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

Steel vs. Wood
Long-Term Thermal Performance Comparison

Valparaiso Demonstration Homes

PATH (Partnership for Advancing Technology in Housing) is a new private/public effort to develop, demonstrate, and gain widespread market acceptance for the "Next Generation" of American housing. Through the use of new or innovative technologies, the goal of PATH is to improve the quality, durability, environmental efficiency, and affordability of tomorrow's homes.

PATH is managed and supported by the U.S. Department of Housing and Urban Development (HUD). In addition, all federal agencies that engage in housing research and technology development are PATH Partners, including the Departments of Energy, Commerce, and Agriculture, as well as the Environmental Protection Agency (EPA) and the Federal Emergency Management Agency (FEMA). State and local governments and other participants from the public sector are also partners in PATH. Product manufacturers, home builders, insurance companies, and lenders represent private industry in the PATH Partnership.

To learn more about PATH, please contact

PATH
PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

451 7th Street, SW
Washington, DC 20410
202-708-4277 (phone)
202-708-5873 (fax)
e-mail: pathnet@pathnet.org
website: www.pathnet.org

Visit PD&R's Website
www.huduser.org
to find this report and others sponsored by
HUD's Office of Policy Development and Research (PD&R).

Other services of HUD USER, PD&R's Research Information Service, include listservs; special interest, bimonthly publications (best practices, significant studies from other sources); access to public use databases; and a hotline 1-800-245-2691 for help accessing the information you need.

Steel vs. Wood
Long-Term Thermal Performance Comparison

Valparaiso Demonstration Homes

Prepared for

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

North American Steel Framing Alliance (NASFA)
Washington, DC

National Association of Home Builders
Washington, DC

by

NAHB Research Center, Inc.
Upper Marlboro, Maryland

Contract No. H-21216CA

January 2002

Disclaimer

While the information in this document is believed to be accurate, neither the authors, nor reviewers, nor the U.S. Department of Housing and Urban Development of the U.S. Government, nor the North American Steel Framing Alliance, nor the National Association of Home builders, nor the NAHB Research Center, Inc., nor any of their employees or representatives make any warranty, guarantee, or representation, expressed or implied, with respect to the accuracy, effectiveness, or usefulness of any information, method, or material in this document, nor assumes any liability for the use of any information, methods, or materials, disclosed herein, or for damages arising form such use.

Notice

The contents of this report are the views of the contractor and do not necessarily reflect the views or policies of the U.S. Department of Housing and Urban Development or the U.S. Government. The U.S. Government does not endorse producers or manufacturers. Trade and manufacturers' names appear herein solely because they are considered essential to the contents of this report.

Acknowledgements

This report was prepared by the NAHB Research Center, Inc. under sponsorship of 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). The principal author is Craig Drumheller, CEM. Nader Elhajj, P.E. and David Dacquisto provided internal technical review. Special appreciation is extended to William Freeborne of HUD and Kevin Bielat of NASFA for their guidance and assistance throughout the project. Special recognition is extended to Dennis Henderlong of Generation Homes for participating in this project. Appreciation is also extended to the following Research Center staff for their assistance: James Lyons, Lynda Marchman, Donna Woodhurst and Mark Nowak.

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. This report focuses on the latter of these issues.

The scope of this report is limited to long-term (May 2000-April 2001) energy use in two nearly identical side-by-side homes in Valparaiso, Indiana. This site has a house framed with conventional dimensional lumber and a second house framed with cold-formed steel. Blower door and Duct Blaster 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 thermal performance between the two houses.

For the side-by-side testing in Valparaiso, Indiana, the energy use for both natural gas (heating) and electric (cooling and blower fan) were slightly higher in the steel framed house. The net normalized difference between the two houses amount to 3.9 percent more winter natural gas usage and 10.7 percent more summer electric use in the steel house. It is believed that solar radiant gains account for a majority of the difference in the seasonal performance.

The cathedral ceiling insulation retrofit, which added R-3.8 to the vaulted portion of the steel house ceiling in March 2001, appears to have slightly improved the overall thermal resistance of the steel house. This is reflected in the nighttime energy use comparison. In February, the steel house required 3.7 percent more energy to heat versus a post-retrofit 2.1 percent difference. The co-heat test (Appendix G) echoed similar results with the wood house performing 3.9 percent better before and a 1.0 percent better post-retrofit.

ENERGY USE SUMMARY

UTILITY	WOOD HOUSE	STEEL HOUSE	PERCENT DIFFERENCE
Total Actual A/C, Blower Load	**1,439 kWh**	1,584 kWh	10.4 percent
Total Normalized A/C, Blower Load	1,470 kWh	1,584 kWh	7.8 percent
Summer Actual A/C, Blower Load	**856 kWh**	1,003 kWh	17.2 percent
Summer Normalized A/C, Blower Load	906 kWh	1,003 kWh	10.7 percent
Total Actual Heating Load	661 Therms	671 Therms	1.5 percent
Total Normalized Heating Load	646 Therms	671 Therms	**3.9 percent**

Note: Normalized usage was determined by using computer simulations (Energy-10) taking into account the differences in internal temperature, duct leakage and air infiltration.

The resulting normalized heating and cooling energy[1] was determined to be 7.8 percent (114 kWh) higher electric use in the steel framed house and 3.9 percent more natural gas (25 therms) usage in the steel framed house. In annual costs, the additional energy use equates to $10.99 for electric and $24.70 for natural gas.[2]

Higher radiant gains in the steel-framed house are believed to be a major contributor to the higher consumption in the summer. The radiant gains can be reduced in a number of ways: Rigid foam insulation on the outside of the roof sheathing, a hybrid framing design with steel walls and wood trusses or rafters or a thermal break between the roof members and the wall members.

Although the steel house falls marginally short of the baseline wood framed house, from a thermal performance standpoint, it still exceeds the 1995 MEC by over 25 percent.[3]

---

[1] Energy 10 version 1.3 was used to calculate normalized use.

[2] Utility rates used are $0.988/therm and $0.09637/kWh, this reflects the NIPSCO local rates as of April 2001.

[3] REM/Design version 10.1 was used to compare the steel house to MEC.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

This report is the first of three in a multi–year study comparing thermal performance of steel and wood framed 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. Steel stud framing for residential building is gaining popularity due to consistently low material cost, simplicity of construction and similarity to wood frame assembly. Despite the availability of cold-formed steel framing, there are still basic barriers that impede its adoption in the residential market. The largest barrier is generally believed to be 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 the question of how the higher thermal conductivity of steel affects energy use in homes.

When building with steel framing members, it is necessary to compensate for the thermal bridging inherent in steel. If a structurally equivalent steel stud were to replace wood without consideration of thermal performance, the overall clear wall R-value of a wall can be reduced by 25 percent[1] with a typical wall section.

The approach taken in Valparaiso was to build a wood house to local standard practices. A nearly identical steel house was also designed using the builders’ standard practices that required ¾” exterior foam insulation and 24” on center stud spacing (in lieu of 16” o.c.). The long-term (1-year) monitoring was designed to determine how these two houses perform thermally in a northern Indiana climate. Monitoring various temperatures and heating and cooling energy use during the test period in unoccupied houses are the basis of the evaluation. Appendix B and C contain graphs reflecting monitoring results for four seasonal months (July, September, January, April).

2.0 OBJECTIVE

The purpose of this report is to compare the thermal performance (i.e., energy consumption) of an unoccupied steel-framed home to that of a nearly identical unoccupied wood-framed home. Co-heat (Appendix G) and infiltration tests (Appendix E) were also conducted to complement the long-term thermal performance of the two houses. The demonstration homes were erected side-by-side in Valparaiso, Indiana, with nearly identical floor plan, dimensions, orientation, exposure and HVAC equipment.

3.0 SITE LOCATION

Generation Homes of Valparaiso, Indiana, constructed the wood and steel framed demonstration homes in the Carriage Crossing development of 57 home sites in the northwest corner of

---

[1] Calculated using the parallel flow method ASHRAE Fundamentals Chapter 25 using a 2x4, 16”o.c., R-11 batt insulation wall assembly.

Keystone Commons, in Valparaiso, Indiana. Valparaiso is located 50 miles southeast of Chicago, Illinois. 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 and an unfinished basement (see Appendix A for plans, Appendix D for photographs). Both exterior and interior walls were built with conventional stick framing techniques.

The builder, Generation Homes, is an EPA "Energy Star" builder that primarily constructs single-family homes, townhomes, and condominiums in northwest Indiana. Generation Homes offers the option of either steel or wood frame houses. They are a "turn key cost" builder, meaning the final price of the home includes all the items necessary to complete the home. The homes were marketed for between $180,000 and $200,000 depending on the options selected.

4.0 CHARACTERISTICS OF DEMONSTRATION HOMES

STRUCTURAL CHARACTERISTICS

All framing elements in the wood and steel framed 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 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, sheathed with 1/2-inch (12.7 mm) nominal OSB, and covered with asphalt fiberglass roofing shingles over 15-pound felt underlayment. A combination of vinyl siding (90 percent) and brick (10 percent) was applied over oriented-strand-board (OSB) sheathing for the exterior finish of the wood framed house. Vinyl siding was used as the exterior finish for the steel framed 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-framed house were covered with ¾ inch (19 mm) rigid extruded polystyrene panels (R-value of 3.8) secured to the exterior side of the OSB with plastic cap nails. The front porch of the steel-framed house was

---

[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.

designed to be larger than that of the wood framed 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. Exteriors were sheathed with 7/16 inch (11 mm) APA rated oriented-strand-board (OSB) attached to the studs (fully sheathed walls). The wood framed 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 and was blocked off with OSB during the testing period. The wood framed house also had the front of the house partially faced with brick veneer.

TABLE 4.1
VALPARAISO DEMONSTRATION HOMES FRAMING DETAILS

COMPONENT	STEEL HOUSE	WOOD HOUSE
Basement	**Unfinished with Steel stud framing**	**Unfinished with Wood stud framing**
Exterior Walls		
Drywall Size	1/2"x4'x8'/12'	1/2"x4'x8'/12'
Stud Size and Spacing	(2x6x33) Steel @ 24" o.c.	2x6 Wood @ 16" o.c.
Wall Sheathing	7/16"x4'x8' OSB	7/16" x4'x8' OSB
Rigid Foam Material & Thickness	3/4" Tenneco Extruded Polystyrene R-3.8 Rigid Foam Panels	N/A
Siding Material	Vinyl Siding	Vinyl Siding, Partial Brick Front
Ceiling Joists and Roof Rafters		
Joist Size and Spacing	(2x10x43) Steel @ 24"o.c.	2x10 Wood @ 16" o.c.
Drywall Size and Fastening	½"x4'x8'/12' w/Drywall screws	1/2"x4'x8'/12' w/Drywall screws
Rafter Size and Spacing	(2x8x54) Steel @ 24" o.c	2x8 Wood @ 16" o.c.
Roof Sheathing	7/16"x4'x8' Oxboard	7/16" x4'x8' Oxboard

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

THERMAL CHARACTERISTICS

Table 4.2 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.

The vaulted ceiling, attic, above ground and basement walls were insulated with R-30 fiberglass batts, R-40 blown in fiberglass, R-19 fiberglass batts, and R13 fiberglass blanket insulation, respectively.

TABLE 4.2
THERMAL 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	Two	Two
Windows	Vinyl Double Glaze U=49	Vinyl Double Glaze U=49
Roof Covering	Dark Asphalt Fiberglass Shingles	Dark Asphalt Fiberglass Shingles
A/C Unit	10 SEER Central Air Conditioning	10 SEER Central Air Conditioning
	Carrier 38CK030	Carrier 38CK030
Furnace	80% A.F.U.E. Gas Forced Air	80% A.F.U.E. Gas Forced Air
	Carrier 58TAV090	Carrier 58TAV090
Basement		
Wall Insulation	R11 Fiberglass Batts	R11 Fiberglass Batts
Crawl Space Insulation	R13 Fiberglass Blanket on Walls	R13 Fiberglass Blanket on Walls
Exterior Walls		
Stud Spacing	24” o.c.	16” o.c.
Wall Sheathing	7/16” OSB	7/16” OSB
Drywall Size	1/2”	1/2”
Rigid Foam Material & Thickness	3/4” Tenneco Extruded Polystyrene R-3.8 Rigid Foam Panels	N/A
Siding Material	Vinyl Siding	Vinyl Siding, Partial Brick Front
Wall Cavity Insulation Type	R19, Fiberglass Batts	R19, Fiberglass Batts
Ceiling Joists and Roof Rafters		
Joist Size and Spacing	2”x10” Steel @ 24”o.c.	2”x10” Wood @ 16” o.c.
Roof Insulation and Thickness	R40 Fiberglass, Blown in (16in+)	R40 Fiberglass, Blown in (16in +)
Cathedral Ceiling Insulation	R30 Fiberglass Batts	R30 Fiberglass Batts

For SI: 1 ft. = 305 mm

Note

[1] Refer to Appendix A for house dimensions.

DIMENSIONAL CHARACTERISTICS

To ensure a fair comparison, both houses were built with the dimensions as similar as possible. Small differences exist in some of the as built measurements, amounting to less than a 0.5 percent difference in living area. A table of important measurements follows:

TABLE 4.3
DIMENSIONS OF VALPARAISO DEMONSTRATION HOMES

COMPONENT	DIMENSIONS
Square footage of living area	2,200 ft^2
Square footage of garage	390 ft^2
Square footage of basement	1,000 ft^2
Square footage of crawl space	200 ft^2
Square footage of first floor	1,270 ft^2
Square footage of second floor	930 ft^2
House Width	34 ft.
House Length	52 ft.
1st Floor Wall Height (avg)	9.8 ft.
2nd Floor Wall Height (avg)	7.6 ft.
Volume of Living Space (excludes Basement)	19,500 Ft^3
Volume of Entire House	28,300 Ft^3

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

5.0 MONITORING EQUIPMENT

Each site was instrumented with a multi-channel data logger to record numerous data points. The data logger has the flexibility to perform many data acquisition and control functions and is capable of downloading or reprogramming the system via modem. Electrical use, gas use, temperature and humidity measurements throughout the house, basement, attic, walls and outside were gathered at 5 second intervals and recorded on a 15 minute basis. Because of concerns related to entry into the houses, in mid-August door sensors were installed to record all openings and closing for the front and back doors.

Located in Appendix A is a layout of the location for all the data sensors. Similar points with the same types of instruments were used to monitor the houses. Sensors that were deemed critical were calibrated. A complete list of recorded data points are listed in Table 5.

TABLE 5.1
DATA POINTS MONITORED AND SENSORS USED

COMPONENT	SENSOR TYPE	ACCURACY
Indoor Temperature	Resistive Temperature Sensor	+/-0.1°F
Indoor Humidity	Capacitance Type Humidity Sensor	+/-1% RH
Front Wall Stud Temperature	Stick-on T-type Thermocouple	+/-1.8°F
Front Wall Cavity Temperature	Resistive Temperature Sensor	+/-1.0°F
Front Wall Cavity Humidity	Capacitance Type Humidity Sensor	+/-2.5% RH
Front Wall Wetness Sensor	Resistive type Wetness Sensor	N/A
Back Wall Stud Temperature	Stick-on T-type Thermocouple	+/-1.8°F
Back Wall Cavity Temperature	Resistive Temperature Sensor	+/-1.0°F
Back Wall Cavity Humidity	Capacitance Type Humidity Sensor	+/-2.5% RH
Back Wall Wetness Sensor	Resistive type Wetness Sensor	N/A
Outdoor Temperature (1)- Wood Only	T-type Thermocouple	+/-1.8°F
Outdoor Temperature (2)- Wood Only	Resistive Temperature Sensor	+/-0.1°F
Outdoor Humidity- Wood Only	Capacitance Type Humidity Sensor	+/-1% RH
South Bedroom Temperature	T-type Thermocouple	+/-1.8°F
North Bedroom Temperature	T-type Thermocouple	+/-1.8°F
Great Room Temperature	T-type Thermocouple	+/-1.8°F
Attic Temperature	T-type Thermocouple	+/-1.8°F
East Cathedral Ceiling Joist Temperature	Stick-on T-type Thermocouple	+/-1.8°F
Basement Joist Temperature	T-type Thermocouple	+/-1.8°F
Basement Slab Temperature	Stick-on T-type Thermocouple	+/-1.8°F
Basement Wall Stud Temperature- 6 ft	Stick-on T-type Thermocouple	+/-1.8°F
Basement Wall Stud Temperature- 2 ft	Stick-on T-type Thermocouple	+/-1.8°F
Basement Ambient North	T-type Thermocouple	+/-1.8°F
Basement Ambient South	T-type Thermocouple	+/-1.8°F
AC Compressor Watt-hour Meter (100A)	Single Phase Watthour Transducer	+/-1% F.S.
Blower Watt-hour Meter (100A)	Single Phase Watthour Transducer	+/-1% F.S.
Natural Gas Run-time	120v AC/12v DC Relay	+/-5 seconds
Front Door Open Sensor	Reed Switch	+/-5 seconds
Back Door Open Sensor	Reed Switch	+/-5 seconds

6.0 METHODOLOGY

Heating and cooling energy use, both natural gas and electric, was the primary focus of the study. One year's worth of data was gathered from each of the two test houses. The two seasons that were of primary interest were the summer (June-September) and winter (November-February) months. The forced air furnace/ air conditioner system was considered the sole energy consumer in each of the houses. Other data points (temperatures, humidity, moisture, and open door sensors) were also monitored to track any unusual differences between the two houses.

Energy use of the houses is assumed to be solely a function of the HVAC systems, as the houses are unoccupied and other potential loads (such as water heaters or lights) are switched off. HVAC equipment consumption is monitored using watt-hour meters that are installed on the indoor blower circuit and the air conditioner compressor circuit, with a relay measuring run time installed on the gas solenoid valve. All signals are routed to the multi-channel data logging equipment, configured to be accessible for remote data monitoring. Also, on a visit in August, run time relays were installed on most of the HVAC electrical circuits as a further data backup. Temperature and humidity measurements are being taken at a number of indoor points, one outdoor location, and in the cavities of the front and back walls of each house. (See Appendix A for plans noting sensor locations.)

Weather

Because the houses were tested simultaneously and side by side, the effect of weather would be identical on both houses. The weather over the testing period (March 2000-April 2001) amounted to a hotter than average summer and a slightly colder than average winter.

Modeling Assumptions

The nature of side-by-side monitoring eliminates most of the variables that can effect energy usage. Three differing characteristics still remain that require “normalization” to ensure a fair comparison. Because the air infiltration and duct leakage tests (Appendix E and F) reflected different results, the potential for a biased result may exist. The third example would be compensating for small temperature differences inside the two houses, a house that is warmer in the winter would require additional energy to heat, and conversely in the summer would take less energy to cool. These three variables can easily be input into the modeling software to compensate for the differences.

Gas runtime was used to determine the amount of natural gas used by the furnace. Since the on/off valve only allows gas to flow at one rate, the runtime is proportional to the gas usage. Once the flow rate is established by calibrating the furnace runtime with the utility gas meter, a simple multiplier can be used to equate BTU’s (energy) to valve runtime.

Any days that there was a known entry into either house, the data for both houses were discarded. It is assumed that whenever the houses were entered, they were left completely sealed. With periodic visits by the Research Center checking these details, there is no reason to believe that this was a problem.

Results are reported in two different forms. The first form is the compiled data that was directly monitored from the datalogger. The second from is a normalized result, this uses computer simulations to compensate for differences in internal house temperature, duct tightness and air infiltration.

7.0 RESULTS

Seasonal results for both energy (Appendix B) and temperature (Appendix C) are graphed for monitoring points.

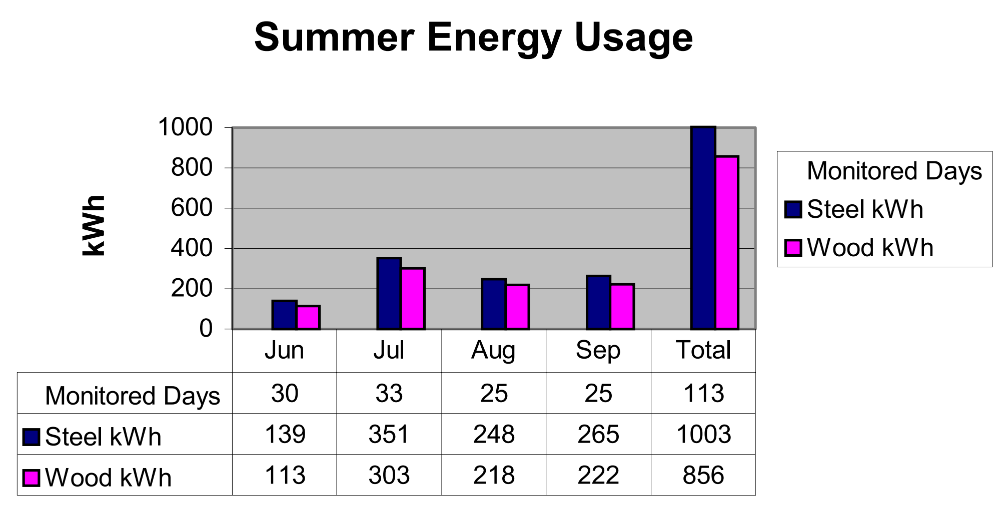
Annual Data (May 2000-April 2001)

Data was gathered from May 2000 until April 2001. Over that time, 253 days worth of “good” data was acquired. Eliminated days were mostly due to two reasons, entry into either of the houses or large deviations between actual house temperatures and thermostat setpoints. The actual measured data for the 253 days reflects a difference in electric consumption of 10.4 percent (1,584.3 kWh Steel, 1,439.4 kWh Wood) that was higher in the steel-framed house than the wood framed house. Gas consumption (which excluded March 2001) differed by 1.5 percent (671.4 therms steel, 661.6 therms wood) with the steel framed house using the larger amount.

Results were then normalized to compensate for differences in air infiltration, duct tightness and temperature, then extended over a typical weather year. The resulting electric consumption for the steel-framed house is 7.8 percent higher than the wood-framed house. The natural gas consumption in the steel-framed house is 3.9 percent higher than the wood framed house.

Summer Data (June 2000-September 2000)

As seen in the energy consumption chart, directly monitored HVAC energy is relatively consistent between months, showing an average of 17.1 percent greater use in the steel-framed house than in the wood-framed house.



	Jun	Jul	Aug	Sep	Total
Monitored Days	30	33	25	25	113
Steel kWh	139	351	248	265	1003
Wood kWh	113	303	218	222	856

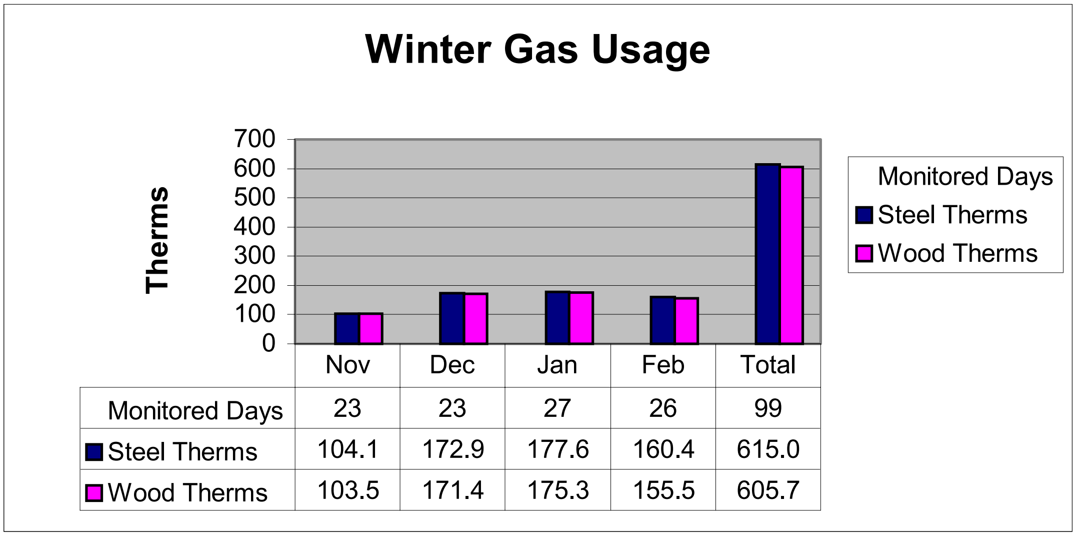
Figure 7.1

June represented the biggest percent difference between the steel and wood-framed houses (23.0 percent). August, the hottest month of the year, had the smallest percentage difference in use between the houses (13.8 percent).

The different internal house temperatures and slightly different air infiltration rates and duct tightness were plugged into a computer simulation model (Energy 10 v1.3). The normalized results tend to reduce the energy needed by the steel-framed house relative to the wood framed house. The net results reflect a reduction of 4.1 percentage points down to 13 percent more energy required to condition the steel-framed house than the wood framed house for the four peak summer months. The primary driver for the change was the 0.5°F lower temperature in the steel-framed house.

Winter Data (November 2000- February 2001)

Directly monitored natural gas consumption indicated that the steel-framed house required 1.5 percent more energy than the wood framed house. The consumption difference was reasonably consistent over the winter months varying from 0.5 percent in November to 3.1 percent in February.



	Nov	Dec	Jan	Feb	Total
Monitored Days	23	23	27	26	99
🟦 Steel Therms	104.1	172.9	177.6	160.4	615.0
🟪 Wood Therms	103.5	171.4	175.3	155.5	605.7

Figure 7.2

The computer-modeled normalization increased the winter difference between the two houses from 1.5 percent to 4.4 percent. The average winter temperature in the steel-framed house was 0.4°F lower than the wood framed house requiring less energy to maintain temperature. Another significant contributor to the increased difference was the duct leakage to outside that was about 50 percent higher in the wood framed house (Appendix F). This required the wood framed house to use more energy to deliver conditioned air to the living space.

Shoulder Month (October 2000)

The thermostat required manual intervention when switching between heating and cooling. Northern Indiana sees wide ranges of temperatures in the shoulder months. Data collected in October 2000 was not usable due to the cold weather that occurred prior to the changeover of the thermostat to heating mode.

Ceiling Insulation Retrofit (March 2001)

Data for the month of March was not used in the analysis. The ceiling insulation retrofit took approximately two weeks, additionally, the Research Center conducted co-heat testing (see Appendix G). This left only a couple days in the period that was not enough data to be considered significant.

Post-Ceiling Retrofit (April 2001)

The steel-framed house was modified with the addition of rigid foam insulation (R-3.8) on the inside of the vaulted portion of the ceiling. The vaulted portion of the ceiling has contains steel rafters that have a direct short between the living space and the asphalt roof. This was believed to be a large source of heat transmission.

Measured gas usage for April showed a 0.7 percent difference and a normalized difference of 2.6 percent, both indicating a higher energy usage by the steel-framed house. The April difference is less than the 3.9 percent heating load for the November-February time frame and is consistent with the improvement seen in the co-heat test (3.8 percent reduced to 1.4 percent). April data consists of 18 days of data.

8.0 DISCUSSION

There are numerous facets that were observed in the data analysis. All notable items are covered below.

SUMMER AND WINTER COMPARISONS

There is an expectation that two similar houses would perform similarly relative to each other in both summer and winter conditions. Initially there appears to be a large discrepancy between the 1.5 percent higher winter energy use and the 17.1 percent higher summer energy use in the steel-framed house vs. the wood framed house. Normalized results (4.4 percent in the winter and 13.0 percent in the summer) reduced the seasonal difference, but a distinct difference still exists which is believed to be primarily attributed to solar gains.

SOLAR GAINS

One of the most noticeable differences between the houses was the winter solar gain. The steel-framed house had significantly different performance between the day and the evening. In the January billing month, the steel-framed house used 3.8 percent less energy than the wood framed house between the daylight hours of 11AM and 7PM. Conversely, in the night hours between 12AM and 7AM, the steel-framed house used 2.9 percent more energy than the wood-framed house.

In the winter, solar gains can be separated out due to the need for heat in both the day and nighttime. It is difficult to separate the summer solar gains due to the lack of cooling need during the night. Northern Indiana typically experiences a cool down during summer nights requiring little cooling after dusk. In July less than 2 percent of the cooling load occurred between 10PM and 7AM.

When looking at the ceiling and attic graphs it is apparent that there are distinct differences in solar gains between the steel and wood framed houses. The steel-framed house records temperatures up to 15°F higher in the attic and 10 °F higher in the vaulted ceiling cavity. It is not unreasonable to conclude that most of the remaining 8.6 percent difference can be attributed to solar gains.

One of the architectural differences between the houses is the front porch. The steel-framed house has a full covered front porch shading both the front door and the family room window. The wood framed house has a smaller covered front stoop that provides shading only to the door. Consequently, there were noticeable differences in the morning energy usage despite shading on all family room windows. Summer mornings reflected an earlier cooling load in the wood framed house due to the solar gains in the family room triggering the A/C to run. Winter mornings had the opposite effect, with the solar gain causing a decreased heating load in the wood-framed house from about 8:00AM to 10:30AM (see graphs below).

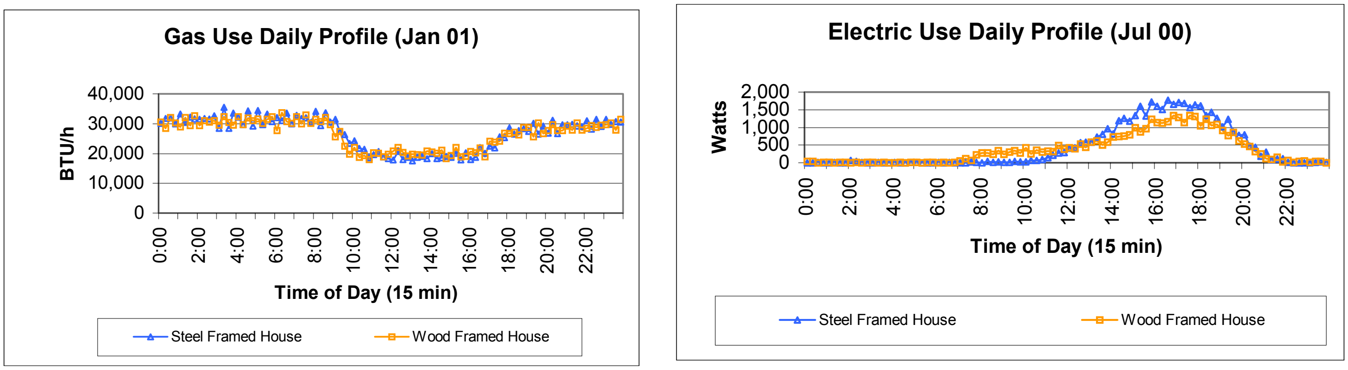


Figure 8.1

HOUSE TEMPERATURES

Other indicators of house conditioning dynamics are the temperature profiles for various areas of the houses. Line graphs showing temperatures for various sensors for monthly averages and five-day periods have been produced, and are included in Appendix C. It is informative to look not only at cooling temperatures, but also at the different temperature profiles of corresponding sensors in the two houses during the non-cooling periods. The steel-framed house temperatures decrease at a faster rate in the nights (especially during the summer) than the wood house temperatures, when the ambient temperature is below the thermostat set point. This indicates higher thermal conductivity in the steel house.

TABLE 8.1
SEASONAL AVERAGE ROOM TEMPERATURES

	Steel House Winter Avg. Room Temp (°F)	Wood House Winter Avg. Room Temp (°F)	Temperature Difference (wood-steel)	Steel House Summer Avg. Room Temp (°F)	Wood House Summer Avg. Room Temp (°F)	Temperature Difference (wood-steel)
Family Room	69.1	69.5	+0.4	72.9	73.4	+0.5
Great Room	67.4	68.7	+1.3	71.6	73.0	+1.4
North Bedroom (Bonus)	67.9	68.4	+0.5	73.6	75.1	+1.5
South (#2) Bedroom	70.0	70.2	+0.2	73.7	75.1	+1.4
Basement (unconditioned)	66.6	68.5	+1.9	66.3	67.2	+0.9
Thermostat Temps (°F)	**69.1**	**69.5**	**+0.4**	**72.9**	**73.4**	**+0.5**

The summer temperature data for the great room (thermostat location) and other rooms were inspected to determine if there was any consistent variance between the two houses. Thermostat temperatures in the wood house appear to be consistently higher than in the steel house during cooling periods – by 0.5 °F. Temperatures in the wood framed basement were higher than in the steel-framed basement by 1.5 °F during cooling hours. Not all rooms had thermocouples installed.

SHADING

Neither house has any appreciable shading. Differences between the shading of the houses by other houses, trees, etc. will affect energy use.

The house just south of the wood house was close enough to investigate the possibility of shading occurring (the steel-framed house had a vacant lot to the south). Measurements were made to determine if and when shading would occur on the wood framed house. By observation, shading will only begin to occur when the sun altitude is approximately 40-45° (at solar noon). By sun angle calculations, sun altitude is between roughly 48° and 68° between May 21 and September 21, the cooling season. Thus, shading will only occur in the heating season. On December 21 at solar noon, the worst case scenario, the gable roofline shadow peak of the neighboring house will only reach about 10 feet up the side of the wood house with the first two feet being the above ground portion of the basement. Even around the winter solstice, the majority of the shading occurs around 4 feet up the side of the house. It is not believed that the shading provides a measurable difference in the heating load in the wood house and was therefore not considered in the normalization process.

MISCELLANEOUS ENERGY USE

Even though only energy use of the HVAC system was measured, any additional internal energy use (e.g. lights, appliances etc.) would contribute to internal gains and change the load on the houses. During a site visit in fall of 2000, the houses were inspected to determine if any lights or other equipment were left on and all the electrical circuits were measured. All miscellaneous electrical use was small and comparable between the two houses. It is possible, though not likely, that lights or other appliances were switched on, left on and then later switched off – the instantaneous an long term measurements would not reveal this.

UNAUTHORIZED ENTRY

Due to the possibility that entries into the house might affect the results, door sensors were installed in mid-August. From that point on, any day where entry was detected in either house, data for both houses was discarded. Twelve (12) days were discarded in the summer time period (June-September) and seventeen (17) days were discarded in the winter (November-February) time period. These days included entries by the builder and the Research Center staff.

WALL CAVITY TEMPERATURE AND HUMIDITY DATA

Wall cavities in both the front (east) and back (west) of the houses were monitored for temperature and humidity. There is no indication from the data of any unusually high humidity levels (condensation or other moisture) in the walls of either of the houses in the areas monitored. Relative humidity tended to vary between 40 percent and 60 percent in the wall cavities of both houses in the summer and, as expected, much lower (15 percent to 40 percent) in the winter. The average relative humidity in the walls of the steel-framed house peaked at 50.1 percent for the months of June and July, about 5 percentage points higher than the walls in the wood-framed house. Winter wall cavity relative humidities were around 13 percentage points lower for the wood house. This was due to the higher wood cavity temperatures and not an increase in absolute moisture.

In both houses, the average humidity in the front and back walls were within 2 percentage points of each other. Maximum relative humidity for the steel house for the period occurred in the back wall on August 6, at 72.3 percent. Maximum relative humidity for the wood house occurred in the front wall on June 6, at 66.8 percent. Neither the moisture grids nor the humidity sensors indicated any evidence of condensation.

Humidity results could change in an occupied house. In these unoccupied houses, there is no moisture source. When occupied, people, cooking and standing water can all generate indoor moisture that can migrate through the walls and condense on cooler surfaces.

ATTIC AND CEILING TEMPERATURE

Dramatic swings in steel stud temperature can be seen at the bottom surface of the cathedral ceiling rafter above the drywall. The close correlation between ceiling stud temperature and ambient temperature indicates that this cathedral ceiling detail is a significant heat path.

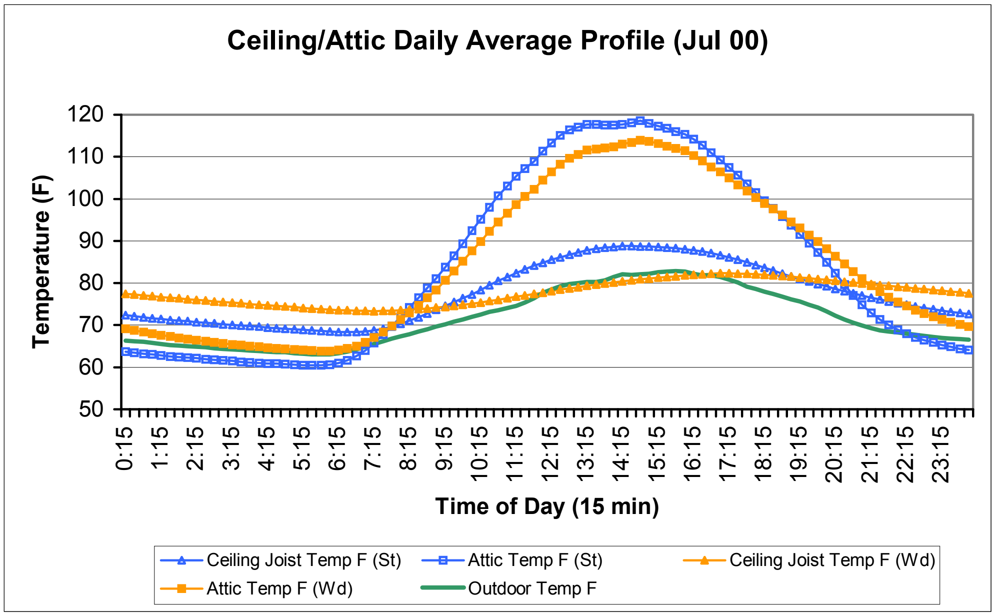


Figure 8.2

AIR DISTRIBUTION

Airflow measurements were taken during the August site visit. The total airflow to the wood framed house is somewhat higher (6 percent) than to the steel-framed house. Note, however, that even though three flow measurements (using a standard flow hood) were taken per supply register and averaged, to lower error, the flow hood error band may be larger than the 6 percent difference in flow between the houses. Air balance dampers in the houses were checked and found to be set similarly.

The measured airflows indicate proper conditioning is occurring in both houses on the first and second floors. No airflow measurements were taken in the basement (which is not considered fully conditioned). Although the airflow in the conditioned space was comparatively close, within 6 percent, the 1,500 cfm air volume was rather high for a 30,000 Btu/h air conditioner. Since the flows were similar in both houses, it is not believed that this had any effect on the results.

BASEMENT TEMPERATURE

The basement temperatures tracked very closely the house temperatures in the summer. The steel-framed house basement air temperature averaged 0.6°F lower than the wood basement. This was also consistent with other points in the basement.

During the winter months, the high (6 ft) temperature measurement on steel stud that in the summer was nearly identical between the houses, was now 10°F lower than the wood. The winter basement slab temperatures maintained the 1°F spread, with the steel being lower, that occurred in the summer.

9.0 CONCLUSIONS

HVAC energy use for both natural gas and electricity were slightly higher in the steel-framed house. The normalized difference between the two houses amount to 3.9 percent more natural gas usage in the winter months and 10.7 percent more electric use in the summer months.

The cathedral ceiling insulation retrofit appears to have marginally improved the overall thermal resistance of the steel house. This is reflected in the April nighttime energy use comparison to the wood framed house that was reduced from a February 3.7 percent shortfall to a post-retrofit 2.1 percent difference. The co-heat test echoed similar results with the steel house requiring 3.9 percent more energy before and only 1.0 percent post-retrofit.

Higher radiant gains in the steel-framed house are believed to be responsible for a majority of the higher consumption in the summer. These radiant gains can be reduced in a number of ways:

Rigid foam insulation on the outside of the roof sheathing. This would reduce the solar gains to the house by limiting the radiant energy making its way to the rafters and the house framing to which the rafters are directly coupled.

Thermal break between the roof members and the wall members most easily done with a wood top plate. This would reduce the transmission of solar energy throughout the framing, but would not help with the increased attic temperatures. Further research would be required to quantify the benefits for this design.

Hybrid framing design with steel walls and wood trusses or wood rafters. The hybrid design, in addition to providing the thermal break, would also lower the attic temperatures.

Normalized heating and cooling energy use during a typical meteorological year, the steel framed house would result in 7.8 percent (114 kWh) more electricity and 3.9 percent more natural gas (25 therms) than the equivalent wood framed house. In annual costs, the additional energy use would amount to \$35.69[5], \$10.99 for electric and \$24.70 for natural gas.

Although the steel framed house falls marginally short to that of the equivalent wood framed house; it still exceeds the 1995 MEC by over 25 percent. This is primarily due to the 2x6" wall construction, R-40 attic insulation and additional R-3.8 exterior wall sheathing insulation.

---

[5] Utility rates used are \$0.988/therm and \$0.09637/kWh, this reflects NIPSCO local rates as of April 2001