wood House
Floors, Walls, and Roof Framing	RSDS Framers	Clark Framers
Roofing	Same subcontractor, K's Roofing	
Rigid Foam Installation	RSDS Framers	N/A
Blown in Insulation	Same subcontractor, EGI Insulation	
HVAC	Same subcontractor, Air-Rite Service	
Electrical	Same subcontractor, Pride Electric	
Plumbing	Same subcontractor, E&M Specialists	
Insulation	Same subcontractor, EGI Insulation	
Siding	Same subcontractor, Allen Builders	
Drywall Installation	Same subcontractor, Different Crew, Prizm Drywall, Inc.	
Trim Carpentry	BB Wolfe Construction	Ryon Klemp
Drywall Finishing	Same subcontractor, Russel Reed	
Painting	Same subcontractor, Russel Reed	
Windows and Doors	RSDS Framers	Clark Framers
Kitchen Cabinets	BB Wolfe Construction	Ryon Klemp
Floor Covering	Same subcontractor, Capital Interiors	
Front Porch Framing	RSDS Framers	Clark Framers
Deck Framing	Dustin Hicks/Trina Fletcher	Dustin Hicks/Trina Fletcher
Stairs	RSDS Framers	Clark Framers
Garage Door/Door Opener Installation	Same subcontractor, Different Crew	
Fire Place Installation	Same Subcontractor, PCS Fire Place, Different Crew	

Table 10.3 - Dimensions of Valparaiso Demonstration Homes

Component	Steel House	Wood House
Square footage of living area	2,207 ft^2	2,198 ft^2
Square footage of garage	393 ft^2	388 ft^2
Square footage of basement	999 ft^2	999 ft^2
Square footage of first floor	1274 ft^2	1,267 ft^2
Square footage of second floor	933 ft^2	931 ft^2
Lineal footage of first story load bearing walls	246 ft.	245 ft.
Square footage of first story load bearing walls	1,965 ft^2	1,957 ft^2
Lineal footage of second story load bearing walls	111 ft.	110 ft.
Square footage of second story load bearing walls	888 ft^2	880 ft^2
Square footage of first story exterior walls	1,585 ft^2	1,580 ft^2
Square footage of second story exterior walls	780 ft^2	771 ft^2
Square footage of ceiling	2,272 ft^2	2,276 ft^2
Square footage of roof	2,572 ft^2	2,432 ft^2
Square footage of porch roof	392 ft^2	140 ft^2
Square footage of dormer roof	N/A	112 ft^2
Lineal footage of first story non-load bearing walls	115 ft.	113 ft.
Square footage of first story non-load bearing walls	920 ft^2	904 ft^2
Lineal footage of second story non-load bearing walls	149 ft.	149 ft.
Square footage of second story non-load bearing walls	1,192 ft^2	1,192 ft^2
Square footage porch	118 ft^2	48 ft^2
Square footage of deck	126 ft^2	126 ft^2
Square footage of additional false dormer	N/A	48 ft^2
Square footage of brick front	N/A	219 ft^2

For SI: 1 ft^2 = 0.093 m^2, 1 ft = 305 mm.

Table 10.4 – Actual Labor Hours for Valparaiso Demonstration Homes

Framing Component	Total Labor Man-Hours (Hours)	
	Steel House	**Wood House**
Floors[1]	60.75	63.67
First Floor Framing[1]	*34.50*	*36.17*
Second Floor Framing[1]	*26.25*	*27.50*
Structural Walls[2]	80.75	55.25
First Story Structural Walls[3]	*39.25*	*35.75*
Second Story Structural Walls[3]	*20.75*	*19.50*
First Story Rigid Foam	*9.75*	*N/A*
Second Story Rigid Foam	*11.00*	*N/A*
Non-Structural Walls[2]	59.25	60.50
First Story Non-Structural Walls	*33.17*	*34.17*
Second Story Non-Structural Walls	*26.08*	*26.33*
Roof[1]	92.25	88.50
Ceiling Joists	*11.00*	*11.00*
Rafters w/Decking	*81.25*	*77.50*
Total Framing	**293.00**	**277.92**
HVAC	45.67	46.25
Electrical	73.25	85.92
Plumbing	58.00	51.25
Batt Insulation	22.00	21.75
Siding[4]	77.42	64.00
Drywall Installation, Finishing & Painting	199.50	209.00
Windows and Doors	42.00	43.25
Kitchen Cabinets	33.50	33.25
Baseboard Trim	26.00	25.75
Floor Covering	30.50	30.50
Front Porch Framing[5]	32.25	16.00
Deck Framing	9.00	9.00
Stairs	9.50	8.75
Garage Door and Door Opener Installation	4.00	4.00
Roof Shingles	40.25	40.50
Fire Place Installation	2.00	2.00
Total Hours	**997.84**	**969.09**

[1] Hours include sheathing.
[2] The wood house has an additional false dormer on the second floor bonus room.
[3] Hours include wall sheathing and for steel house only rigid foam installation.
[4] The wood house has a 228 ft^2 (21.18 m^2) of the front wall finished with brick.
[5] The front porch for the steel house is 118 ft^2 (10.96 m^2) vs. 48 ft^2 (4.46 m^2) for the wood house

Table 10.5 – Normalized Labor Hours for Valparaiso Demonstration Homes

Framing Component	Total Labor Man-Hours (Hours)	
	Steel House	**Wood House**
Floors[1]	60.75	63.67
First Floor Framing[1]	*34.50*	*36.17*
Second Floor Framing[1]	*26.25*	*27.50*
Structural Walls[2]	80.75	55.25
First Story Structural Walls[2]	*39.25*	*35.75*
Second Story Structural Walls[2]	*20.75*	*19.50*
First Story Rigid Foam	*9.75*	*N/A*
Second Story Rigid Foam	*11.00*	*N/A*
Non-Structural Walls[2]	59.25	60.50
First Story Non-Structural Walls	*33.17*	*34.17*
Second Story Non-Structural Walls	*26.08*	*26.33*
Roof[1,4]	92.25	88.50
Ceiling Joists	*11.00*	*11.00*
Rafters[1]	*81.25*	*77.50*
Total Framing	**293.00**	**267.92**
HVAC	39.20	39.20
Electrical	68.25	76.25
Plumbing	58.00	52.75
Batt Insulation	22.00	21.50
Siding[5]	64.00	64.00
Drywall Installation, Finishing & Painting	199.50	209.50
Windows and Doors	42.00	42.00
Kitchen Cabinets	33.50	33.00
Baseboard Trim	26.00	25.75
Floor Covering	30.50	30.50
Front Porch Framing[6]	13.12	16.00
Deck Framing	10.00	10.00
Stairs	9.50	8.75
Garage Door and Door Opener Installation	4.00	4.00
Roof Shingles[4]	40.25	39.58
Fire Place Installation	2.00	2.00
Total Hours	**954.82**	**942.70**

[1] Hours include sheathing.
[2] Adjusted for the additional dormer time (dormer framing time backed out).
[3] Hours include wood sheathing.
[4] Adjusted for roof size.
[5] Adjusted for square footage of vinyl siding.
[6] Adjusted for porch size (same size porch is used).

Table 10.6 – Normalized Labor Hours with Weather Adjustment Factors for Valparaiso Demonstration Homes[1]

Framing Component	Total Labor Man-Hours (Hours)	
	Steel House	**Wood House**
Floors[1]	51.64	60.49
First Floor Framing[2]	*29.33*	*34.36*
Second Floor Framing[2]	*22.31*	*26.13*
Structural Walls[3]	68.64	52.49
First Story Structural Walls[4]	*33.36*	*33.96*
Second Story Structural Walls[4]	*17.64*	*18.53*
First Story Rigid Foam	*8.29*	*N/A*
Second Story Rigid Foam	*9.35*	*N/A*
Non-Structural Walls[2]	56.29	57.48
First Story Non-Structural Walls	*31.51*	*32.46*
Second Story Non-Structural Walls	*24.78*	*25.02*
Roof[1,5]	78.41	84.08
Ceiling Joists	*9.35*	*10.45*
Rafters[2]	*69.06*	*73.63*
Total Framing	**254.98**	**254.54**
HVAC	39.20	39.20
Electrical	68.25	76.25
Plumbing	58.00	52.75
Batt Insulation	22.00	21.50
Siding[6]	64.00	64.00
Drywall Installation, Finishing & Painting	199.50	209.50
Windows and Doors	42.00	42.00
Kitchen Cabinets	33.50	33.00
Baseboard Trim	26.00	25.75
Floor Covering	30.50	30.50
Front Porch Framing[7]	13.12	16.00
Deck Framing	10.00	10.00
Stairs	9.50	8.75
Garage Door and Door Opener Installation	4.00	4.00
Roof Shingles[5]	40.25	39.58
Fire Place Installation	2.00	2.00
Total Hours	**916.80**	**929.32**

[1] An adjustment factor of 0.85 is used on floor, structural walls and roof framing of the steel house. An adjustment factor of 0.95 is used for the floor, walls and roof framing of the wood house as well as the non-structural wall framing of the steel house.
[2] Hours include sheathing.
[3] Adjusted for the additional dormer time (dormer framing time backed out).
[4] Hours include wood sheathing.
[5] Adjusted for roof size.
[6] Adjusted for square footage of vinyl siding.
[7] Adjusted for porch size (same size porch is used).

Labor hours summarized in Table 10.5 are taken directly from the detailed man-minutes contained in Appendix C. Tables 10.7 provides a summary of material and labor cost for each of the demonstration homes. Table 10.8 provides a summary of fasteners (nails, screws, … etc) cost (material only) as paid by builder. The costs in Tables 10.7 and 10.8 were taken directly from the builder's invoices and budget reports. Table 10.9 normalizes the material costs shown in table 10.7. Material costs that are not impacted by the framing material were set to be equal (such as fireplace, siding, plumbing, etc.)

Table 10.7 – Total Material and Labor Cost Paid by Builder

Component/Trade	Total Material Cost from Builder's Invoices		Total Labor Cost from Builder's Invoices	
	Steel House	Wood House	Steel House	Wood House
Framing	$13,836	$16,178	$12,100	$9,062
Fasteners	$1,059	$497	-	-
Rigid Foam	$706	N/A	(1)	N/A
Trim Carpentry	$6,049	$6,012	$2,271	$2,337
Exterior Doors	$989	$988	(1)	(1)
Windows	$1,834	$2,362	(1)	(1)
Plumbing	$1,803	$1,895	$3,800	$3,800
HVAC	$5,530[3]	$5,530[3]	(2)	(2)
Electrical	$702	$704	$4,090	$3,815
Drywall	$2,804	$2,564	$4,404	$4,164
Roofing	$1,348	$1,328	$1,127	$1,038
Insulation	$3,677[3]	$3,237[3]	(2)	(2)
Siding	$2,897	$2,709	$2,865	$2,815
Fireplace	$1,013	$1,071	(1)	$290
Cabinets, vanities, tops	$2,841	$2,782	(4)	(4)
Garage Door	$830	$830	(2)	(2)
Painting	$2,546	$2,706	(2)	(2)
House Cleaning	-	-	$142	$151
Total	**$50,464**	**$51,393**	**$30,799**	**$27,472**

[1] Labor cost included in the framing labor cost.
[2] Labor cost included in the material cost.
[3] Includes labor cost.
[4] Included in Trim Carpentry labor cost.

Table 10.8 – Fasteners Cost Paid by Builder

Fastener	Steel House	Wood House
ET&F Pins	$648	-
Grabber Floor Screws	$20	-
No. 10x3/4" Hex Head	$200	-
No. 10x1-1/4" Hex Head	$40	-
No. 8x1/2" Pan Head	$40	-
No. 6x1-1/4" Drywall Screws	$80	(1)
No. 6x2-3/8" Drywall Screws	$5	(1)
Plastic Cap Nails	$26	-
Senco Power Nails 16d	-	$94.27
Senco Power Nails 10d	-	$68.04
Senco Power Nails 8d	-	$198.28
16d Nails, Sinkers	-	$42.70
8d Nails, Sinkers	-	$42.70
1-3/4" Quick Drive Screws	-	$47.14
Galvanized casement Nails 16d and 8d Nails	-	$4.30
Total	**$1,059**	**$497.43**

[1] Cost of drywall screws is included in the drywall material cost.

Table 10.9 – Normalized Material and Actual Labor Cost Paid by Builder

Component/Trade	Total Material Cost from Builder's Invoices		Total Labor Cost from Builder's Invoices	
	Steel House	Wood House	Steel House	Wood House
Framing	$13,836	$16,178	$12,100	$9,062
Fasteners	$1,059	$497	-	-
Rigid Foam	$706	N/A	(1)	N/A
Trim Carpentry	$6,049	$6,012	$2,271	$2,337
Exterior Doors	$989	$989	(1)	(1)
Windows	$1,834	$1,834	(1)	(1)
Plumbing	$1,803	$1,803	$3,800	$3,800
HVAC	$5,530[3]	$5,530[3]	(2)	(2)
Electrical	$702	$704	$4,090	$3,815
Drywall	$2,564	$2,564	$4,404	$4,164
Roofing	$1,348	$1,348	$1,127	$1,038
Insulation	$3,677[3]	$3,237[3]	(2)	(2)
Siding	$2,709	$2,709	$2,865	$2,815
Fireplace	$1,013	$1,013	(1)	$290
Cabinets, vanities, tops	$2,841	$2,782	(4)	(4)
Garage Door	$830	$830	(2)	(2)
Painting	$2,546	$2,706	(2)	(2)
House Cleaning	-	-	$142	$151
Total	**$50,036**	**$50,736**	**$30,799**	**$27,472**

[1] Labor cost included in the framing labor cost.
[2] Labor cost included in the material cost.
[3] Includes labor cost.
[4] Included in Trim Carpentry labor cost.

11. ANALYSIS OF DATA

Framing plans were not available for either of the two homes, as the normal construction practice in Valparaiso is to have floor plans and house elevation drawings only. Material invoices and builder's budget reports were used to allocate approximate cost of materials for each framing component.

Valparaiso Demonstration Homes

Tables 11.1 and 11.2 summarize the total labor hours and material cost for each framing component of the steel and wood demonstration homes in Valparaiso, respectively. Normalized labor hours (from Tables 10.5, 10.7 and 10.8) are used in these tables. Costs associated with framing only are included in these tables (e.g. roof shingles are independent of framing materials and thus are not included).

Tables 11.3 and 11.4 summarize normalized labor and material costs (from Table 10.9) for the different trades (and sub trades) for each of the two demonstration homes. The material costs used in these tables were taken directly from builder's invoices. Hours per square foot for each of the trades are also tabulated in Tables 11.3 and 11.4

Tables 11.5 through 11.8 itemize the cost of each of the main framing components in the house (floors, walls, and roof) using labor cost as paid by the builder and normalized labor hours as shown in Table 10.5. The tabulated costs include sheathing installation and for the steel-framed house the rigid foam installation. Labor costs were taken from builder's invoices and allocated to each framing element based on the number of hours spent. The allocation is calculated based on the number of hours spent for each activity multiplied by the total labor cost paid by builder divided by the total labor hours spent as follows:

$$Labor\ Cost = \frac{\$12{,}100\, x\, Hours / Activity}{321.62} \qquad \text{for the steel house}$$

$$Labor\ Cost = \frac{\$9{,}062\ x\ Hours / Activity}{298.67} \qquad \text{for the wood house}$$

Where the 321.62 and the 298.67 are the total labor hours for the steel and wood homes respectively. These hours include framing and sheathing (floors, walls, roof), porch framing, stairs framing, fireplace framing, and rigid foam installation. These hours are calculated from Table 10.5 as follows:

Total Hours = Framing hours + Fire place + Garage Door + Stairs + Porch
Steel House Hours = 293 + 2 + 4 + 9.50 + 13.12 = 321.60 hours
Wood House Hours = 267.92 + 2 + 4 + 8.75 + 16 = 298.67 hours

Tables 11.9 provides the cost per square foot of floor area, roof area or wall area for the different trades. Normalized builder's costs were used.

Table 11.10 provides the total framing cost of each of the two houses. The framing cost includes material cost from Tables 11.1 and 11.2 (including fasteners and insulation) and labor cost for floors, walls, and roof from table 10.9 (without roof covering).

Table 11.11 shows the total cost of the framing and trades for each of the two demonstration homes. The cost includes materials and labor for framing, HVAC, electrical, plumbing, insulation, siding, drywall, painting, windows and doors, cabinets, vanities and tops, trim carpentry, floor covering, deck, and roof covering (from Tables 11.1, 11.2, and 11.9).

Fasteners cost for the wood house were obtained from the builder's material invoices, which were provided and categorized by framing component (i.e., floors, walls and roof). Fasteners cost for the steel house, on the other hand, were proportioned based on the square footage of the framing component (i.e., the fastener cost from Table 10.8 was proportioned based on the square footage of each framing component and directly added to the cost of each framing component.)

Tool costs were not included in any of the tables. Tool costs vary based on the type of tools used. Furthermore, the wood contractor had the cost of the tools built into the labor cost. The builder supplied the steel-framers with the framing tools and did not have a separate line item for tools on his budget reports.

The steel demonstration home in Valparaiso had several factors that could have impacted the total costs (for the steel house) documented in this report. Some of these factors could have falsely showed the cost of steel-framed homes to be "in the same ballpark" as wood framed homes. These factors include:

1. Engineering costs were not included because the steel house was built in accordance with the Prescriptive Method (steel framing provisions are currently in the IRC[12] and the Prescriptive Method have been accepted by some jurisdictions),
2. Generation Homes is an experienced steel-homes builder (wood house framer was also experienced in wood homes),
3. Generation Homes used steel framing members cut to length by the steel supplier (not common practice in residential steel framing),
4. Generation Homes supplied the framers with all necessary tools (although tool costs were not included for both steel and wood homes),
5. The steel studs were framed at 24" (610 mm) on center while the wood studs were framed at 16" (406 mm) on center (refer to Section 14 of this report for impact of 24" (610 mm) versus 16" (406 mm) spacing),

[12] International Residential Code for One- and Two-Family Dwellings, 2000 Edition. International Code Council. Falls Church, Virginia.

Table 11.1 – Normalized Framing Labor and Material Cost of Valparaiso Steel House

Framing Component	Labor Hours (Hrs.)	Material Cost ($)	Fastener Cost[1] ($)	Misc. Wood Cost ($)	Total Material Cost ($)
First Floor[2]	34.50	$3,303	$114	$94	$3,511
Second Floor[2]	26.25	$1,694	$83	$126	$1,903
1st Story Structural Walls[2]	39.25	$1,915	$173	$240	$2,328
2nd Story Structural Walls[2]	20.75	$796	$85	$160	$1,041
1st Story Non-Structural Walls	33.17	$350	$104	$112	$566
2nd Story Non-Structural Walls	26.08	$302	$97	$112	$511
Ceiling Joists	11.00	$993	$83	-	$1,076
Rafters/Roof[2]	81.25	$2,826	$205	$454	$3,485
Porch	13.12	$138	$10	$96	$244
Stairs	9.50	-	-	$125	$125
Rigid Foam	20.75	$706	$26	-	$732
Totals	**315.62**	**$13,023**	**$980**	**$1,519**	**$15,522**

[1] Cost of screws for framing out basement walls is not included.
[2] Material cost include wood sheathing for floors, walls and roofs.

Table 11.2 – Normalized Framing Labor and Material Cost of Valparaiso Wood House

Framing Component	Labor Hours (Hrs.)	Material Cost ($)	Fastener Cost[1] ($)	Misc. Wood Cost ($)	Total Material Cost ($)
First Floor[2]	36.17	$3,745	$239	-	$3,984
Second Floor[2]	27.50	$2,112	$36	-	$2,148
1st Story Structural Walls[2]	35.75	$2,060	$30	-	$2,090
2nd Story Structural Walls[2]	19.50	$1,730	$75	-	$1,805
1st Story Non-Structural Walls	34.17	$884	$10	-	$884
2nd Story Non-Structural Walls	26.33	$759	$25	-	$794
Ceiling Joists	11.00	$552	$16	-	$568
Rafters/Roof[2]	77.50	$3,911	$50	-	$3,961
Porch	16.00	$200	$4	-	$204
Stairs	8.75	$225	$4	-	$229
Rigid Foam	N/A	-	-	-	-
Totals	**292.67**	**$16,178**	**$489**	**-**	**$16,667**

[1] Cost of nails for framing out basement walls is not included.
[2] Material cost include wood sheathing for floors, walls and roofs.

Table 11.3 – Trades Normalized Labor and Material Cost for Valparaiso Steel House

Trade	Builder's Material Cost ($)	Labor Hours	Builder's Labor Cost ($)	Hours/ ft^2 of House[1]
HVAC	$5,530[2]	39.20	(3)	0.018
Electrical	$702	68.25	$4,090	0.031
Plumbing	$1,803	58.00	$3,800	0.026
Insulation	$3,677[2]	22.00	(3)	0.010
Siding	$2,897	71.20	$2,865	0.032
Drywall	$2,804	99.75	$4,404	0.045
Drywall Finish and Paint	$2,546[2]	99.75	(3)	0.045
Windows and Ext. Doors	$2,823	42.00	(4)	0.019
Cabinets, Vanities, Tops	$2,841	33.50	(5)	0.015
Trim Carpentry	$6,049	26.00	$2,271	0.012
Floor Covering	$5,327[2]	30.50	(3)	0.014
Deck	$554	10.00	$420	0.004
Roof Covering	$1,348	40.25	$1,127	0.018
Total	**$38,901**	**640.40**	**$18,977**	**0.289**

For SI: 1 ft^2 = 0.093 m^2

[1] Hours per square foot of the living area (2,207 ft^2).

[2] Includes labor cost.

[3] Included in builder's material cost.

[4] Included in builder's framing labor cost.

[5] Included in builder's trim carpentry labor cost.

Table 11.4 – Trades Normalized Labor and Material Cost for Valparaiso Wood House[1]

Trade	Builder's Material Cost ($)	Labor Hours	Builder's Labor Cost ($)	Hours/ ft^2 of House[1]
HVAC	$5,530[2]	39.20	(3)	0.018
Electrical	$704	76.25	$3,815	0.035
Plumbing	$1,895	52.75	$3,800	0.024
Insulation	$3,237[2]	21.50	(3)	0.010
Siding	$2,709	71.20	$2,815	0.032
Drywall	$2,564	95.75	$4,164	0.043
Drywall Finish and Paint	$2,706[2]	113.75	(3)	0.052
Windows and Ext. Doors	$2,823	42.00	(4)	0.019
Cabinets, vanities, tops	$2,782	33.00	(5)	0.015
Trim Carpentry	$6,012	25.75	$2,337	0.012
Floor Covering	$5,037	30.50	(3)	0.014
Deck	$620	10.00	$420	0.005
Roof Covering	$1,328	39.58	$1,038	0.018
Total	**$37,947**	**651.23**	**$18,389**	**0.297**

For SI: 1 ft^2 = 0.093 m^2

[1] Hours per square foot of the living area (2,198 ft^2).

[2] Includes labor cost.

[3] Included in builder's material cost.

[4] Included in builder's framing labor cost.

[5] Included in builder's trim carpentry labor cost.

Table 11.5 – Total Floor Framing Cost

House	Floor Area (ft^2)	Material and Fastener Cost ($)	Total Hours (hours)	Labor Cost ($)	Material Cost per FT^2 of Floor Area ($\$/ft^2$)	Labor Cost per FT^2 of Floor Area ($\$/ft^2$)	Hours per FT^2 of Floor Area (hours/ft^2)	Total Cost per FT^2 of Floor Area ($\$/ft^2$)
Steel House	2,207	$5,414	60.75	$2,285	$2.45	$1.04	0.028	$3.49
Wood House	2,198	$6,132	63.67	$1,932	$2.79	$0.88	0.029	$3.67

Table 11.6 – Total Structural Walls Framing Cost

House	Wall Length (ft)	Material and Fastener Cost ($)	Total Hours (hours)	Labor Cost ($)	Material Cost per Foot of Wall Length ($/ft)	Labor Cost per Foot of Wall Length ($/ft)	Hours per Foot of Wall Length (hours/ft)	Total Cost per Foot of Wall Length ($/ft)
Steel House	357	$4,963	80.75	$3,038	$13.90	$8.51	0.226	$22.41
Wood House	355	$3,895	55.25	$1,676	$10.97	$4.72	0.156	$15.69

Table 11.7 – Total Non-Structural Walls Framing Cost

House	Wall Length (ft)	Material and Fastener Cost ($)	Total Hours (hours)	Labor Cost ($)	Material Cost per Foot of Wall Length ($/ft)	Labor Cost per Foot of Wall Length ($/ft)	Hours per Foot of Wall Length (hours/ft)	Total Cost per Foot of Wall Length ($/ft)
Steel House	264	$1,077	59.25	$2,229	$4.08	$8.44	0.224	$12.52
Wood House	262	$1,678	60.50	$1,836	$6.41	$7.01	0.231	$13.42

Table 11.8 – Total Roof Framing Cost

House	Floor Area (ft^2)	Material and Fastener Cost ($)	Total Hours (hours)	Labor Cost ($)	Material Cost per FT^2 of Roof Area ($\$/ft^2$)	Labor Cost per FT^2 of Roof Area ($\$/ft^2$)	Hours per FT^2 of Roof Area (hours/ft^2)	Total Cost per FT^2 of Roof Area ($\$/ft^2$)
Steel House	2572	$4,561	92.25	$3,470	$1.77	$1.35	0.036	$3.12
Wood House	2432	$4,529	88.50	$2,685	$1.86	$1.10	0.036	$2.96

Table 11.9 – Trades Costs[1]

Trade	STEEL HOUSE				WOOD HOUSE			
	Labor Cost ($)	Material Cost ($)	Total Cost ($)	Cost per FT^2 of House ($/ft²)	Labor Cost ($)	Material Cost ($)	Total Cost ($)	Cost per FT^2 of House ($/ft²)
HVAC	(3)	$5,530 [2]	$5,530	$2.51	(3)	$5,530 [2]	$5,530	$2.52
Electrical	$4,090	$702	$4,792	$2.17	$3,815	$704	$4,519	$2.06
Plumbing	$3,800	$1,803	$5,603	$2.54	$3,800	$1,895	$5,695	$2.59
Insulation	(3)	$3,677 [2]	$3,677	$1.67	(3)	$3,237 [2]	$3,237	$1.47
Siding[6]	$2,865	$2,709	$5,762	$2.24	$2,815	$2,709	$5,524	$2.60
Drywall	$4,404	$2,804	$7,208	$3.27	$4,164	$2,564	$6,728	$3.06
Drywall Finish and Paint	(3)	$2,546 [2]	$2,546	$1.15	(3)	$2,706 [2]	$2,706	$1.23
Windows and Ext. Doors	(4)	$2,823	$2,823	$1.28	(4)	$3,350	$3,350	$1.52
Cabinets, vanities, tops	(5)	$2,841	$2,841	$1.29	(5)	$2,782	$2,782	$1.27
Trim Carpentry	$2,271	$6,049	$8,320	$3.77	$2,337	$6,012	$8,349	$3.80
Floor Covering	(3)	$5,327 [2]	$5,327	$2.41	(3)	$5,037	$5,037	$2.29
Deck	$420	$554	$974	$0.44	$420	$620	$1,040	$0.47
Garage Door	(4)	$830	$830	0.38	(4)	$830	$830	0.38
Fire Place	(4)	$1,013	$1,013	0.46	$290	$1,013	$1,303	0.60
Roof Covering[7]	$1,127	$1,348	$2,475	$0.96	$1,038	$1,328	$2,366	$1.11
Total	**$18,997**	**$40,556**	**$59,741**	**$26.54**	**$18,679**	**$40,317**	**$58,996**	**$26.97**

For SI: 1 $ft^2 = 0.093\ m^2$
[1] Costs are shown per square foot of living area (2,207 ft^2 for the steel house and 2,198 ft^2 for the wood house) unless noted otherwise (such as roofs and walls).
[2] Includes labor cost.
[3] Included in builder's material cost.
[4] Included in builder's framing labor cost.
[5] Included in builder's trim carpentry labor cost.
[6] Cost is calculated per square foot of exterior wall surface area (2365 ft^2 steel walls and 2125 ft^2 for wood walls).
[7] Cost is calculated per square foot of roof area (2572 ft^2 steel roof and 2432 ft^2 wood roof).

Table 11.10 – Total Framing Cost [1]

House	Total Living Area (ft)	Material Cost ($)	Builder's Labor Cost ($)	Builder's Total Cost ($)	Total Cost/FT^2 of Living Area ($/ft²)
Steel House	2207	$15,522	$12,100	$27,622	$12.52
Wood House	2198	$16,667	$9,062	$25,729	$11.71

For SI: 1 $ft^2 = 0.093\ m^2$
[1] Includes framing materials, sheathing and fasteners.

Table 11.11 – Total Framing and Trades Cost [1]

House	Total Living Area (ft)	Material Cost ($)	Builder's Labor Cost ($)	Builder's Total Cost ($)	Total Cost/FT^2 of Living Area ($/ft²)
Steel House	2207	$54,423	$31,077	$85,500	$38.74
Wood House	2198	$54,614	$27,451	$82,065	$37.34

For SI: 1 $ft^2 = 0.093\ m^2$
[1] Includes framing materials, rigid foam, insulation and fasteners.

12. AIR LEAKAGE TEST COMPARISON

The blower door and duct blaster tests were performed on the wood and steel houses in Valparaiso, Indiana on March 9, 2000 (the blower door test was repeated in March 2001). The results are summarized in Table 12.1 below:

Table 12.1 – Summary of Blower Door and Duct Blaster Tests

Measurement	Wood House	Steel House
Blower door – building tightness (March 2000 Test)	4.6 ACH50	4.7 ACH50
Blower door – building tightness (March 2001 Test)	4.87 ACH50	4.80 ACH50
Duct blaster – total duct leakage	1038 CFM25 (47% of floor area)	944 CFM25 (43% of floor area)
Duct blaster – duct leakage to outdoors	206 CFM25 (9% of floor area)	133 CFM25 (6% of floor area)

For SI: 1 CFM = 0.0283 m^3/minute.

The blower door results are virtually identical for the two houses, as the difference between the two is only 2% (1.4% for the March 2001 test). All values are representative of a fairly tight house when compared to a general database of building tightness measurements. The wood house achieved its tightness value despite the fact that the steel house has a layer of exterior foam. The similarity of the results may indicate that the leakage is originating from common details like the rim joists, windows, plumbing/electrical penetrations, recessed lights, and attic hatches. The volume of the basement is included in the calculations, which brings the ACH50 value down considerably. The March 2001 blower door test indicates that both homes still exhibit relatively similar tightness, with the steel house being slightly tighter than the wood house.

The total duct leakage results are judged to be high, but not surprising considering that a substantial portion of each system is formed with sheet metal, the large size of the systems, and the use of panned return ducts. No tape was applied to sheet metal joints. The duct leakage to outdoors is far more reasonable, and is due primarily to the flex duct runs in the attic. It is also possible that some leakage is occurring between the attic and panned wall cavities used as returns on the second floor. The source of the sizeable difference between the wood (206-cfm) and steel (133-cfm) leakage rates is not evident.

13. SHORT-TERM ENERGY TEST COMPARISON

Short term automated thermal measurement tests were performed on the two nearly identical homes in Valparaiso, Indiana in late April 2000 and repeated in mid-December 2000 and in March 2001 with additional insulation added to the vaulted ceiling in the steel house. The co-heat test, as it is commonly known, is an overnight evaluation of the building envelopes' thermal performance. Testing was intended to evaluate the thermal performance of a steel-framed house relative to a traditional wood framed house.

April 2000 Short Term Energy Test

During the April tests, two unexpected problems occurred that made it difficult to arrive at a definitive answer regarding the UA values for the steel and wood houses. The first had to do with an imbalance in basement temperature in the two homes. Temperature measurements were taken prior to the setup of the test in both basements. There was an average difference of 4°F (2.22°C) (both ambient and slab temperatures) between the houses with the steel house basement being warmer. The "build-up" of heat in the steel basement could significantly skew the results of the test without backing out the energy required to heat the basement. Second, calculating the UA co-heat value for the living space was complicated by a secondary condition of room heaters internally overheating and shutting down. This made it impossible to isolate the basement heater run-time and back out the actual energy (heat) supplied solely to the basement.

December 2000 Short Term Energy Test

The co-heat tests were repeated in mid-December (2000) with modified testing equipment and run over three consecutive nights, one night in the wood house and two nights in the steel house.

Prior to setup, preliminary ambient temperatures were taken in both houses. Temperatures in the wood house were determined to be in the 68-70°F (20-21°C) range in the living areas and 66-68°F (18.9-20°C) in the basement. The steel house temperatures were also 68-70°F (20-21°C) in the living areas and 65-69°F (18.3-20.6°C) in the basement. These measurements were done to insure that the test settings would be as close as possible to the established equilibrium temperatures of the homes.

The first night of testing was performed in the wood house. A total of 16 heaters were used (each heater was paired with two temperature sensors) and placed in all rooms with exterior exposure. Where necessary, fans were used to assist in the distribution of heat. Heaters in the living areas were set to turn on when the temperature went below 68°F (20°C) in the room and turn off when the temperature exceeded 70 °F. The respective on-off temperatures in the basement were 67°F (19.4°C) and 69°F (20.6°C). Outdoor, garage, attic and crawl space temperatures as well as wind speed and power consumption were monitored.

For the second night of testing, all equipment was moved from the wood to the steel house. Careful attention was paid to move the heaters and sensors to the same corresponding positions in the steel house. In addition, the same indoor temperature set points were used. This test was repeated for the third night in the steel house.

- **Measured Results (December 2000 Test)**

The resulting data were all taken from 2:00AM-5:00AM on each respective testing night. The 2-5 AM time frame was used for a number of reasons: 1) The outdoor temperatures were very steady (within 2°F range on each night); 2) This time of the day is the farthest from any solar radiation effects that can skew the data; 3) Two of the three nights had minimum wind speed over this time period. Wind speed can have a dramatic effect on the results of the test therefore, the results of the third night testing of the steel house where the wind speed was over seven times that of the wood house was not used in the determination of the final $UA_{co\text{-}heat}$ calculations. Results are summarized in Table 13.1 below.

Table 13.1 – Co-Heat Test Results for Valparaiso Demonstration Homes (December 2000)

House Type	$UA_{co\text{-}heat}$[3] (BTU/hr °F)	Wind Speed (mph)	Average Outside Temperature (°F)	Standard Deviation of UA[1] (BTU/hr °F)	$U_{Overall}$ Value[2,3] (BTU/hr °F ft^2)	Overall R Value (hr ft^2 °F/BTU)
Wood House–1st Night	308	0.59	-2.6	13.9	0.084	11.90
Steel House–2nd Night	326	0.52	19.2	12.9	0.089	11.24
Steel House–3rd Night	341	3.74	9.9	18.1	0.093	10.75

For SI: 1 BTU/hr °F = 0.53 W/ºC, 1 mph = 1.6 km/hr, °F = (1.8°C + 32), 1 BTU/hr ft^2 °F = 5.71 W/ºCm^2,
1 hr ft^2°F/BTU = 0.175 m^2K/W

1 Standard deviation of UA for 15 minute averages of 5-second data.

2 $U_{Overall}$ values were determined by dividing the UA values by the external surface area of each house.

3 $UA_{co\text{-}heat}$ and $U_{Overall}$ include the effects of infiltration, $UA_{thermal}$ and $U_{thermal\ overall}$ could have a lower value.

Using the resulting data, the $UA_{co\text{-}heat}$ of the wood house, 308 BTU/hr°F (163 W/°C), was 5.8 percent better than that of the steel house based upon the second night testing in the steel house (Table 13.1), 326 BTU/hr°F (173 W/°C).

- **Analysis of Results (December 2000 Test)**

To establish if the tested UA and $U_{overall}$ (U_o) from the thermal testing are reasonable numbers, a comparison can be made between the tested results and modeled values. There are several commercially available software packages to do this type of modeling. For this study MECcheck[13] and REM/Design[14] were used. Because of limited capabilities of these programs (and most of the off-the-shelf programs) in determining the UA and $U_{overall}$ values for steel framed houses, only the wood home was modeled and the results were compared to the tested ones. MECcheck resulted in a thermal UA ($UA_{thermal}$) of 284 Btu/hrºF (151W/°C) that is 8.5% less than the tested results. REM/Design, a more sophisticated simulation program, produced a thermal U_o of 0.067 Btu/hrºFft^2 ($UA_{thermal}$ of 245 Btu/hrºF) (U_o of 0.382W/°Cm^2; $UA_{thermal}$ of 130 W/°C) that is 25.4% less than the tested result. The simulated results represent $UA_{thermal}$ and do not include infiltration losses.

The UA values shown in Table 13.1 (field tested) also include infiltration effects. Because both the Blower Door test results and the wind speed over the test period were nearly the same (first night and second night of testing), it is concluded that air infiltration effects are similar for both houses.

All of the results have excluded the effects of the basement. There is a large amount of thermal mass in the basement that requires a sizable amount of energy to overcome any temperature differences in the basements, thereby biasing the results in favor of the basement with the higher temperature. Heaters were placed in the basement solely to counteract the heat transfer between the basement and the first floor. The energy used by the basement heaters was subtracted from the power consumed during the tests thus eliminating the basement effects from the tests.

Thermal resistance (R-value) of materials is known to change with changes in temperature. There was a 21.8ºF and 13ºF difference in the average outdoor temperature and attic temperature, respectively between the wood house test and the first night test of the steel house. There are two

13 MECcheck version 3.0. Developed by Pacific Northwest National Laboratory for the Department of Housing and Urban Development.

14 REM/Design version 9.12, copyright Architectural Energy Corporation.

dynamics occurring with the ways the houses in Valparaiso were constructed that can affect the tested R-value. First, the effective R-value of blown-in fiberglass insulation gradually increases until an approximate 30-40ºF-temperature difference is reached. At that point, there is an inversion in the R-value which begins to decrease as the temperature difference increases[15]. Secondly, the batting in the wall increases slightly in R-value with an increase in temperature difference[16]. Taking these thermophysical properties into account, it has been concluded that thermal conductivity, within the range of temperatures observed during the various co-heat tests, were determined to be minimal (<1%). Therefore, the impact of the outdoor temperature difference on the tested UA values was found insignificant.

March 2001 Short Term Energy Test

Follow-up short-term automated thermal measurement tests were again performed on the two nearly identical homes in Valparaiso, Indiana in March 2001. This series of tests was done after 3/4-inch (19 mm) R-4 rigid foam insulation was installed on the vaulted part of the ceilings in the great room, living room and bonus room of the steel house. The rigid foam insulation was installed on the interior face of the vaulted ceiling on top of the drywall. Another layer of drywall was applied on top of the rigid foam. As in the previous runs, the tests were run over three consecutive nights, one night in the wood house and two separate nights of testing in the steel house.

The test procedure and heater locations were similar to the tests conducted in December 2000.

- **Measured Results (March 2001)**

The resulting data from the March 2001 tests used to determine the UA were taken from 12:00AM-6:00AM on each respective testing night. The 12:00 AM to 6:00 AM time frame was used for a number of reasons:

1) The outdoor temperatures were steady (within a 3ºF range on each night).
2) This time of the day is the farthest from any solar radiation effects that can bias the results.
3) The three-hour increase in the duration of the test was due to fluctuations that occurred during the middle of the testing period. The additional three hours of test data increased the confidence levels and accuracy of the data.

Table 13.2 summarizes the results of the December 2000 and March 2001 tests and gives the average of these tests for the wood house and the steel house (before insulation retrofit and after insulation retrofit). Table 13.2 also lists the $UA_{thermal}$ for each of the houses without any influence due to infiltration.

[15] Graves, Wilkes, Mc Elroy, 1994, Thermal Resistance of Attic Loose-Fill Insulations Decreases Under Simulated Winter Conditions, ORNL/M-3253, ORNL
[16] Wilkes, Thermophysical Properties Data Base Activities at Owens-Corning Fiberglass

Table 13.2 – Co-Heat Test Results for Valparaiso Demonstration Homes

House Type	$UA_{co\text{-}heat}$[1] (BTU/hr °F)	$UA_{thermal}$[2] (BTU/hr °F)	Sampling Error[3]	$U_{Overall}$[4] (BTU/hr ft^2 °F)	Overall R Value (hr ft^2 °F/BTU)
Wood House Dec. 2000 Test	308	283	-	.0772	12.96
Wood House March 2001 Test	327	281	-	.0766	13.05
Wood House Average	**317**	**282**	**1.8%**	**0.0769**	**13.00**
Steel House Dec. 2000 2nd Night	326	302	-	.0824	12.14
Steel House Dec. 2000 3rd Night	341	284	-	.0774	12.91
Steel House Dec. 2000 Average	**326**	**293**	**2.1%**	**0.0799**	**12.52**
Steel House March 2001 2nd Night	340	295	-	.0804	12.43
Steel House March 2001 3rd Night	335	276	-	.0753	13.29
Steel House March 2001 Average	**337**	**286**	**2.8%**	**0.0777**	**12.87**

For SI: 1 BTU/hr °F = 0.53 W/ºC, °F = (1.8°C + 32), 1 BTU/hr ft^2 °F = 5.71 W/ºCm^2,
1 hr ft^2°F/BTU = 0.175 m^{2}K/W

[1] $UA_{co\text{-}heat}$ is calculated based upon the total heat loss for the test (conduction and infiltration)

[2] UA_{hermal} values exclude the effects of infiltration as described in the LBL single zone equation with a calculated stack coefficient of 0.008 and a calculated wind coefficient of 0.0121.

[2] Sampling error is at the 95% confidence level.

[4] $U_{Overall}$ values were determined by dividing the UA values by the external surface area of each house.

- **Basement**

Basements in the test homes would fall under the category of semi-conditioned non-living space. Small variations in basement ambient or slab temperatures can cause a large change in heating needs (in the basement) due to the thermal mass of the concrete slab and its coupling with the ground. Because of these conditions the energy used to condition the basements has been eliminated from the tests (for both wood and steel homes).

Temperature measurements were taken in both homes to ensure test settings were as close as possible to the existing equilibrium temperatures of the homes. Temperatures in both homes were determined to be in the 68-70ºF (20 - 21ºC) range in the living area and 66-68ºF (18.9 - 20ºC) in the basement. Co-heat test protocol recommends that each house be at a constant temperature for at least 48 hours prior to testing[17]. Sufficient time was allowed for both homes to reach equilibrium. Heaters were placed in the basement to, in effect, zero out the heat transfer between the basement

[17] NYSERDA, New York State Energy Research and Development Authority, Short-Term Test Methods for Predicting the Thermal Performance of Buildings, Albany, NY (August 1991).

and the first floor. The energy used by the basement heaters was subtracted from the power consumed during the tests thus eliminating the basements from the tests.

- **Infiltration**

In March 2001 a blower door test was performed on both houses establishing ELA values for both houses. The wood house leakage area was 105.5 in^2 (68,064 mm^2) and the steel house was 104.8 in^2 (67,613 mm^2). With nearly identical ELA's, it can be assumed that the infiltration for both houses is similar under similar conditions.

The baseline wood house was calibrated to itself using the two nights of testing in determining the stack coefficient in the LBL model. The same calibration factor was used for the steel house based on similar blower door results and house shape.

The tested mean $UA_{thermal}$ of the wood house (282 Btu/hr°F from Table 13.2) was 3.9% more thermally resistant than that of the steel house (293 Btu/hr°F from Table 13.2) before ceiling insulation retrofit. After the retrofit, the tested difference was reduced to 1.4% (286 Btu/hr°F from Table 13.2). A two-tail t-test at a 90% confidence level indicated that the difference between the means of the wood and retrofitted steel house is statistically insignificant. The addition of the rigid foam insulation on the vaulted portions of the ceiling in the steel house showed an overall thermal improvement of 2.5%. A one-tailed t-test indicated that the change was statistically significant at the 90% confidence level.

In summary, the tested 3.9% difference between the wood and steel house (as originally constructed) was small yet statistically different. After the retrofit, the thermal difference between the two houses was determined to be statistically insignificant. The final test results indicated that there was no discernable thermal performance difference between the two homes.

- **Analysis of Results**

To establish if the tested $UA_{thermal}$ and $U_{overall}$ from the thermal testing are reasonable numbers, a comparison can be made between the tested results and modeled values. There are a variety of software packages available on the market to do this type of modeling. For this study MECcheck[18] version 3.0 and REM/Design version 9.12 were used. Because of limited capabilities for most of the off-the-shelf programs in measuring the UA and $U_{overall}$ in steel framed houses, a comparison between the modeled results of the wood and the tested numbers was performed. MECcheck calculated the $UA_{thermal}$ for the wood house to be 284 Btu/hr°F that was nearly identical to the average of the two nights tested results (282 Btu/hr°F as shown in Table 13.2). REM/Design[19], a more sophisticated simulation program, came up with a $U_{overall}$ of 0.067 Btu/hr°Fft^2 ($UA_{thermal}$ of 245 Btu/hr°F) that is 12.9% less than the tested result of 0.0769 Btu/hr°Fft^2 ($UA_{thermal}$ of 282 Btu/hr°F) as shown in Table 13.2

[18] MECcheck version 3.0. Developed by Pacific Northwest National Laboratory for the Department of Housing and Urban Development.
[19] REM/Design version 9.12, copyright Architectural Energy Corporation.

14. CONCLUSION

This report provides a description of each demonstration home, a description of the framing components, list of materials, productivity and unit cost comparisons and short-term energy comparisons. Engineering costs were not included in this report as these costs typically vary depending on who provides the service.

Cost Comparison

The cost data indicate that the costs of certain framing components of steel-framed-homes (such as floors and interior non-load bearing walls) are comparable with those framed with wood. However, using the builder's costs, a steel-framed home cost is shown to be 4.2% higher than the cost of a nearly identical wood-framed home. The steel-framing package cost (framing labor and material) is 7.4% higher than that of a wood-framing package. The total framing time (labor hours) for the steel house was 6.9% higher than that for a nearly identical wood house; the framing material cost for the steel house was 7.8% higher (a good portion of that was attributed to rigid foam installation). The lumber for the wood house was purchased in late December, 1999 to early January 2000 when the Random Length lumber index was at $393 per 1000 board feet[20] and the CME futures price index was at $352.4[21]

It should be noted that the differences in the framing method (such as 16" (406 mm) on center for wood vs. 24" (610 mm)) on center for steel) and having the steel members delivered to the job site pre-cut to length could have a significant impact on the total cost and could potentially put the steel-framed home at a higher cost disadvantage. In fact the structural walls could cost an additional 10% if the steel labor and material costs were adjusted for the stud spacing[22]. However, the wall framing spacing in the two homes is representative of the standard construction practice for each material. In addition, if the weather-related productivity adjustment factors were applied the difference in cost between steel and wood would be slightly narrower.

The cost impact on trades and sub trades, due to steel framing, does not appear to be significant. In fact, for certain trades, the difference in cost between wood and steel-framed homes was negligible, while for others the cost differential was favorable to steel. The trades cost (labor and material) for the steel house were 1.3% higher than those for the identical wood house.

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 a particular material's final cost. The unit costs developed in this report were based on the data obtained from a small sample. This information does not include nonproductive time, builder overhead or profit. Results do not reflect a definitive study but rather indicate whether builders should consider cold-formed steel framing when searching for solutions to lumber problems and concerns. The reader should also be careful when using the cost data shown in Appendix B for a specific activity, as the data provided may not be representative of the true cost for that specific activity in another project, location, or circumstances.

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[20] Random Lengths. January 7, 2000.

[21] Chicago Mercantile Exchange. January 7, 2000.

[22] An additional $226 in labor cost (6 hours) and ≈$550 in material cost (assuming additional 180 studs at $2.50/stud plus $100 for screws), for an additional $776.

Infiltration and Short-Term Energy Comparison

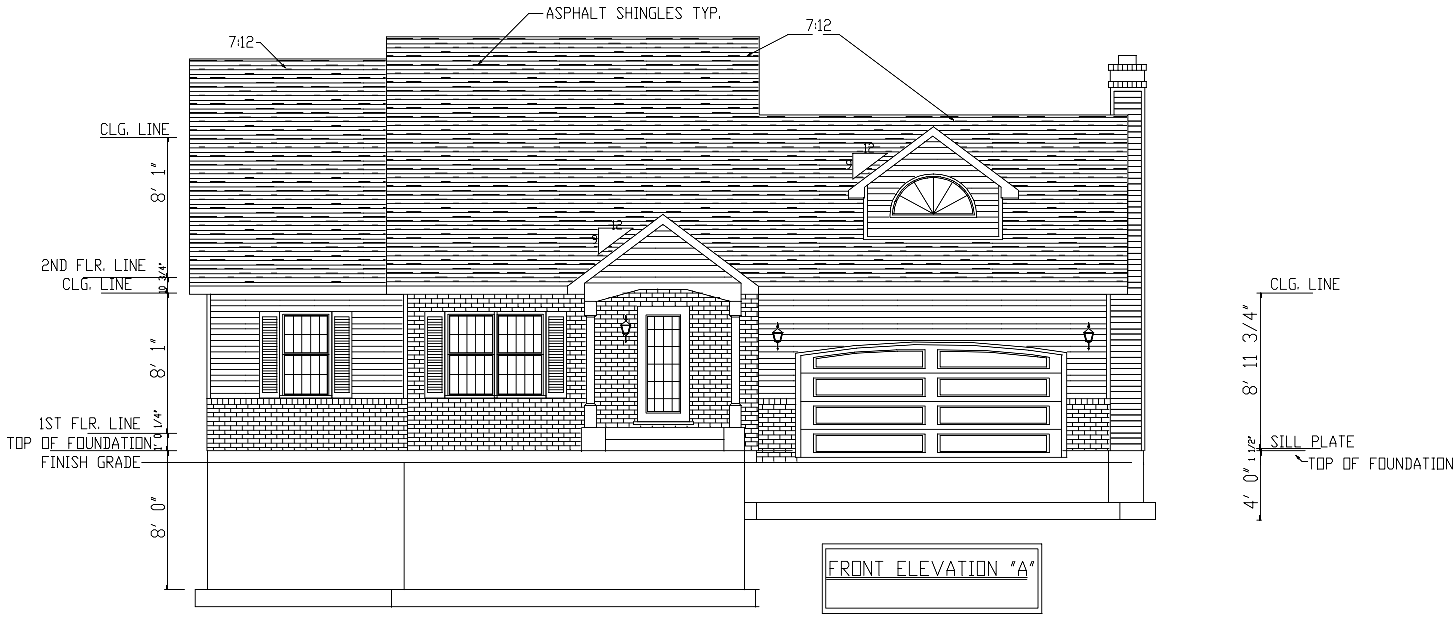
Blower door (infiltration) tests concluded that both steel-framed and wood-framed homes have approximately the same leakage rate. Blower door tests performed one year after construction completion (March 2001) indicated that the steel house is slightly tighter than the wood house, while earlier results (March 2000) indicated the opposite. This can be attributed to slight shrinkage in the wood-framing members that could have resulted in slightly more leakage in the wood house.

Co-heat test results showed that the tested UA values of the wood and steel homes are statistically insignificant when foam insulation is added to the ceiling of the steel house. Without the added foam insulation (to the ceiling) the difference in UA values was only about 4% (the wood house was 4% better than the steel house).

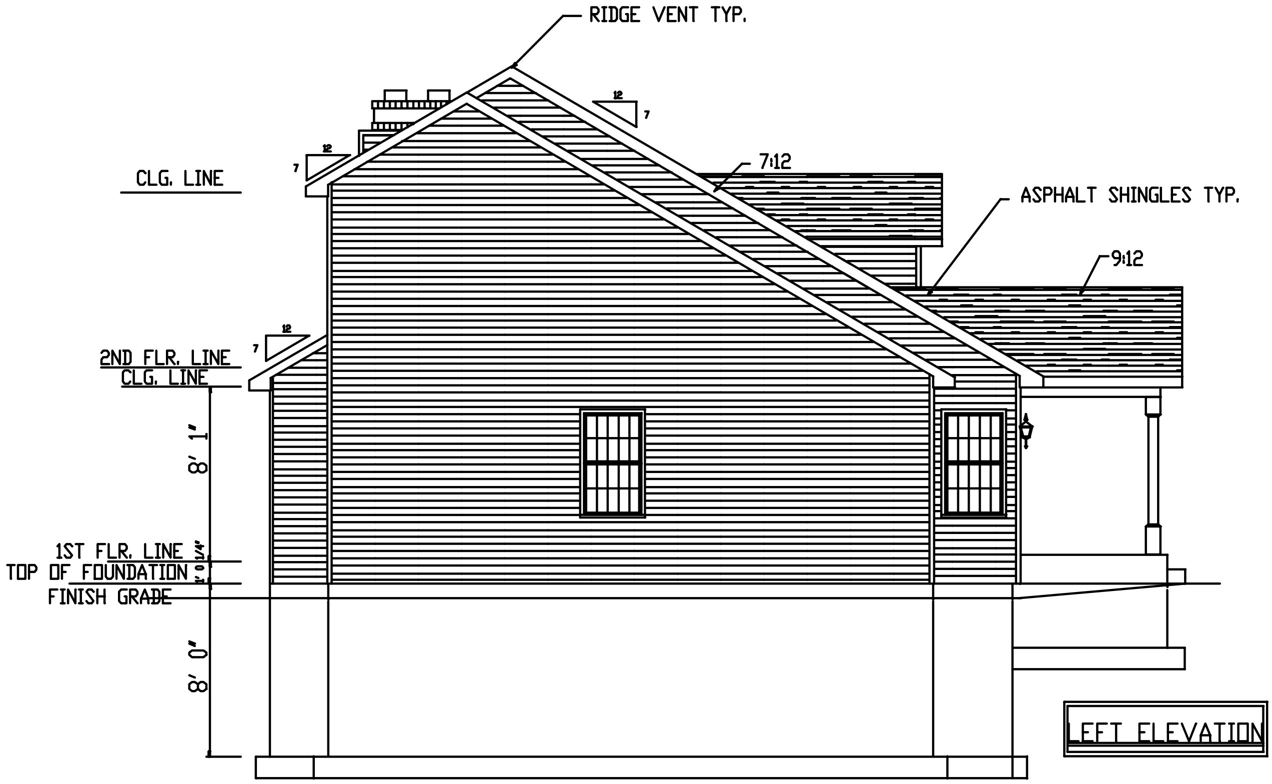
This report is the first of three reports that will be summarized and compiled into one comprehensive report at the end of the program. The final report will average the labor and material costs from the three sites to provide a more accurate cost comparison for steel and wood-framed homes.

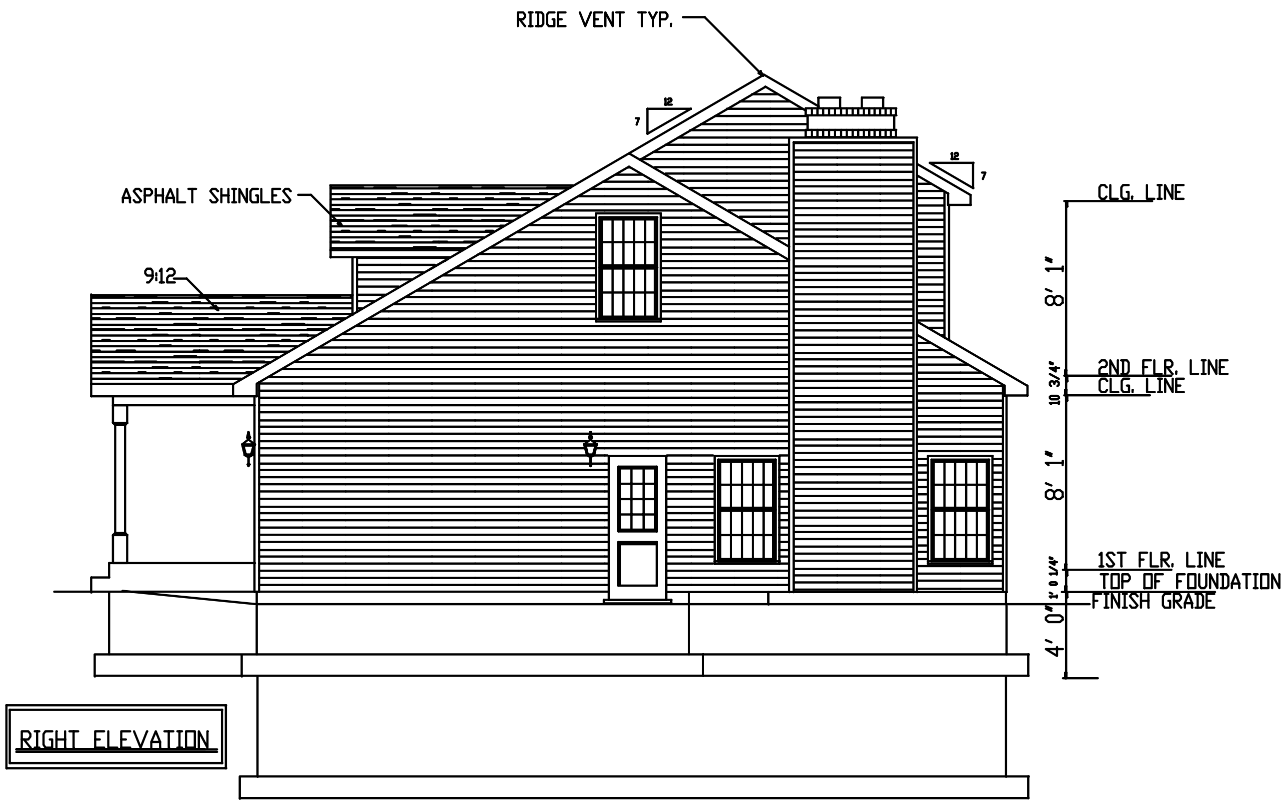
APPENDIX A

DEMONSTRATION HOME PLANS

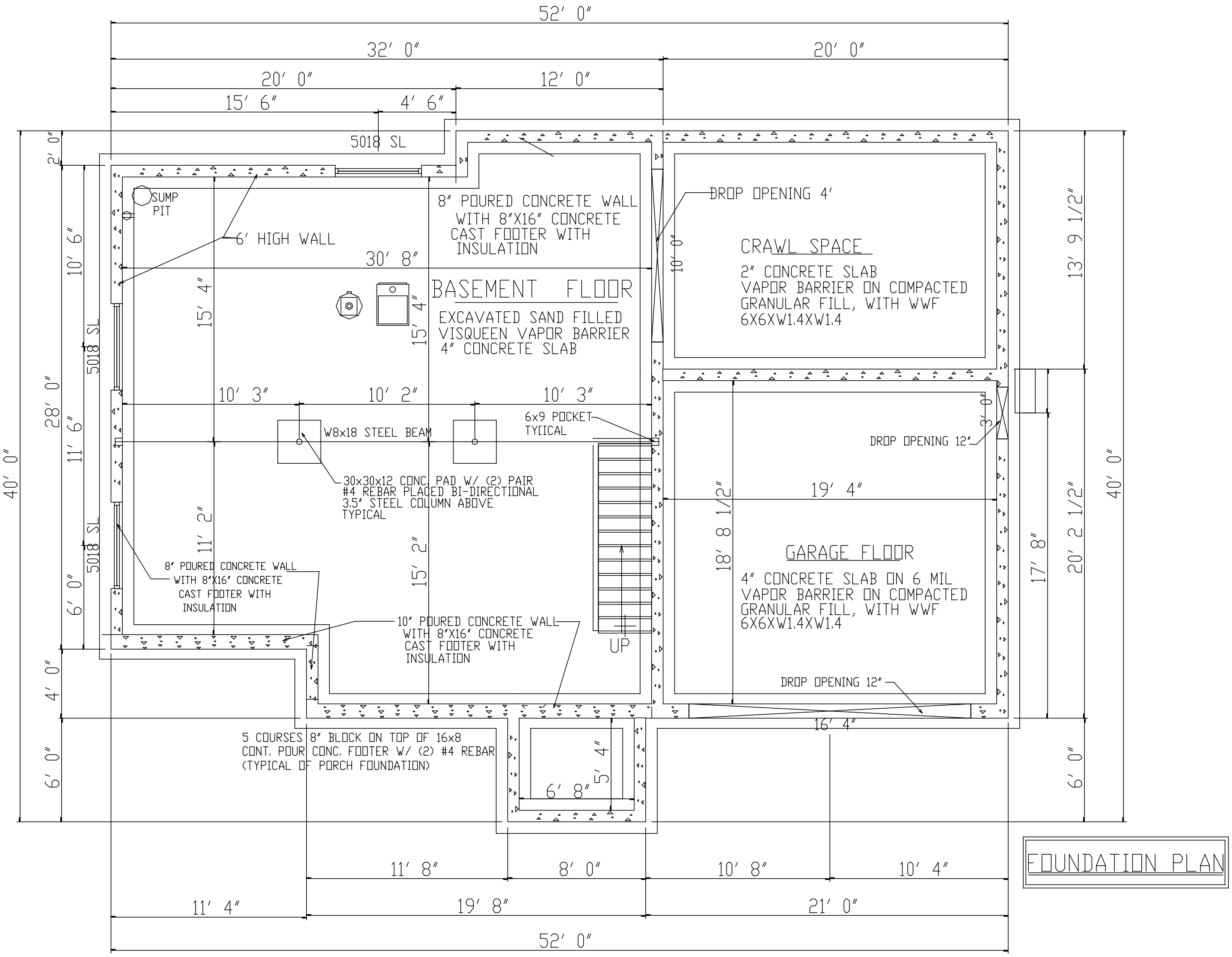


Wood Demonstration Home

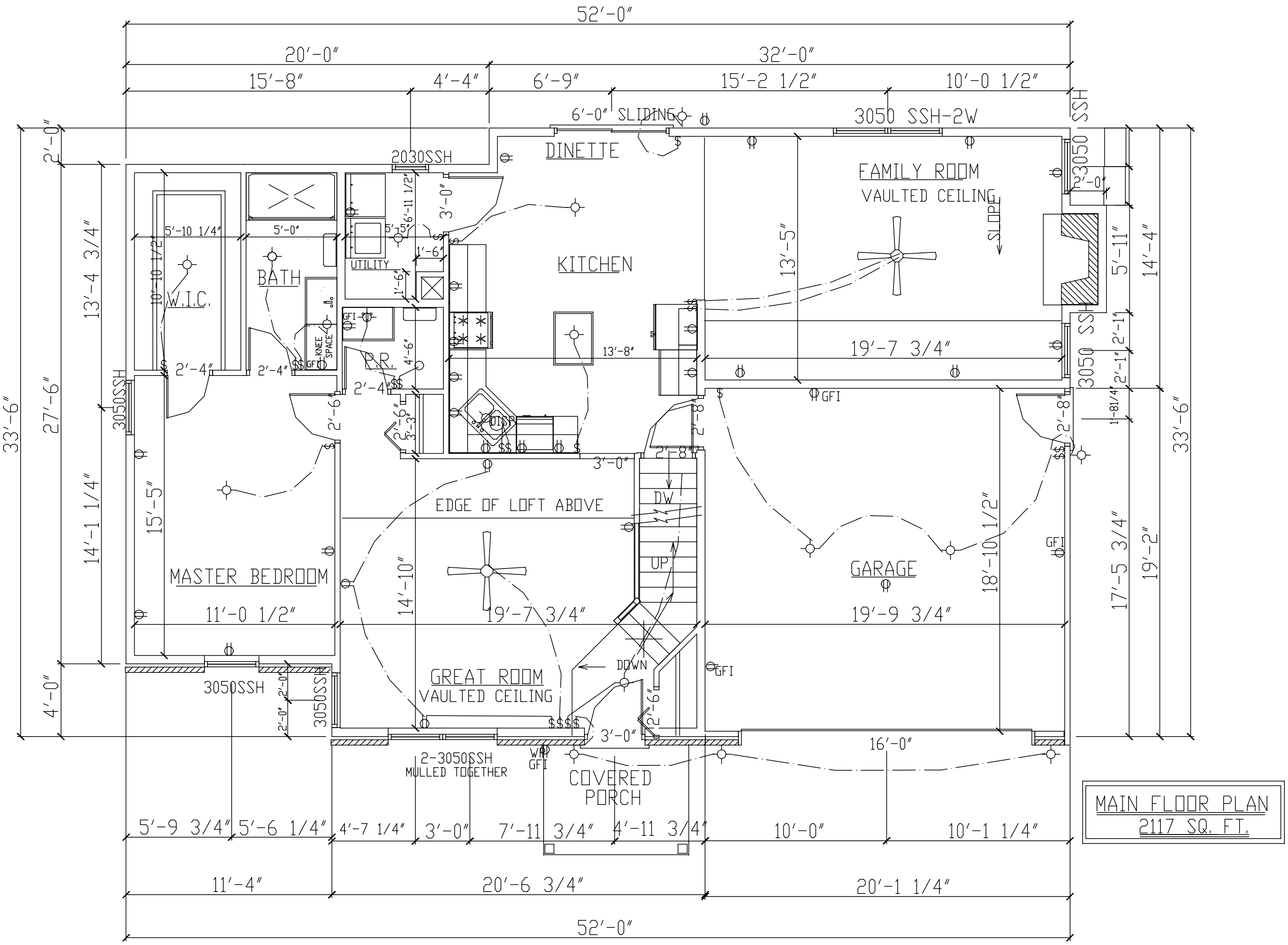




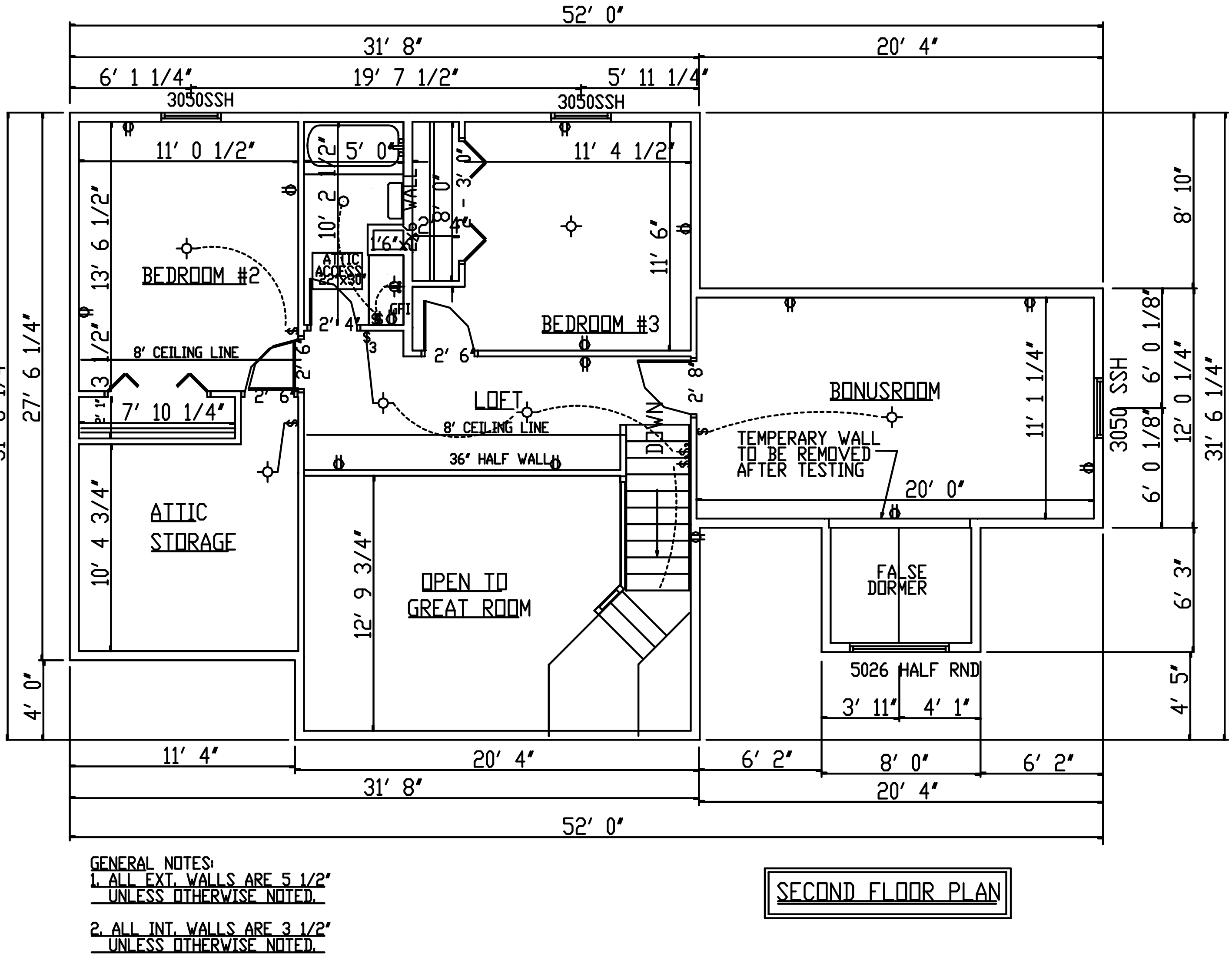
Wood Demonstration Home



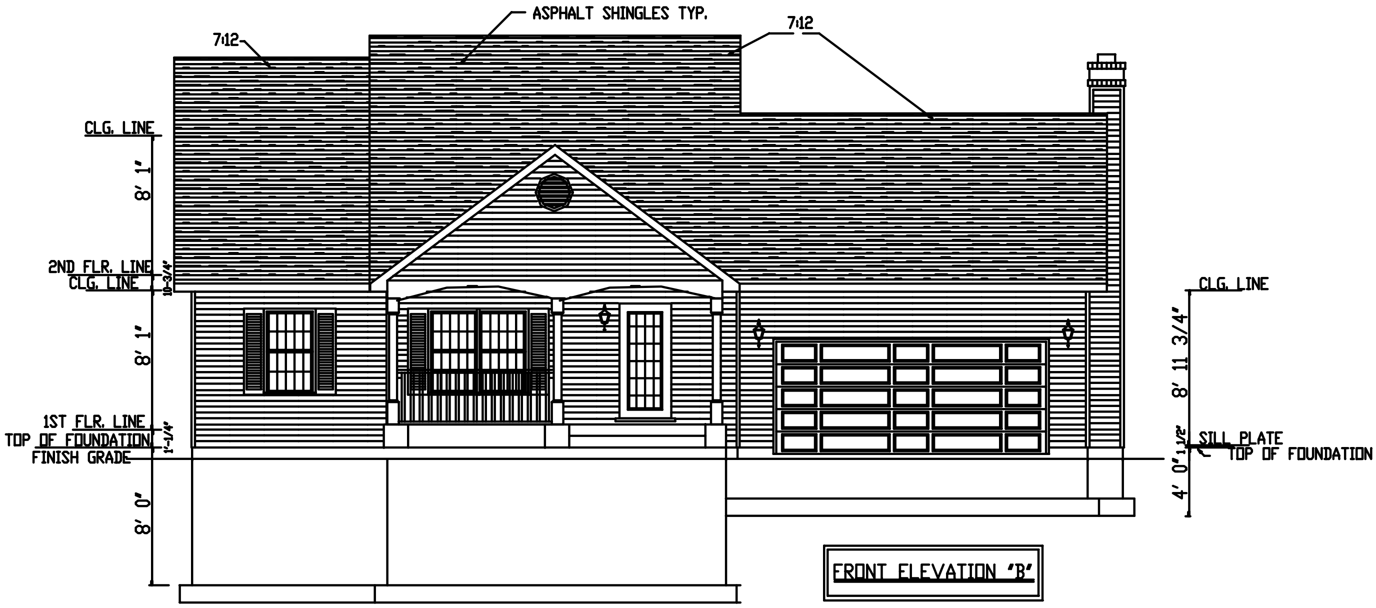
Wood Demonstration Home



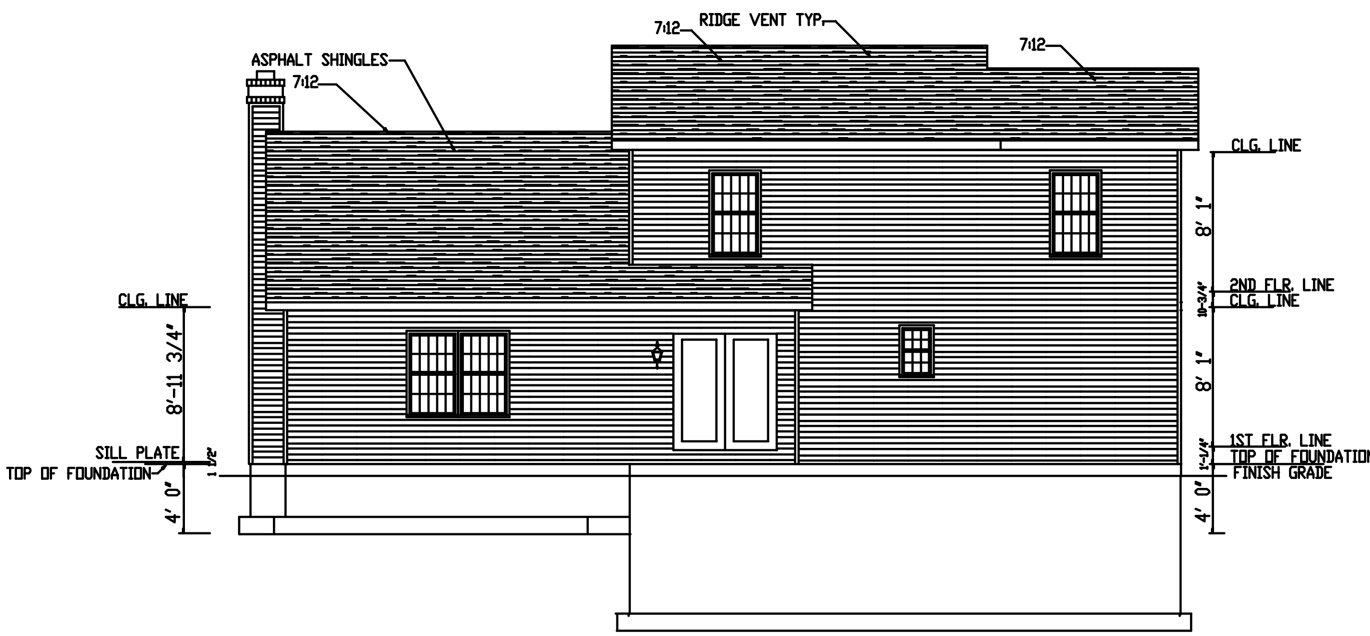
Wood Demonstration Home



Wood Demonstration Home

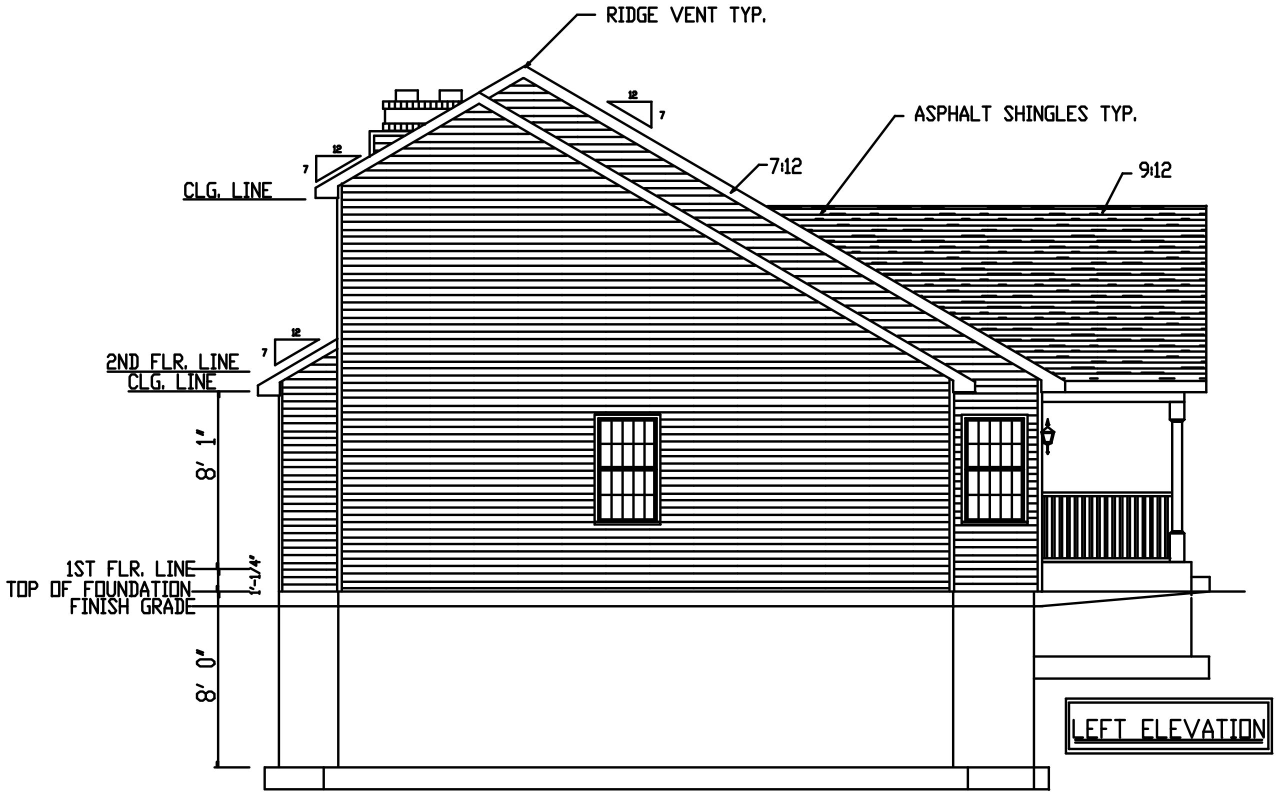


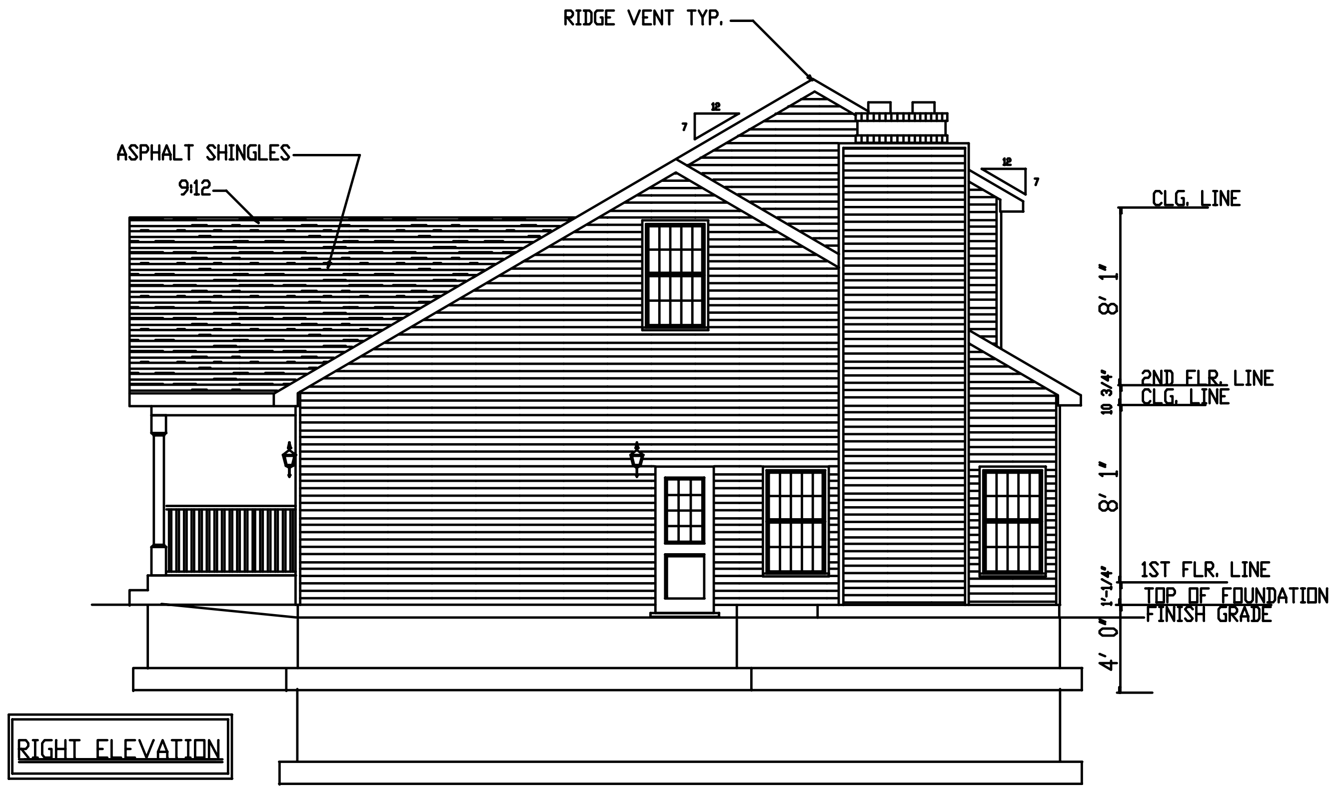
FRONT ELEVATION 'B'



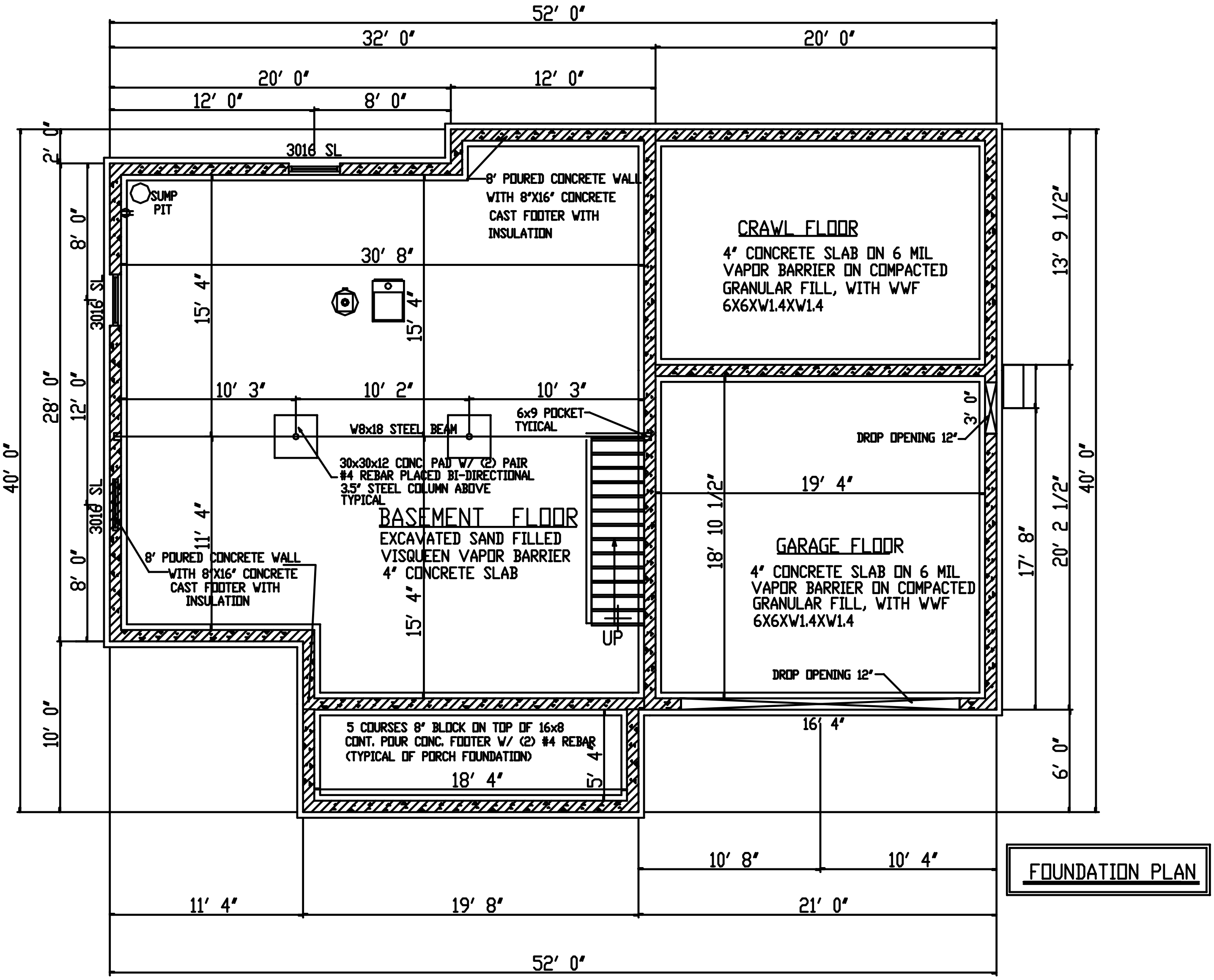
REAR ELEVATION

Steel Demonstration Home

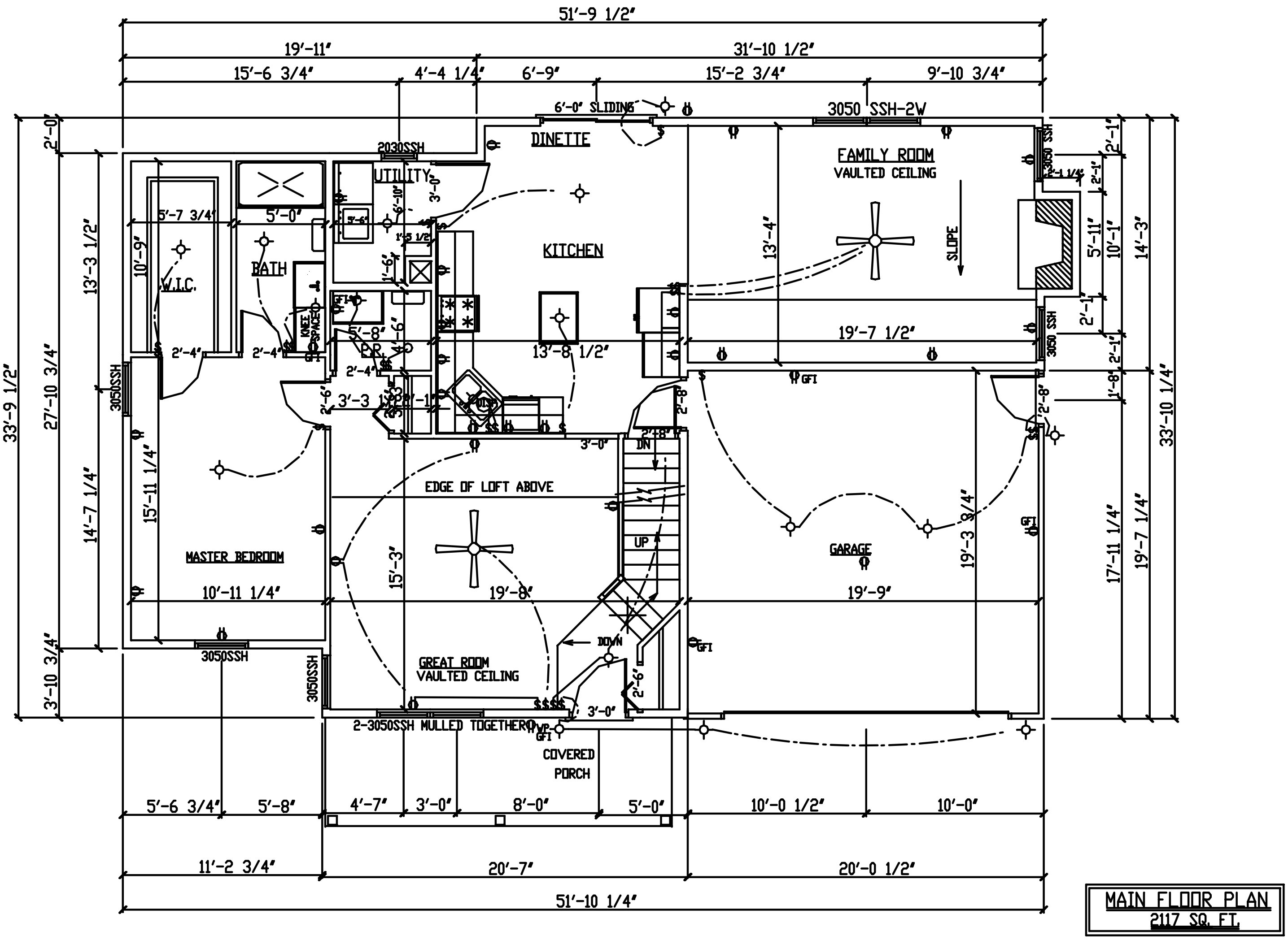




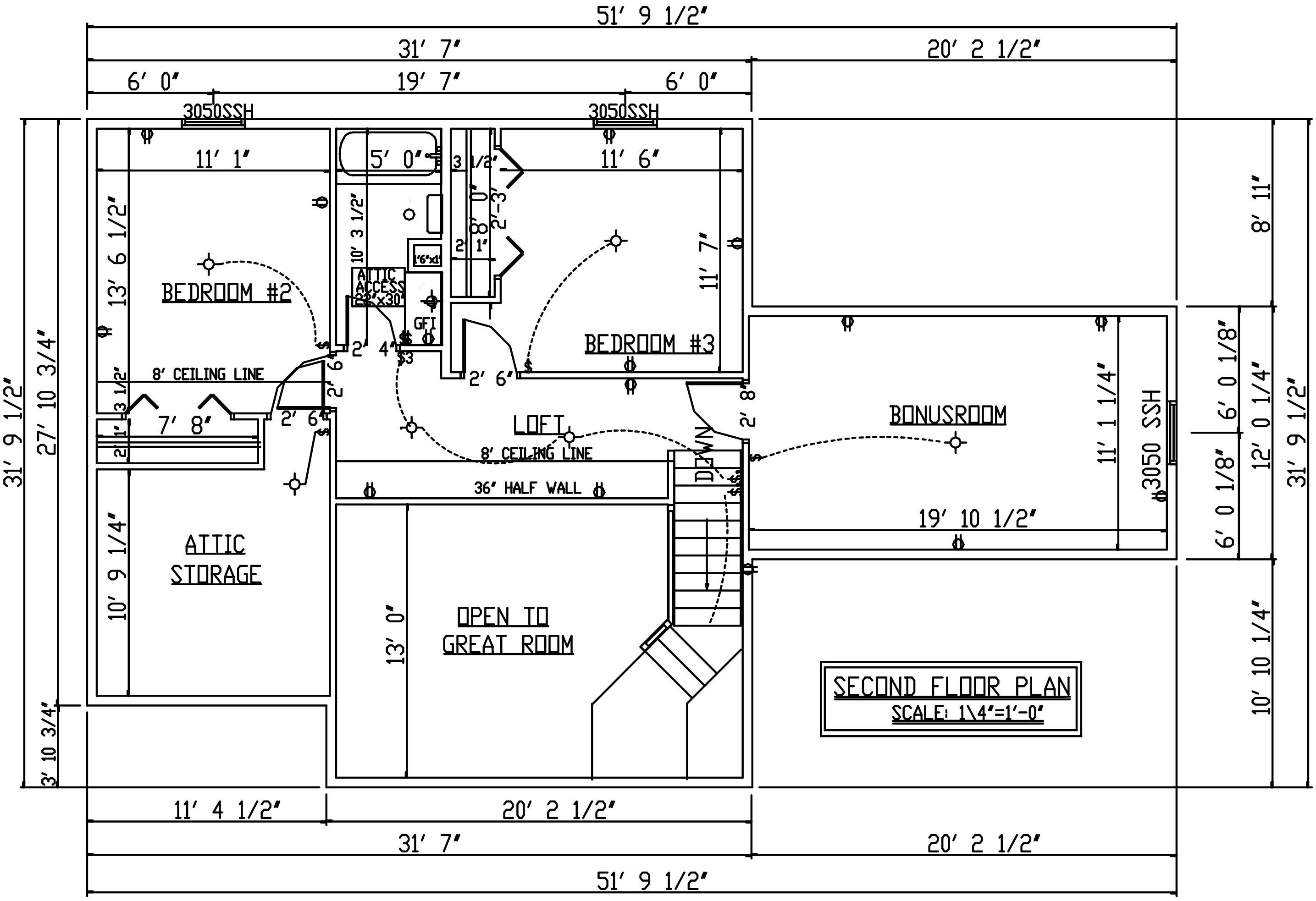
Steel Demonstration Home



Steel Demonstration Home



Steel Demonstration Home



Steel Demonstration Home

APPENDIX B

LABOR MAN-MINUTES

Summary of Floor Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
First Floor		
Read Plans	30	30
Layout	90	105
Snap Lines	90	90
Organize Material	30	15
Mark	30	30
Position	30	30
Measure	30	30
Sill Plate (cut, align & install)	420	630
Cut and install Joists and Tracks	405	430
Cut Blockings	60	60
Install Blockings/Strapping	120	105
Cut Web Stiffeners	45	-
Install Web Stiffeners	30	-
Cut OSB Sheathing	195	195
Install OSB Sheathing	465	420
Total	**2070**	**2170**
Second Floor		
Read Plans	30	30
Layout	75	90
Snap Lines	75	75
Organize Material	30	30
Mark	30	30
Position	30	30
Measure	45	45
Install Top Plates/Tracks	345	435
Cut and install Joists and Tracks	360	405
Cut Blocking	15	30
Install Blocking/Strapping	120	135
Cut Web Stiffeners	60	-
Install Web Stiffeners	45	-
Cut OSB Sheathing	105	105
Install OSB Sheathing	210	210
Total	**1575**	**1650**

Summary of First-Story Load Bearing Walls Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
First Story Load Bearing Walls		
Read Plans	30	15
Layout	30	30
Snap Lines	15	15
Organize Material	30	30
Mark	15	15
Position	30	30
Measure	45	60
Cut Studs and Tracks/Plates	285	240
Cut Blocking/Strapping	30	30
Install Blocking/Strapping	15	15
Construct House Headers	180	135
Construct Garage Door Header	225	225
Brace Walls	180	180
Frame Walls	390	330
Measure/Cut OSB Sheathing	75	75
Install OSB Sheathing	195	180
Framing for Fire Place	585	540
Total	**2355**	**2145**
First Story Walls Rigid Foam Installation		
Layout	30	-
Organize Material	15	-
Measure	30	-
Cut Foam	165	-
Install Rigid Foam	345	-
Total	**585**	**0**
Total First Story Walls	**2940**	**2145**

Summary of Second-Story Load Bearing Walls Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
Second Story Load-Bearing Walls		
Read Plans	15	15
Layout	30	30
Snap Lines	30	30
Organize Material	15	15
Mark	15	15
Position	30	30
Measure	15	30
Cut Studs and Tracks/Plates	300	285
Cut Blocking/Strapping	30	30
Install Blocking/Strapping	45	30
Construct Headers	90	90
Brace Walls	75	60
Frame Walls	330	315
Measure/Cut OSB Sheathing	60	60
Install OSB Sheathing	165	135
Total	**1245**	**1170**
Second Story Walls Rigid Foam Installation		
Layout	30	-
Organize Material	15	-
Measure	30	-
Cut Foam	135	-
Install Rigid Foam	450	-
Total	**660**	**0**
Total Second Story Walls	**1905**	**1170**

Summary of Roof Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
Ceiling Joists		
Read Plans	15	15
Layout	15	15
Obtain Materials	15	15
Organize Material	15	15
Mark	30	30
Position	15	15
Measure	30	60
Cut Joists and Tracks	15	15
Cut Blocking	165	150
Install Blocking/Strapping	30	45
Cut Web Stiffeners	30	-
Install Web Stiffeners	45	-
Install Ceiling Joists	210	240
Job Site Cleaning	30	45
Total	**660**	**660**
Roof Rafters		
Read Plans	30	30
Layout	60	75
Organize Material	30	45
Mark	30	30
Position	15	15
Measure	30	45
Cut Rafters	105	90
Construct Ridge Member	225	-
Cut Blocking	45	45
Install Blocking/Strapping	120	90
Measure/Cut Roof Sheathing	120	120
Install Rafters	1875	1920
Install Roof Sheathing	2190	2145
Total	**4875**	**4650**
Roof Shingles	**2415**	**2430**
Total Roof Framing	**7950**	**7740**

Summary of Non-Load Bearing Walls Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
First Story Non-Load Bearing Walls		
Read Plans	30	30
Layout	15	30
Organize Material	15	15
Mark	30	30
Position	30	30
Measure	45	45
Cut Studs and Tracks	240	300
Cut Blocking/Strapping	60	45
Install Blocking/Strapping	105	90
Frame Headers	135	180
Frame Walls	1060	1000
Brace Walls	165	180
Job Site Cleaning	60	75
Total	**1990**	**2050**
Second Story Non-Load-Bearing Walls		
Read Plans	30	30
Layout	30	30
Organize Material	30	30
Mark	15	15
Position	15	30
Measure	45	45
Cut Studs and Tracks	130	100
Cut Blocking/Strapping	60	45
Install Blocking/Strapping	90	75
Frame Headers	75	90
Frame Walls	910	940
Brace Walls	90	105
Job Site Cleaning	45	45
Total	**1565**	**1580**
Total Non-Load Bearing Walls	**3555**	**3630**

Summary of HVAC and Electrical Trades Installation Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
HVAC		
Read Plans	45	45
Layout	75	75
Organize Material	75	75
Measure	45	60
Cut Tracks/Plates	1020	1005
Install Ducts	840	825
Install Furnace	175	180
Install A/C Unit	390	420
Install Thermostat	15	30
Tape/Mask Ducts	15	15
Job Site Cleaning	45	45
Total	**2740**	**2775**
Electrical		
Read Plans	30	30
Organize Material	60	75
Measure	75	75
Punch/Cut Studs/Tracks/Wood Plates	60	405
Run Electrical Wires	705	960
Install/Fasten Electrical Boxes	1050	900
Install receptacles, Connect Wires & Install Cover Plates for Boxes	960	975
Install Lighting Fixtures	285	285
Run Power Supply to House	300	450
Install Electrical Panel	450	550
Ceiling Fans Installation	180	180
Job Site Cleaning	240	270
Total	**4395**	**5155**

Summary of Plumbing, Insulation and Siding Trades Installation Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
Plumbing		
Read Plans	30	45
Layout	75	60
Organize Material	45	45
Measure	45	45
Punch/Cut Studs/Tracks/Top Plates	315	150
Run Piping	1575	1425
Install Kitchen Plumbing Fixtures	180	180
Install Bathrooms Plumbing Fixtures	525	540
Install Gas Meter	15	30
Install Toilets	90	90
Install Showers	240	180
Install Vanities and Sinks	180	135
Job Site Cleaning	165	150
Total	**3480**	**3075**
Batt Insulation		
Read Plans	30	30
Layout	45	45
Organize Material	30	45
Measure/Cut	105	120
Install Insulation in Wall Cavity	795	780
Install Attic Insulation	285	255
Job Site Cleaning	30	30
Total	**1320**	**1305**
Siding		
Read Plans	70	30
Layout	90	45
Organize Material	90	75
Measure/Cut Siding	1095	915
Install Siding	3300	2775
Total	**4645**	**3840**

Summary of Drywall, Windows/Doors, Drywall Finishing, and Painting Trades Installation Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
Drywall[1]		
Layout	75	60
Organize Material	90	90
Measure	195	180
Cut Drywall Sheets	240	210
First Floor Drywall Installation (Walls)	2760	2655
Second Floor Drywall Installation (Walls)	915	885
First Floor Ceiling Drywall Installation	795	765
Second Floor Ceiling Drywall Installation	765	720
Job Site Cleaning	150	150
Total	**5985**	**5715**
Windows and Doors (exclude garage)		
Layout	15	15
Organize Material	15	30
Measure	15	15
Install Windows	810	825
Install Exterior Doors	45	60
Install Interior Doors	585	615
Job Site Cleaning	15	15
Install Locks, Kick Plates & Stair trim	1020	1020
Total	**2520**	**2595**
Kitchen Cabinets		
Layout	45	45
Organize Material	75	60
Measure	165	135
Install Cabinets	645	630
Install Kitchen Counter, & Fresh Doors	870	885
Kitchen Appliances Installation	90	105
Job Site Cleaning	120	120
Total	**2010**	**1980**
Drywall Finishing and Painting		
Layout	15	30
Organize Material	15	30
Tape Joints	2010	2490
First Paint Coat	1275	1440
Final Paint Coat	735	840
Job Site Cleaning	525	540
Sand Drywall	480	420
Paint Touch Up, & Paint The Front Porch	930	1035
Total	**5985**	**6825**

[1] Drywall installation excludes additional dormer for the wood house.

Summary of Miscellaneous Trades Installation Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
Baseboard Trim		
Layout	15	15
Organize Material	15	15
Measure	345	345
Cut Trim	465	450
Install Trim	645	630
Job Site Cleaning	75	90
Total	**1560**	**1545**
Flooring (Floor Covering)		
Layout	105	105
Organize Material	45	45
Measure	75	75
Carpet Installation	825	810
Hardwood Installation	360	375
Vinyl Floor Installation	345	330
Job Site Cleaning	75	75
Total	**1830**	**1815**
Front Porch		
Layout	30	15
Organize Material	15	15
Measure	45	30
Cut Joists/Studs	180	60
Frame Porch	1065	510
Sheath Porch	120	90
Frame Porch Roof	480	240
Total	**1935**	**960**
Deck Framing		
Layout	45	45
Organize Material	30	30
Frame Deck	435	495
Job Site Cleaning	30	30
Total	**540**	**600**
Other Miscellaneous Components		
Mirrors	60	60
Concrete Driveway Construction	3150	3510
Brick Installation	-	1860
Excavators	210	225
Fire Place Installation	120	165
Run Gas Pipe to House	405	330
Final House Cleaning	1080	1020
Total	**5025**	**7170**

Summary of Stairs Installation Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
First Floor Stairs		
Layout/Organize Material	15	15
Measure	30	30
Cut Framing Members	75	60
Frame Stairs	150	135
Job Site Cleaning	15	15
Total	**285**	**255**
Second Floor Stairs		
Layout/Organize Material	15	15
Measure	30	30
Cut Framing Members	75	75
Frame Stairs	150	135
Job Site Cleaning	15	15
Total	**285**	**270**
Total Stairs	**570**	**525**
Dormer Drywall	**-**	275
Installation and finishing	**-**	**270**
Total Dormer Drywall		
Garage		
Concrete slab	270	345
Install Garage Door/Door Openers	240	225
Total Garage	**510**	**570**

APPENDIX C

NORMALIZED LABOR MAN-MINUTES

Normalized Labor Time

Normalized Labor Man-Minutes
Summary of Floor Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
First Floor		
Read Plans	30	30
Layout	90	105
Snap Lines	90	90
Organize Material	30	15
Mark	30	30
Position	30	30
Measure	30	30
Sill Plate (cut, align & install)	420	630
Cut and install Joists and Tracks	405	430
Cut Blockings	60	60
Install Blockings/Strapping	120	105
Cut Web Stiffeners	45	-
Install Web Stiffeners	30	-
Cut OSB Sheathing	195	195
Install OSB Sheathing	465	420
Total	**2070**	**2170**
Second Floor		
Read Plans	30	30
Layout	75	90
Snap Lines	75	75
Organize Material	30	30
Mark	30	30
Position	30	30
Measure	45	45
Install Top Plates/Tracks	345	435
Cut and install Joists and Tracks	360	405
Cut Blocking	15	30
Install Blocking/Strapping	120	135
Cut Web Stiffeners	60	-
Install Web Stiffeners	45	-
Cut OSB Sheathing	105	105
Install OSB Sheathing	210	210
Total	**1575**	**1650**

Normalized Labor Man-Minutes
Summary of First-Story Load Bearing Walls Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
First Story Load Bearing Walls		
Read Plans	30	15
Layout	30	30
Snap Lines	15	15
Organize Material	30	30
Mark	15	15
Position	30	30
Measure	45	60
Cut Studs and Tracks/Plates	285	240
Cut Blocking/Strapping	30	30
Install Blocking/Strapping	15	15
Construct House Headers	180	135
Construct Garage Door Header	225	225
Brace Walls	180	180
Frame Walls	390	330
Measure/Cut OSB Sheathing	75	75
Install OSB Sheathing	195	180
Framing for Fire Place	585	540
Total	**2355**	**2145**
First Story Walls Rigid Foam Installation		
Layout	30	-
Organize Material	15	-
Measure	30	-
Cut Foam	165	-
Install Rigid Foam	345	-
Total	**585**	**0**
Total First Story Walls	**2940**	**2145**

Normalized Labor Man-Minutes
Summary of Second-Story Load Bearing Walls Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
Second Story Load-Bearing Walls		
Read Plans	15	15
Layout	30	30
Snap Lines	30	30
Organize Material	15	15
Mark	15	15
Position	30	30
Measure	15	30
Cut Studs and Tracks/Plates	300	285
Cut Blocking/Strapping	30	30
Install Blocking/Strapping	45	30
Construct Headers	90	90
Brace Walls	75	60
Frame Walls	330	315
Measure/Cut OSB Sheathing	60	60
Install OSB Sheathing	165	135
Total	**1245**	**1170**
Second Story Walls Rigid Foam Installation		
Layout	30	-
Organize Material	15	-
Measure	30	-
Cut Foam	135	-
Install Rigid Foam	450	-
Total	**660**	**0**
Total Second Story Walls	**1905**	**1170**

Normalized Labor Man-Minutes
Summary of Roof Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	**Steel House**	**Wood House**
Ceiling Joists		
Read Plans	15	15
Layout	15	15
Obtain Materials	15	15
Organize Material	15	15
Mark	30	30
Position	15	15
Measure	30	60
Cut Joists and Tracks	15	15
Cut Blocking	165	150
Install Blocking/Strapping	30	45
Cut Web Stiffeners	30	-
Install Web Stiffeners	45	-
Install Ceiling Joists	210	240
Job Site Cleaning	30	45
Total	**660**	**660**
Roof Rafters		
Read Plans	30	30
Layout	60	75
Organize Material	30	45
Mark	30	30
Position	15	15
Measure	30	45
Cut Rafters	105	90
Construct Ridge Member	225	-
Cut Blocking	45	45
Install Blocking/Strapping	120	90
Measure/Cut Roof Sheathing	120	120
Install Rafters	1875	1920
Install Roof Sheathing	2190	2145
Total	**4875**	**4650**
Roof Shingles	**2415**	**2375**
Total Roof Framing	**7950**	**7685**

Normalized Labor Man-Minutes
Summary of Non-Load Bearing Walls Framing Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
First Story Non-Load Bearing Walls		
Read Plans	30	30
Layout	15	30
Organize Material	15	15
Mark	30	30
Position	30	30
Measure	45	45
Cut Studs and Tracks	240	300
Cut Blocking/Strapping	60	45
Install Blocking/Strapping	105	90
Frame Headers	135	180
Frame Walls	1060	1000
Brace Walls	165	180
Job Site Cleaning	60	75
Total	**1990**	**2050**
Second Story Non-Load-Bearing Walls		
Read Plans	30	30
Layout	30	30
Organize Material	30	30
Mark	15	15
Position	15	30
Measure	45	45
Cut Studs and Tracks	130	100
Cut Blocking/Strapping	60	45
Install Blocking/Strapping	90	75
Frame Headers	75	90
Frame Walls	910	940
Brace Walls	90	105
Job Site Cleaning	45	45
Total	**1565**	**1580**
Total Non-Load Bearing Walls	**3555**	**3630**

Normalized Labor Man-Minutes
Summary of HVAC and Electrical & Plumbing Trades Installation Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
HVAC		
Read Plans	45	45
Layout	75	75
Organize Material	75	75
Measure	45	60
Cut Tracks/Plates	1020	1005
Install Ducts	840	825
Install Furnace	175	175
Install Thermostat	15	30
Tape/Mask Ducts	15	15
Job Site Cleaning	45	45
Total	**2350**	**2350**
Electrical		
Read Plans	30	30
Organize Material	60	60
Measure	75	75
Punch/Cut Studs/Tracks/Wood Plates	60	405
Run Electrical Wires	705	960
Install/Fasten Electrical Boxes	1050	900
Install receptacles, Connect Wires & Install Cover Plates for Boxes	960	960
Install Lighting Fixtures	285	285
Install Electrical Panel	450	450
Ceiling Fans Installation	180	180
Job Site Cleaning	240	270
Total	**4095**	**4575**
Plumbing		
Read Plans	30	30
Layout	75	75
Organize Material	45	45
Measure	45	45
Punch/Cut Studs/Tracks/Top Plates	315	150
Run Piping	1575	1425
Install Kitchen Plumbing Fixtures	180	180
Install Bathrooms Plumbing Fixtures	525	525
Install Gas Meter	15	15
Install Toilets	90	90
Install Showers	240	240
Install Vanities and Sinks	180	180
Job Site Cleaning	165	165
Total	**3480**	**3165**

Normalized Labor Man-Minutes
Summary of Insulation, Drywall and Siding Trades Installation Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
Batt Insulation		
Read Plans	30	30
Layout	45	45
Organize Material	30	30
Measure/Cut	105	120
Install Insulation in Wall Cavity	795	780
Install Attic Insulation	285	255
Job Site Cleaning	30	30
Total	**1320**	**1290**
Drywall		
Layout	75	75
Organize Material	90	90
Measure	195	195
Cut Drywall Sheets	240	240
First Floor Drywall Installation (Walls)	2760	2655
Second Floor Drywall Installation (Walls)	915	885
First Floor Ceiling Drywall Installation	795	765
Second Floor Ceiling Drywall Installation	765	720
Job Site Cleaning	150	150
Total	**5985**	**5775**
Drywall Finishing and Painting		
Layout	15	15
Organize Material	15	15
Tape Joints	2010	2490
First Paint Coat	1275	1440
Final Paint Coat	735	840
Job Site Cleaning	525	540
Sand Drywall	480	420
Paint Touch Up, & Paint The Front Porch	930	1035
Total	**5985**	**6795**
Siding[1]		
Read Plans	33	30
Layout	50	45
Organize Material	83	75
Measure/Cut Siding	1018	915
Install Siding	3088	2775
Total	**4272**	**3840**

[1] Adjusted for actual square footage of exterior wall surface area (2365 ft^2 for steel house and 2125 ft^2 for wood house).

Normalized Labor Man-Minutes
Summary of Carpentry and Front Porch Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
Baseboard Trim		
Layout	15	15
Organize Material	15	15
Measure	345	345
Cut Trim	465	465
Install Trim	645	630
Job Site Cleaning	75	75
Total	**1560**	**1545**
Kitchen Cabinets		
Layout	45	45
Organize Material	75	75
Measure	165	165
Install Cabinets	645	630
Install Kitchen Counter, & Fresh Doors	870	870
Kitchen Appliances Installation	90	90
Job Site Cleaning	120	120
Total	**2010**	**1995**
Windows and Doors (exclude garage)		
Layout	15	15
Organize Material	15	15
Measure	15	15
Install Windows	810	810
Install Exterior Doors	45	45
Install Interior Doors	585	585
Job Site Cleaning	15	15
Install Locks, Kick Plates & Stair trim	1020	1020
Total	**2520**	**2520**
Front Porch		
Layout	30	15
Organize Material	15	15
Measure	45	30
Cut Joists/Studs	180	60
Frame Porch	1065	510
Sheath Porch	120	90
Frame Porch Roof	480	240
Total	**1935**	**960**

Normalized Labor Man-Minutes
Summary of Flooring, Deck Framing, Stair Framing and Windows and Doors Installation
Labor Time by Subcomponent
Man-Minutes

Component/Subcomponent	Steel House	Wood House
First Floor Stairs		
Layout/Organize Material	15	15
Measure	30	30
Cut Framing Members	75	60
Frame Stairs	150	135
Job Site Cleaning	15	15
Total	**285**	**255**
Second Floor Stairs		
Layout/Organize Material	15	15
Measure	30	30
Cut Framing Members	75	75
Frame Stairs	150	135
Job Site Cleaning	15	15
Total	**285**	**270**
Total Stairs	**570**	**525**
Flooring (Floor Covering)		
Layout	105	105
Organize Material	45	45
Measure	75	75
Carpet Installation	825	825
Hardwood Installation	360	360
Vinyl Floor Installation	345	345
Job Site Cleaning	75	75
Total	**1830**	**1830**
Deck Framing		
Layout	45	45
Organize Material	30	30
Frame Deck	435	435
Job Site Cleaning	30	30
Total	**540**	**540**
Other Miscellaneous Components		
Install Mirrors	60	60
Fire Place Installation	120	120
Install A/C Unit (outside)	390	390
Run Gas Pipe to House	405	405
Brick Installation	N/A	1860
Run Power Supply to House	300	300
Final House Cleaning	1080	1080
Garage Concrete slab	270	270
Install Garage Door/Door Openers	240	240
Excavators	210	210
Concrete Driveway Construction	3150	3150
Dormer Drywall Installation and Finishing	-	270

APPENDIX D

BUILDER'S MATERIAL COST

Material List
Valparaiso Steel Demonstration Home

Quantity	**Description**	**Designation**	**Length (ft-in.)**	**Price ($)**
58	Stud	350S162-33	8’-1”	$178.70
18	Stud	350S162-33	10’-0”	$68.61
21	Track	350T162-33	15’-0”	$108.82
192	Stud	350S125-27	8’-1”	$332.44
42	Track	350T125-27	15’-0”	$127.67
228	Stud	550S162-33	8’-1”	$981.12
30	Stud	550S162-33	8’-11.75”	$143.40
35	Stud	550S162-33	10’-0”	$186.32
28	Stud	550S162-33	6’-3”	$93.17
65	Track	550T125-33	15’-0”	$426.90
7	Stud	800S162-43	7’-7.5”	$48.14
11	Stud	800S162-43	9’-10.625”	$98.08
13	Stud	800S162-43	12’-8.75”	$149.26
7	Stud	800S162-54	12’-6”	$87.56
22	Stud	800S162-54	19’-11.875”	$440.06
11	Stud	800S162-54	16’-4.75”	$180.47
10	Stud	800S162-54	16’-4.75”	$164.06
7	Stud	800S162-54	25’-5.375”	$178.25
11	Stud	800S162-54	27’-8.5”	$304.99
32	Stud	1000S162-54	16’-6”	$635.34
11	Stud	1000S162-54	14’-3”	$188.62
8	Stud	1000S162-54	17’-2”	$165.25
11	Stud	1000S162-54	20’-4”	$269.14
21	Stud	1000S162-43	22’-0.75”	$538.04
8	Stud	1000S162-43	12’-0”	$111.49
12	Stud	1000S162-43	18’-6”	$257.81
12	Track	1000T125-54	15’-0”	$195.43
127	Web Stiffeners	1000S162-54	1’-5”	$212.12
7	Flat Strap	2”x54	10’-0”	$17.49
10	Angle	150L150-54	10’-0”	$31.61
Steel Total				**$6,920.34**
Floor, wall, and roof sheathing and miscellaneous lumber				**$6,915.67**

Material List
Valparaiso Wood Demonstration Home

Quantity	Description	Length (ft-in.)	Price ($)
44	¾"x4'x8' Advantech Flooring	-	$1,013.61
42	2x10 Doug Fir	16'	$809.58
10	2x10 Doug Fir	12'	$144.57
10	2x10 Doug Fir	18'	$231.94
16	2x6 treated SYP #1	16'	$172.48
6	2x6 Construction	8'	$28.91
3	2x12 #1 SYP	16'	$79.95
4	2x4 Construction	16'	$25.69
8	2x4	8'	$21.71
1	50 lb. Box 16 CC Sinkers	-	$21.35
1	50 lb. Box 8 CC Sinkers	-	$21.35
1	1-3/4" Quick Drive Screws (Box)	-	$47.14
8	2x6 Construction	16'	$77.10
12	PL400 Construction Adhesive	-	$35.32
1	Box Senco Power 10d Nails	-	$68.04
1	Box Senco Power 16d Nails	-	$41.89
4	7/16"x4'x8' Oxboard	-	$43.96
16	2x10 Doug Fir	14'	$283.61
6	Roll 6"x40' Sill Sealer	40'	$26.29
57	7/16"x4'x8' Oxboard	-	$417.40
42	2x6 Construction	16'	$330.88
130	2x6 Precut Studs	7'-8-5/8"	$597.88
45	2x4 Construction	16'	$288.99
40	2x4 Precut Studs	7'-8-5/8"	$104.34
65	2x4 Precut Studs	7'-10-1/8"	$176.37
25	2x4 Precut Studs	8'-6-5/8"	$67.83
2	2x12 #1 SYP	18'	$62.23
1	2x12 #1 SYP	22'	$16.34
12	2x4 Precut Studs	7'-10-1/8"	$55.31
1	Box Senco Power 8d Nails	-	$41.89
5	2x10 Doug Fir	16'	$101.25
85	7/16"x4'x8' Oxboard	-	$1,114.73
2	7/16" Teco Steel H-Clips	-	$52.48
16	2x12 Doug Fir	22'	$645.96
18	2x12 #1 SYP	30'	$1,321.11
25	2x8 Doug Fir	22'	$644.44
18	2x8 #1 SYP	12'	$264.60
11	2x8 #1 SYP	10'	$134.79
6	2x10 #1 SYP	16'	$117.62
16	2x8 Construction	14'	$187.82
26	2x6 Construction	16'	$251.16
1	Box Senco Power 8d Nails	-	$52.21

Material List
Valparaiso Wood Demonstration Home (cont.)

Quantity	Description	Length (ft-in.)	Price ($)
25	¾”x4’x8’ Advantech Flooring	-	$579.93
16	2x10 Doug Fir	16’	$308.42
10	2x10 Doug Fir	12’	$144.57
18	2x10 Doug Fir	18’	$417.50
3	2x12 #1 SYP	16’	$79.95
3	2x4 Construction	16’	$19.27
1	50 lb. Box 16 CC Sinkers	-	$21.35
1	50 lb. Box 8 CC Sinkers	-	$21.35
12	PL400 Construction Adhesive	-	$35.32
6	2x8 Construction	8’	$40.17
16	2x10 Doug Fir	14’	$283.61
16	2x10 Doug Fir	10’	$202.48
50	7/16”x4’x8’ Oxboard	-	$654.24
36	2x6 Construction	16’	$283.61
100	2x6 Precut Studs	7’-8-5/8”	$459.91
42	2x4 Construction	7’-8-5/8”	$109.56
60	2x4 Precut Studs	7’-10-5/8”	$162.80
30	2x4 Construction	16’	$192.66
2	2x10 #1 SYP	14’	$34.22
1	2x10 #1 SYP	10’	$12.23
2	Box Senco Power 8d Nails	-	$104.18
1	Box Senco Power 16d Nails	-	$52.38
30	2x4 Precut Studs	7’-8-5/8”	$78.26
12	2x12 Doug Fir	16’	$243.56
1	5-1/8”x18” Lam Beam	21’	$476.28
1	5-1/8”x18” Lam Beam	21’	$476.28
3	11-1/4” LVL	12’	$148.87
20	2x4 Construction	16’	$128.73
20	2x4 Construction	8’	$52.08
2	1x8 Rough Sawn Cedar	16’	$37.97
1	1 lb. 10d Galvanized casement Nails	-	$2.15
1	1 lb. 16d Galvanized casement Nails	-	$2.15
Total (including shipping and tax)			**$16,675**

APPENDIX E

HOUSE PHOTOGRAPHS

Steel House Floor Framing

Wood House Floor Framing

Steel House Wall Framing

Wood House Wall Framing

Steel House Roof Framing

Wood House Wall Framing

Steel House Framing

Wood House Framing

Finished Steel House

Finished Wood House