PD&R

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

Steel vs. Wood Framing
Long-Term Thermal Performance Comparison
Beaufort, SC Demonstration Homes

PATH
PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

PATH (Partnership for Advancing Technology in Housing) is a 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

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 Framing
Long-Term Thermal Performance Comparison
Beaufort, SC Demonstration Homes

Prepared for:

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

Steel Framing Alliance
Washington, D.C.

National Association of Home Builders
Washington, D.C.

by:

NAHB Research Center, Inc.
Upper Marlboro, Maryland

Contract No. H-21216CA

July 2003

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 Steel Framing Alliance (SFA) and the National Association of Home Builders (NAHB). The principal author is Craig Drumheller, CEM. Nader Elhajj, P.E., provided internal technical review. Special appreciation is extended to William Freeborne of HUD and Jonathan Humble of AISI for their guidance and assistance throughout the project. Special recognition is extended to Habersham Land Company and Seaway Development for participating in this project.

DISCLAIMER

Executive Summary

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 some clear 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 (April 2001-March 2002) energy use in two nearly identical side-by-side homes in Beaufort, South Carolina. The subject houses consist of one house framed with conventional dimensional lumber and a second house framed with cold-formed steel. For the side-by-side testing in Beaufort, South Carolina, the energy use for both natural gas (heating) and electric (cooling and blower fan) were slightly higher in the steel framed house. The normalized difference between the two houses amount to 5.1 percent less winter natural gas usage and 16 percent more summer electric use in the steel house.

Table E1 - Energy Use Summary

Utility	Wood House	Steel House	Percent Difference
Total Normalized Electric	4,846 kWh	5,598 kWh	15.5 percent
Total Normalized Heating Load	374 Therms	355 Therms	-5.1 percent

Note: Normalized usage was determined by using calibrated 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 751 kWh more electric use in the steel framed house as well as 18 fewer heating therms in the steel framed house. In annual costs, using local utility rates, the additional energy use equates to $41.[2]

Because of differences in rafter dimensions (Wood 2x8, Steel 2x6), less insulation (R-6) was added to the rafter portion of the steel house. Attempting to compensate for the shortage, an additional R-19 was added to the floor of the partially ventilated attic. These differences may have skewed the results by increasing heating energy use in the wood framed house and increasing cooling energy usage in the steel framed house.

With that being said, the results are in line with the numbers in a previous report comparing two identical houses in Valparaiso, Indiana[3]. That report showed a 3.9 percent and 9.7 percent annualized higher gas and electric usage in the steel framed house respectively.

Taking into account the additional exterior wall insulation (R-3.5) installed on the Valparaiso steel framed house (the Beaufort steel house did not have additional wall insulation) and the attic differences in Beaufort adding to the summer steel load, the Beaufort results seem to be consistent with Valparaiso. Showing that steel framed attics are significantly more susceptible to solar gains than wood framed attics.

---

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

[2] Utility rates used are $0.846/therm and $0.075/kWh, this reflects the SCE&G local rates as of March 2002.

[3] *Steel vs. Wood Long-Term Thermal Performance Comparison, Valpariso, IN, Demonstration Homes*, NAHB Research Center for the US Department of Housing and Urban Development. Washington, DC. 2001.

Table of Contents

Page

LIST OF TABLES

LIST OF FIGURES

1.0 Introduction

This report is the second 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 Steel Framing Alliance, and the National Association of Home Builders (NAHB). This study is conducted by the NAHB Research Center, Inc.

Light gauge 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 been gaining wider acceptance in load bearing wall, floor, and roof framing applications in residential construction. Steel stud framing for residential building is gaining popularity due to 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. This report addresses the question of how the higher thermal conductivity of steel affects energy use in homes.

When building with steel framing members, it is highly recommended 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] in a typical wall section. Using exterior rigid foam insulation can compensate for this reduction.

The approach taken in the Beaufort demonstration site was to build a wood house to local standard practices. A nearly identical steel house was also designed using the prescriptive method[2]. Additional exterior wall insulation was not required for the steel framed house according to the Thermal Design Guide[3]. The long-term (1-year) monitoring was designed to determine how these two houses perform thermally in a humid southern climate. Monitoring various temperatures and heating and cooling energy use during the test period in unoccupied houses are the basis of the evaluation.

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. In addition to energy consumption, any notable differences between the houses will be pointed out and discussed. Air infiltration, duct tightness and HVAC performance tests were also conducted to complement the long-term thermal performance of the two houses. The demonstration homes were erected side-by-side in Beaufort, South Carolina, with nearly identical floor plan, dimensions, orientation, exposure and HVAC equipment.

---

[1] Calculated using the parallel flow method 2001 ASHRAE Fundamentals Chapter 25 using a 2x4, 16”o.c., R-11 batt insulation wall assembly.

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

[3] *Thermal Design Guide for Exterior Walls, Publication RG-9405*, American Iron and Steel Institute, January 1995.

3.0 Site Location

Beautfort, South Carolina: Habersham Development

Habersham is a waterfront community located on the banks of the Broad River in northern Beaufort County, South Carolina, and sited on a 283 acres former antebellum plantation. The demonstration houses are built on lots 113 and 115 across the street from the Mum Grace Park in Phase I of the Habersham development. The front doors of both homes face north-northwest. The average annual maximum temperature in Beaufort is 101°F (38°C); the average annual minimum temperature is 13°F (-11°C)[4].

Figure 3.1. Demonstration Homes
Steel Framed House (Left) and Wood Framed House (Right)

The address for each of the houses is as follows:

Steel House: 34 Grace Park Rd.
Habersham, SC 29901

Wood House: 32 Grace Park Rd.
Habersham, SC 29901

Builder: Seaway Development
Habersham Land Company

Steel Supplier: Steel Framing Inc.
Charleston SC.

---

[4] *2001 ASHRAE Fundamentals Handbook*, page 27.18.

The approximately 1,500-square-foot (140 m^2) homes were built with three bedrooms and two and a half baths over a crawl space (see Appendix A for plans). Both exterior and interior walls were built with conventional stick framing techniques.

The builder, Seaway Development builds single-family homes, town-homes, and condominiums in South Carolina. They offer the option of either steel or wood frame houses.

4.0 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 the wood house. One-half inch (12.7 mm) anchor bolts secured the sill plates to the top of foundation walls. The bottom steel track was secured directly to the top of the foundation of the steel house. The roofs were framed using ceiling joists and rafters, and sheathed with 1/2 inch (12.7 mm) nominal OSB, and covered with asphalt fiberglass roofing shingles over 15-pound felt underlayment. The attics, walls and crawl space floors were insulated with blown-in cellulose, R-19 and R13 fiberglass batt insulation, respectively. Fiber cement siding was applied over oriented-strand-board (OSB) sheathing for the exterior finish of both houses.

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 (in-line framing). All exterior steel studs were 350S162-33 mil (0.84 mm) (2x4x33 mil). All steel-framed members were designed using the *Prescriptive Method for Residential Cold-Formed Steel-Framing*[5]. 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. Exterior walls were sheathed with 7/16 inch (11 mm) APA rated oriented-strand-board (fully sheathed walls). The front porch of the steel house was designed with a gable roof to provide a slightly different appearance of that of the wood house (flat roof).

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 Beaufort area (high wind region) for wood framing. All exterior wood studs were 2x4 Spruce Pine Fir cut to length. Exterior walls were sheathed with 7/16 inch (11 mm) APA rated oriented-strand-board (fully sheathed walls). The front porch has a flat roof to provide a different architectural look than the steel house's porch.

Both homes were sold for around $200,000 prior to the end of the testing, but were not occupied until the completion of the test. Table 4.1 summarizes the characteristics and geometry of each of the demonstration homes built at the Beaufort site.

---

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

Table 4.1 - Dimensional and Material Characteristics of the Demonstration Homes[1]

Characteristic	Steel House	Wood House
House Orientation	Front Door Faces north-northwest	Front Door Faces north-northwest
House Type	Colonial	Colonial
Number of Stories	2	2
Foundation Type	Crawl Space	Crawl Space
Roof Type	Steel Ceiling Joists and Rafters	Wood Ceiling Joists and Rafters
Roof Covering	Asphalt Fiberglass Shingles	Asphalt Fiberglass Shingles
Floor Area	1,500 ft^2	1,500 ft^2
House Width	22 ft.	22 ft.
House Length	34 ft.	34 ft.
Walls- Exterior	Steel	Wood
Floor/Wall Height	9 ft.	9 ft.
No. of Bedrooms	3	3
Porch Roof	Gabled with attic	Flat – No attic
Front Porch Size	8 ft. x 21 ft.	8 ft. x 21 ft.

For SI: 1 ft. = 305 mm

[1] Refer to Appendix A for detailed house dimensions.

5.0 Thermal Characteristics

Table 5.1 provides a summary of thermal characteristics of the two demonstration homes. Detailed floor plans are shown in Appendix A to this report.

Table 5.1 - Thermal Characteristics of Each Beaufort Demonstration Home[1]

Characteristic	Steel House	Wood House
House Orientation	Front Door Faces North-northwest	Front Door Faces North-northwest
Number of Stories	Two	Two
Windows	Wood Double Glaze Low-E U=0.36	Wood Double Glaze Low-E U=0.36
Roof Covering	Dark Asphalt Fiberglass Shingles	Dark Asphalt Fiberglass Shingles
A/C Unit	10 SEER 3-Ton Central A/C	10 SEER 3-Ton Central A/C
	Trane XE1000 (2-zone)	Trane XE1000 (2-zone)
Furnace	80% A.F.U.E. Gas Forced Air	80% A.F.U.E. Gas Forced Air
Crawl Space		
Crawl Space Insulation	R19 Fiberglass Blanket under floor	R19 Fiberglass Blanket under floor
Exterior Walls		
Stud Size Spacing	24” o.c. 350S162 & 550S162 steel studs	16” o.c. 2x4, 2x6 wood studs
Wall Sheathing	7/16” OSB	7/16” OSB
Drywall Size	1/2”	1/2”
Siding Material	Fiber Cement Siding	Fiber Cement Siding
Wall Cavity Insulation Type	R13, Fiberglass Batts	R13, Fiberglass Batts
Ceiling Joists and Roof Rafters		
Joist & Rafter Size and Spacing	24”o.c. 550S162 (2”x 6”) Steel studs	2”x 8” Wood @ 16” o.c.
Attic Insulation (Thickness)	R-19 Cellulose, Blown in (5.5in)	R-27 Cellulose, Blown in (7.5in)
Attic Floor Insulation (Thickness)	R-19 Cellulose, Blown in (5.5in)	None

For SI: 1 ft. = 305 mm

Note [1]Refer to Appendix A for detailed house dimensions.

6.0 House Performance Tests

Various tests were performed to characterize the house on items that are independent of the wall systems. This is done to segregate differences unrelated to the framing systems being studied.

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 can comprises a large portion of the overall heating and cooling load in a home.
The blower door test quantifies the unconditioned air entering 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. Appendix B contains further information on the test method and results.

Results showed a 7.6 percent larger estimated leakage area (ELA) in the steel-framed house. Upon inspection of the houses during the tests, there were no discernable locations with distinctly different leakages. The majority of the leakage appeared to be from wall penetrations, both interior and exterior. Compensation was made for this difference in the computer model.

Blower Door testing was performed on September 10, 2001 at the subject houses in Beaufort, South Carolina. Testing was performed to ASTM Standard E 1827-96 (Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door)[6]. The table below summarizes the results of the blower door tests:

Table 6.1- Blower Door Results

Measurement	Steel House	Wood House
Blower Door- ACH_{50}	7.17	6.93
Estimated – $ACH_{natural}$	0.34	0.33
Estimated Leakage Area- ELA (in^2)	99.2	92.2

Estimated Leakage Area was used in the computer modeling to normalize the thermal performance of the two houses. The results were relatively close with the ELA in the steel framed house being 7.0 in^2 (7.6 percent) larger. The impact of the larger leakage area will increase infiltration resulting in more summer cooling and winter heating.

DUCT TIGHTNESS TEST (DUCT BLASTER TEST)

Duct leakage can be a very large source of energy loss, especially when lost to unconditioned space. Ducts in the subject house were located in the unconditioned crawl space, conditioned space and in a "semi-conditioned" attic offering many opportunities for leakage to both conditioned and unconditioned space.

Both houses had leakage to unconditioned space that would be considered in the average range with the steel house coming in slightly higher than the wood house. Leakage in the steel-framed

---

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

house was 25 percent higher than the wood house. Although the leakage difference was substantial, the technicians were unable to identify specific locations with higher leakage. Appendix C contains further information on the test methods.

Tests were conducted in accordance with ASTM E1554-94[7]. Below are the results of the duct blaster tests of the subject houses in Beaufort, South Carolina. The tests were performed on September 10, 2001.

Table 6.2- Duct Tightness Test Results

Measurement	Steel House	Wood House
Duct Leakage @ 25 Pa- Total (CFM)	255	221
Duct Leakage @ 25 Pa- to Outside (CFM)	173	138

Results indicate that a much larger leakage to the outside existed in the steel house (25 percent higher). This would require the HVAC system in the Steel framed house to work more to produce the same amount of heating/cooling delivered to condition the air in the house. This difference should not be attributed to the framing materials of the house. The HVAC system is independent of the house's structural components.

HVAC FIELD TEST

Field-testing of the equipment was performed in September of 2001. This was done to document the differences in performance of the Heating, Ventilating and Air Conditioning (HVAC) system. Many identical systems can perform differently in the field due to both manufacturing differences and inconsistencies in field installations.

AIRFLOW

A flow hood was used to determine the supply and return air flows for the HVAC systems. Summed supply-register flows in the wood and steel framed houses indicated both houses were below the expected nominal airflow of 1,200 cfm. The steel framed house recorded a flow of 1058 cfm (12 percent below rated) and the wood-framed house was 966 cfm (20 percent below rated).

HEATING

The field test for heating revealed that both natural gas input and heat output were roughly 10 percent higher in the furnace of the steel-framed house than the wood-framed house. This would increase the on/off furnace cycling in the steel house but, efficiency changes would be negligible. Testing consisted of temperature and humidity recording sensors in the supply and return ducts combined with the tested airflow to determine the heat output. Energy input into the system is determined by measuring the natural gas usage over a defined time. All calculations of consumption were based on runtime using the calibrated consumption rate.

COOLING

---

[7] ASTM E1554-94 *Standard Test for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization*. American Society for Testing and Materials, West Conshohocken PA.

A field test, similar to the heating test, was performed to determine an instantaneous energy efficiency ratio (EER). Temperature, humidity measurements were taken both upstream and downstream of the cooling coil and power draw was measured from the compressor. Cooling efficiency testing showed both units performed identically with an EER of 9.8, in line with the rated seasonal energy efficiency ratio (SEER) of 10.0.

7.0 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 averaged or (summed) on a 15 minute basis to a data file. Because of concerns related to entry into the houses, 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 is listed in Table 7.1.

Table 7.1 - Data Points Monitored and Sensors Used

Component	Sensor Type	Accuracy[1]
Indoor Temperature (calibrated)	Resistive Temperature Sensor	+/-0.4°F
Indoor Humidity (calibrated)	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
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
Outdoor Temperature - Wood Only (calibrated)	Resistive Temperature Sensor	+/-0.4°F
Outdoor Humidity- Wood Only (calibrated)	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/5v DC Relay	+/-5 seconds/event[2]
Front Door Open Sensor	Reed Switch	+/-5 seconds/event[2]
Back Door Open Sensor	Reed Switch	+/-5 seconds/event[2]

[1] Accuracy includes error introduced by the instrument and datalogger
[2] Five- second accuracy due to the program cycle not the instrument.

8.0 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 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 was assumed to be solely a function of the HVAC systems, as the houses were unoccupied and other potential loads (such as water heaters, lights etc.) were switched off. HVAC equipment consumption is monitored using watt-hour meters that were 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 were routed to the multi-channel data logging equipment, configured to be accessible for remote data monitoring. Temperature and humidity measurements were 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 (April 2001-March 2002) amounted to slightly cooler than average summer and an average winter. The total heating degree days (HDD) for the test period was 1,729 (average 1766) and cooling degree days (CDD) for the period were 2,347 (average 2471).

MODELING ASSUMPTIONS

The nature of side-by-side monitoring eliminates most of the variables that can affect energy usage. Three differing characteristics remain that required "normalization" to ensure a fair comparison. Because the air infiltration and duct leakage tests reflected different results, the potential for a biased result may exist. It was also necessary to compensate for temperature differences inside the two houses, as a house that is warmer in the winter would require less energy to heat, and conversely in the summer would take additional 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 the time the gas valve is open.

Any days with a known entry into either house, the data for both houses were discarded. It was assumed that whenever the houses were entered, they were left completely sealed.

9.0 Results

Results are reported only as normalized results, using computer simulations to compensate for differences in internal house temperature, duct tightness and air infiltration.

9.1 ANNUAL DATA (April 2001- March 2002)

Data was gathered from April 2001 through March 2002. House temperatures were set to maintain temperatures between 70°F (21°C) heating and 76°F (24°C) cooling. Days with temperatures outside this range were eliminated from data.

Measured data was then normalized to compensate for differences in air infiltration, duct tightness and temperature, then projected over a typical meteorological year (TMY). The resulting electric consumption for the steel-framed house was 15.5 percent higher than the wood-framed house. The natural gas consumption in the steel-framed house was 5.1 percent lower than the wood-framed house.

9.2 ELECTRIC USAGE

Figure 9.1 shows the steel-framed house using more electricity through the peak months (11 percent June-August) and less than the wood framed house (10 percent) during the low electric usage winter months (December-February). The swing months reflected a significantly higher percentage difference (79 percent in October) and (66 percent in March) this was attributed to the more solar sensitive steel framed house.

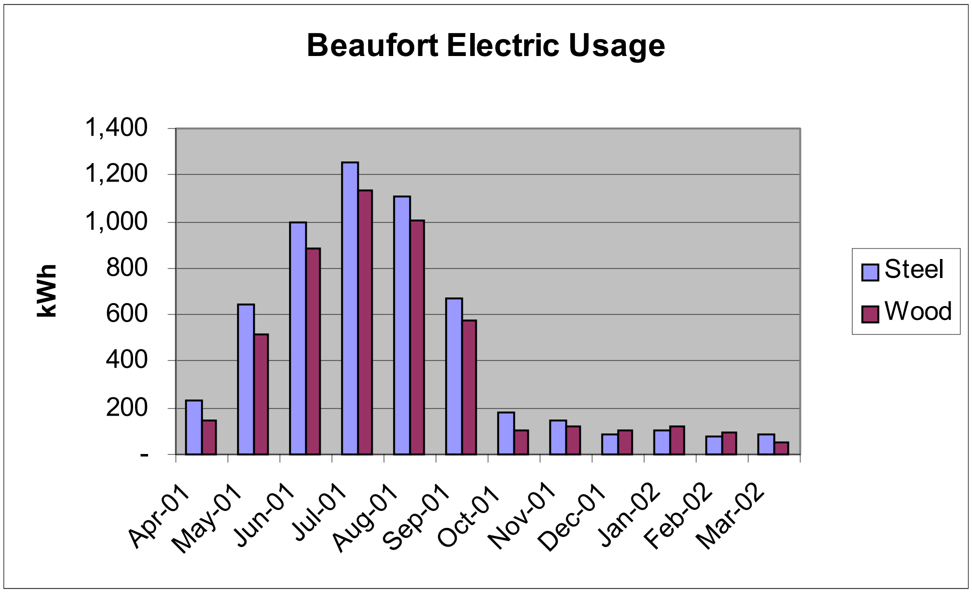

Figure 9.1. Beaufort Electric Usage

9.3 GAS USAGE

Natural gas consumption in the steel-framed house was slightly lower during the heating months averaging 5.1 percent less than the wood-framed house for the year as shown in Figure 9.2. On a monthly basis, the energy was consistently around 6 percent lower with the lower-use shoulder months of April and October coming in at 1 percent and 14 percent higher for the steel framed house respectively. The actual differences are both less than 2 therms for each month, but it illustrates the sensitivity of the steel house to changing outdoor conditions.

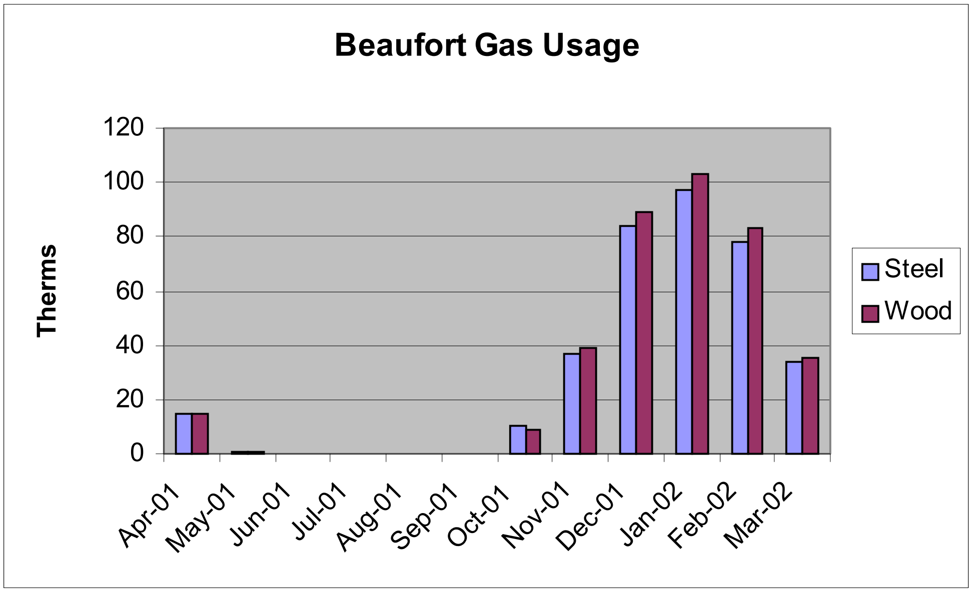

Figure 9.2. Beaufort Gas Usage

10.0 Discussion

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

HEATING AND COOLING COMPARISONS

In the early morning hours of the heating season, midnight until 8:00 am, the wood house uses much more energy (about 21 percent) than the steel house. As the solar exposure increases in the afternoon, the heating load decreases dramatically in the wood house with the steel house energy usage from 2:00 pm until 11:00 pm, as seen in Figure 10.1.

This unusual scenario is attributed to the vented attic and the lack of insulation on the floor of the wood attic. Solar attic gains could conduct directly into the wood house through the uninsulated attic floor during the day thus reducing energy use. After the sun sets, the vented attic would begin to cool and heat from the house would conduct back into the vented attic, thereby increasing the nighttime load. The net result is 5.1 percent less heating energy being consumed by the steel house.

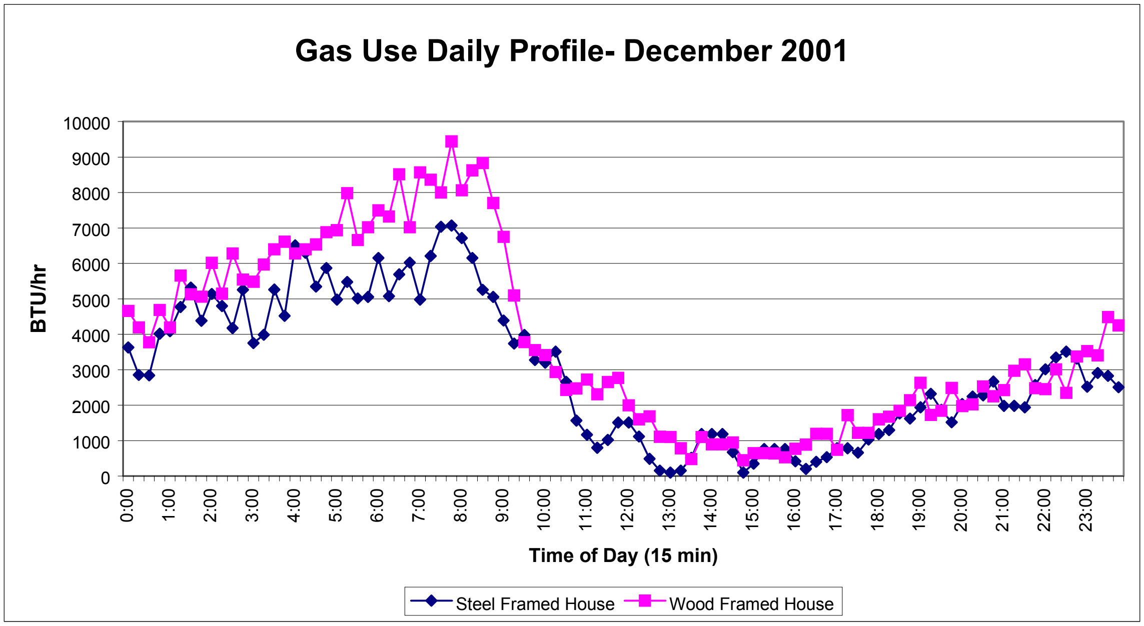

Figure 10.1. Gas Use Daily Profile-December 2001

Summer energy use for the steel framed house jumps around 9:00 AM (see Figure 10.2) and remains generally higher than the wood framed house through the peak solar hours up to around 1:00 AM. It is suspected that the solar gain is responsible for the differences in morning and early afternoon energy use. Peak temperatures typically are not reached until 16:00 at which time the energy usage for the two houses become much closer.

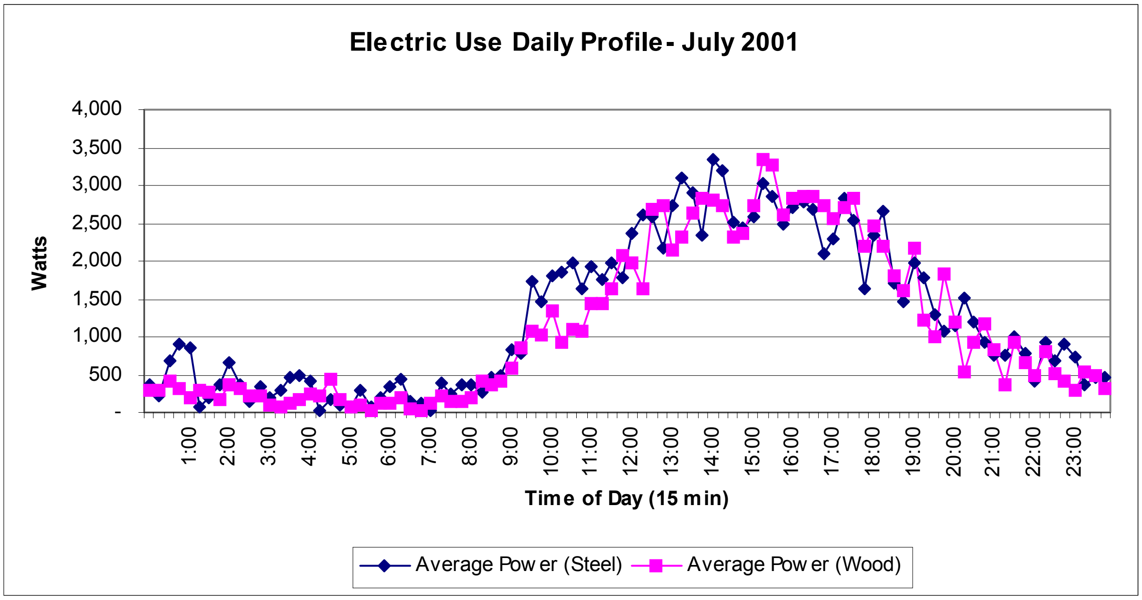

Figure 10.2. Electric Use Daily Profile-July 2001

ATTIC TEMPERATURES

Throughout the year, daytime attic temperatures were significantly higher in the steel-framed attic. The temperature differences in excess of 25°F were measured. The highest differences were in the late spring when solar gains are high and ambient temperatures are still moderate. (refer to Figures 10.3 & 10.4).

Radiated heat from the sun is conducted in the steel framed attic much more readily than the wood attic. Figure D.2 (Appendix D) shows that in the steel attic, the framing will conduct the roof temperature (which can exceed 170°F) directly into the attic air space through the steel rafters. The roof heat encounters no insulative barrier to slow down the transmission of heat. The wood attic has the insulative value of the wood members to reduce the direct solar gains.

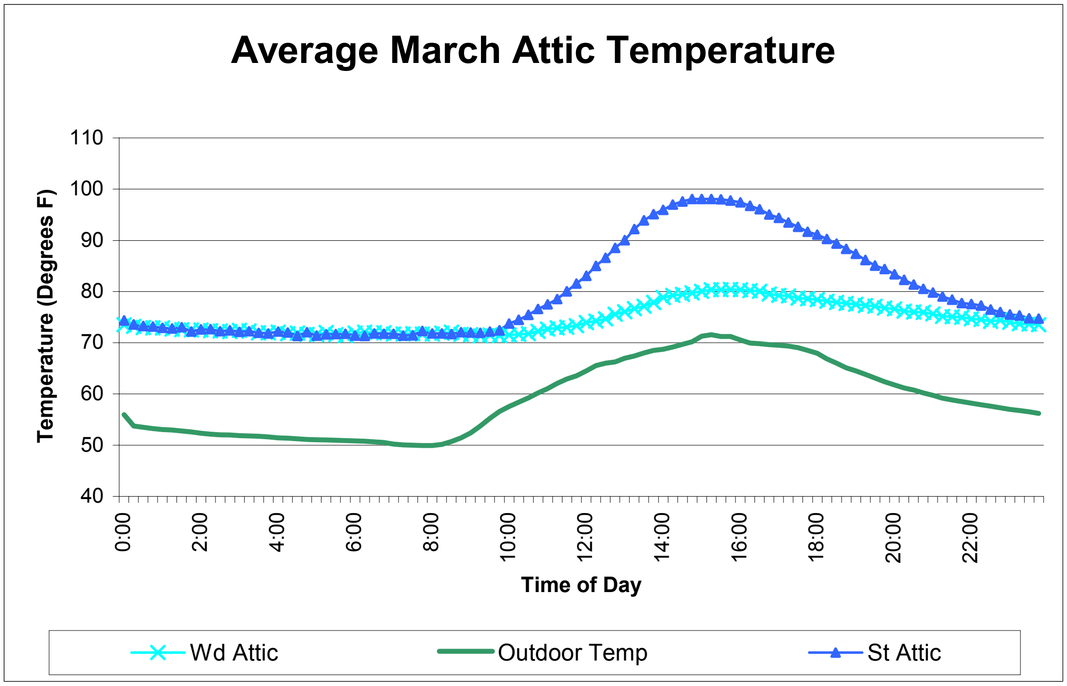

Figure 10.3. Average March Attic Temperature

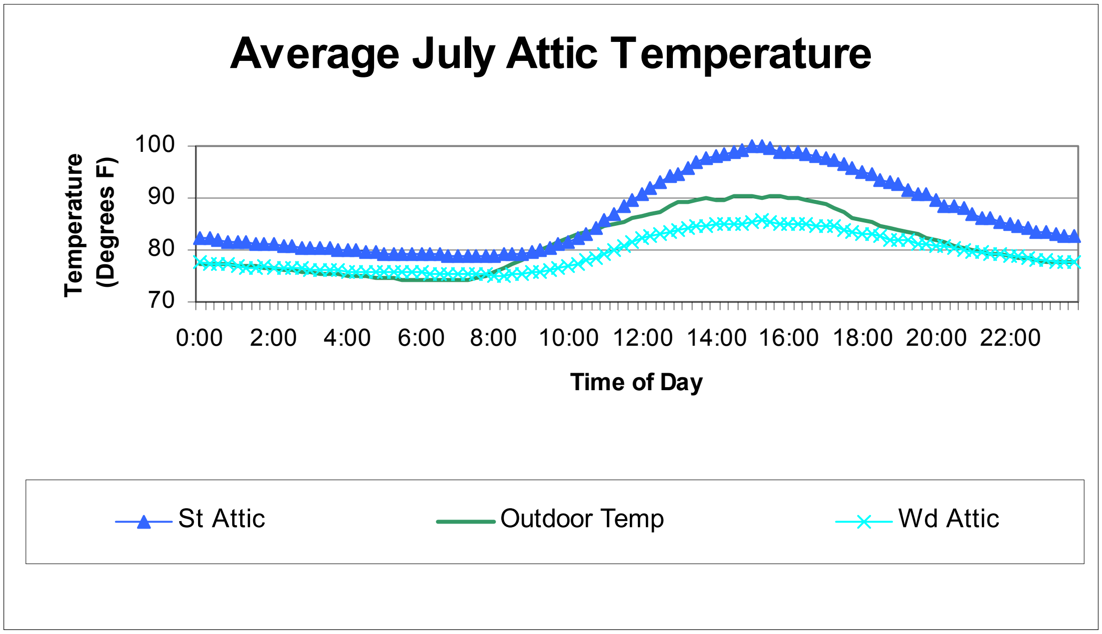

Figure 10.4. Average July Attic Temperature

In the peak summer months, higher ambient temperatures caused the air-handling unit, located in the attic, to operate this would lower the attic temperatures due to the cold air handler and some of the duct leakage that existed in the attic.

ATTIC INSULATION AND VENTING

Attic insulation requirements could not be satisfied in the steel framed attic because the rafters were only 5.5” deep only allowing R-19 to fit between the rafter and the sheathing. This required additional insulation (R-19) to be blown on the attic floor. The total insulation added to the wood house amounted to R-27.

The attics were constructed in a non-standard manner. The vaulted portions of the attics were insulated in both houses making the attic a conditioned space. But, contrary to good design, the conditioned attics also contained vents to the outside. Good design would locate the thermal barrier at the same point as the air barrier. In the wood house the air barrier is the attic floor and the thermal barrier is the vaulted portion of the attic, allowing air to vent into the attic, bypassing the insulation and conduct into the house with no insulation. This was not as much of an issue with the steel house that also had insulation on the attic floor, thus creating a second thermal plane.

This non-conventional attic construction potentially skewed the results of the testing for both houses. Figure 10.1 shows how the heating can be affected by this design. Cooling will have much less of an impact because the primary cause for the rise in attic temperatures is solar gains. The existing insulation provides a good barrier for these gains and is reflected in the small temperature difference between the attic and house (see Figure 10.4).

SHADING

Both houses had some shading from neighboring houses as well as mature trees that provided intermittent shading throughout the day. It did not appear that either house was affected differently throughout a day. Most of the shading would be on the siding of the houses and generally not to the roof.

MISCELLANEOUS ENERGY USE

The datalogger was only measuring electric use of the HVAC system. The electric utility meter usage tracked the HVAC electric usage nearly identical with only a few kWh that were unaccounted for. Except for the furnace, all other gas-burning appliances were turned off. The gas meter for both houses registered zero (0) therms between May and September 2001, indicating that it would be very unlikely that any leaks or other loads would have existed during the heating months.

WALL CAVITY TEMPERATURE AND HUMIDITY DATA

Wall cavities in both the front (north) and back (south) 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 house in the areas monitored. Relative humidity tended to vary between 40 percent and 50 percent in the wall cavities of both houses in the summer, as expected, and slightly higher (55 percent to 65 percent) in December. This can be attributed to the mild weather with nighttime temperatures rarely reaching the 30s. The average relative humidity in the walls of the steel-framed house peaked at 69 percent in the month of December, about 4 percentage points higher than the walls in the wood-framed house.

Humidity results would be different in an occupied house. In these unoccupied houses, there was 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. Seasonal graphs of the wall conditions and be found in Appendix E.

AIR DISTRIBUTION

HVAC airflow measurements were taken during the September 2001 site visit. The total HVAC supply airflow in the steel framed house was 11 percent higher than that of the steel-framed house. Where air balance dampers were installed, they were checked and found to be set similarly. The measured airflows indicated that proper conditioning occurred in both houses on both floors.

Note: Even though three flow measurements (using a standard flow hood) were taken at each supply register and averaged, the flow hood error of roughly 6 percent could make between 5 and 17 percent difference in flow between the two houses.

INFILTRATION AND DUCT LEAKAGE

The differences in both infiltration and duct leakage were accounted for in the modeling. The air tightness of both houses was average by current standards. The Estimated Leakage Area of the steel framed house was 7.6 percent higher than that of the wood-framed house.

The typical standard for duct leakage is a ratio of cfm of the HVAC system to conditioned floor area. A 3 to 5 percent range is considered excellent, 10 percent is average and above 20 percent is poor. Although 11.5 percent and 9.2 percent outside duct leakage for the steel and wood framed houses respectively are close to average, this amounts to a 25 percent higher leakage rate in the steel house. This can cause more than a two percent increase in both overall heating and cooling costs.

CRAWL SPACE TEMPERATURE

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

Expected Results

The only designed differences between the two houses were framing materials and wall stud spacing (16” o.c. wood, 24” o.c. steel). With that being the case, the expected differences in energy use would be 18 percent higher for heating and 5 percent higher cooling requirements for the steel-framed house. This was determined through computer modeling using REM/Rate 11.0. The actual differences, including the location of the insulation and ventilated attics are believed to be primary contributors in the shifting of the measured results.

11.0 Conclusions

Differences in attic insulation levels and placement along with the ventilation in the attic could have skewed winter results by increasing energy consumption in the wood framed house, and summer results by increasing energy usage in the steel framed house.

The results, however, are compare well with the thermal testing of the demonstration houses in Valparaiso, Indiana. Valparaiso test results showed a 3.9 percent and 9.7 percent higher gas (heating) and electric (air conditioning and blower fan) usage in the steel framed house respectively. The Beaufort results seem to be reasonably consistent with Valparaiso, as both the Valparaiso and Beaufort locations showed a susceptibility of steel framed attics to solar gains much more so than wood framed attics.

Steel “shorts” between roof sheathing and conditioned space should be addressed. This can be done with the addition of exterior rigid foam insulation. It is also recommended that a thermal break be created between conditioned and unconditioned space.

Hybrid construction utilizing both steel and wood structural components may eventually become the optimal framing. This may consist of wood trusses, slotted steel wall studs, steel floor joists and wood bucks around windows and doors. What is optimal will vary by climate and builder. Further investigation into this type of design may prove beneficial to the building industry.

APPENDIX A

DEMONSTRATION HOMES PLANS
AND SENSOR LOCATIONS

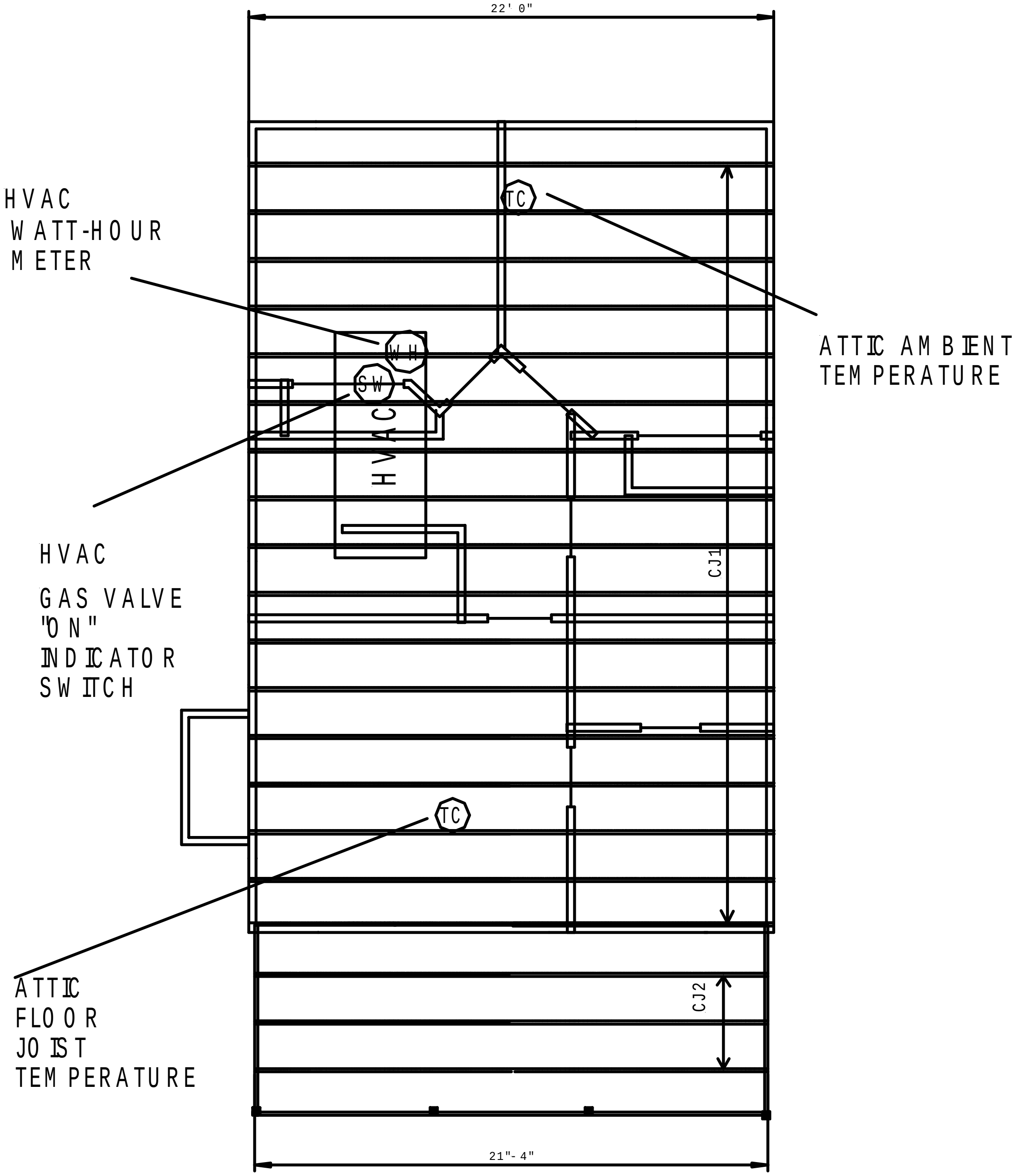

Figure A1. Attic Layout and Sensor Locations

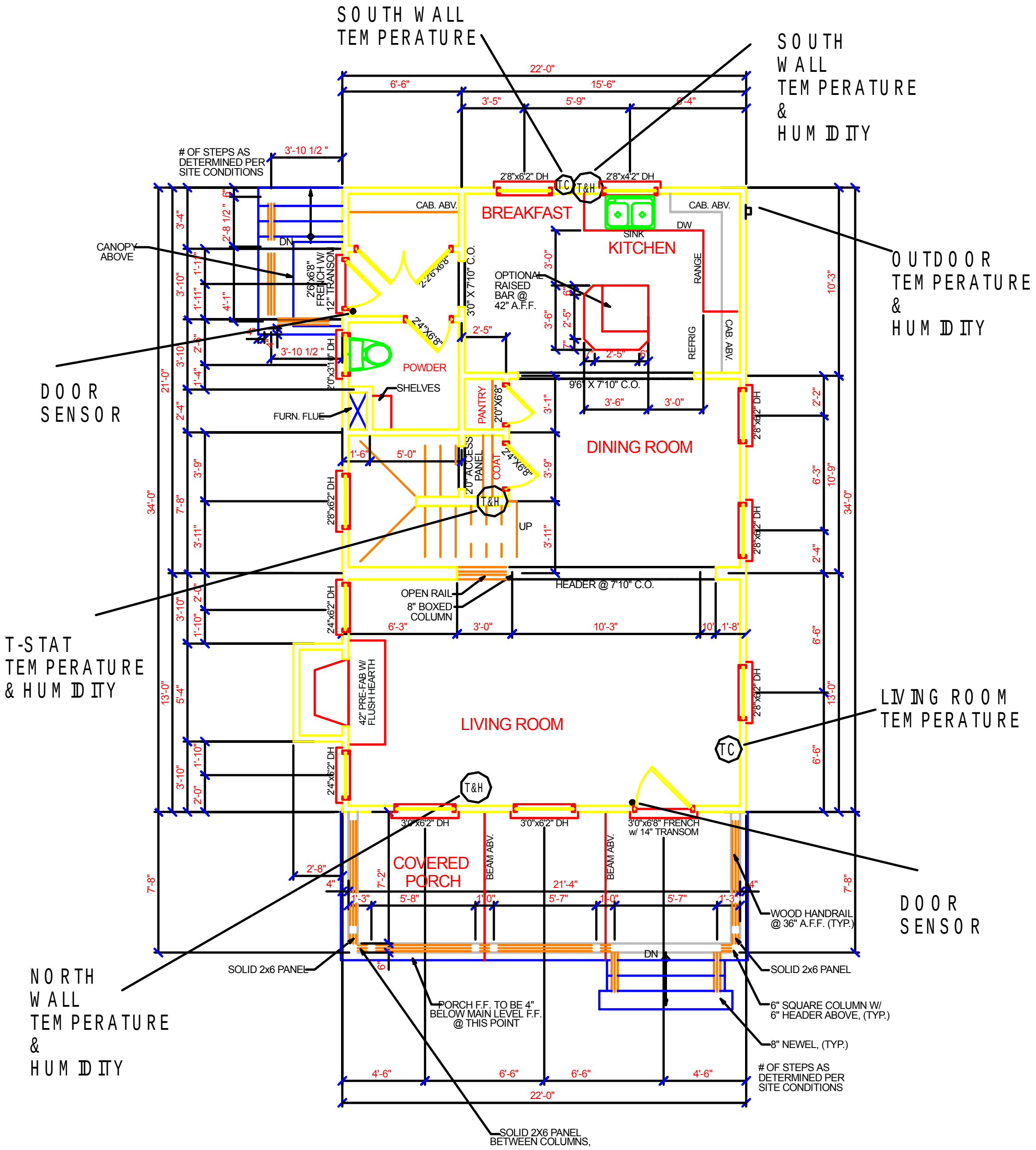

Figure A2. First Floor Layout and Sensor Locations

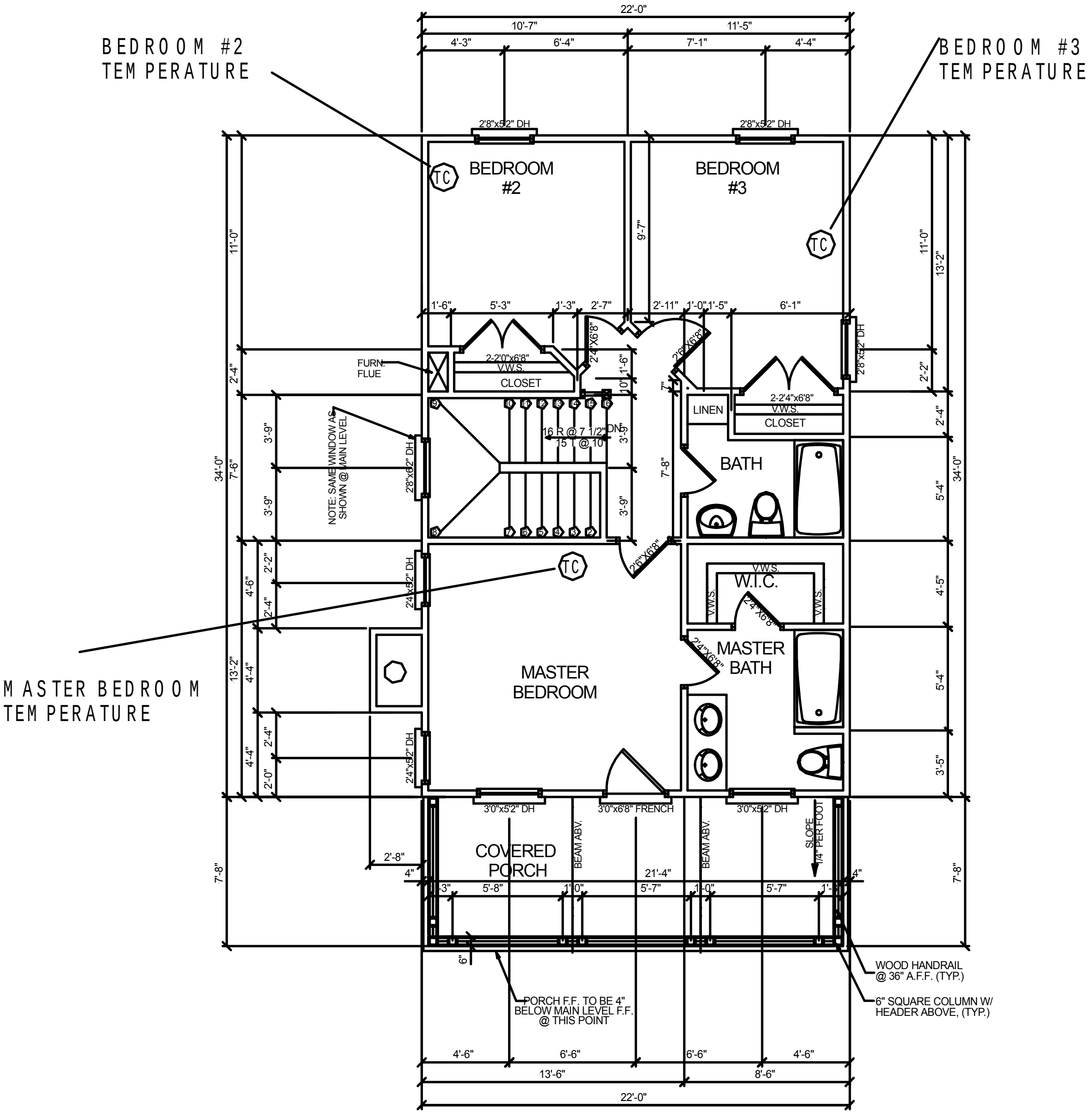

Figure A3. Second Floor Layout and Sensor Locations

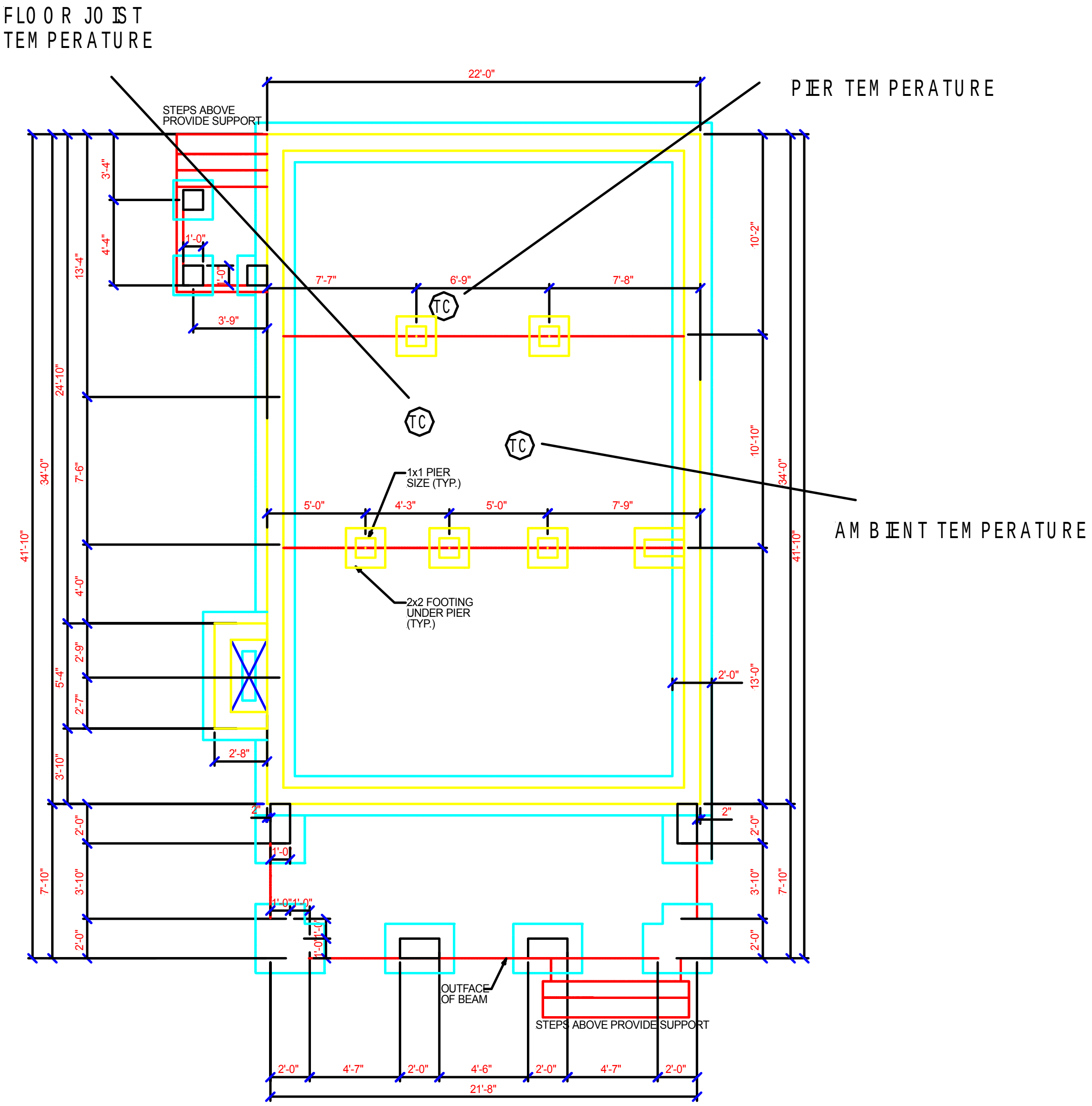

Figure A4. Crawl Space Layout and Sensor Locations

APPENDIX B

BLOWER DOOR TEST

BLOWER DOOR TESTING

The blower door test is a standardized technique designed to measure and quantify the air-tightness of a building envelope. The test uses fan pressurization of the building and measures the flow volume across the fan and compares it to the pressure differential between the building and outside. With a single pressure differential measurement, or a series of pressure measurements, the air-tightness of the building envelope can be accurately measured.

The procedure consists of installing a variable speed fan located in a sealed exterior doorway and blowing air out of (or into) the building. With the fan blowing outward, a slight (typically 20 to 60 Pascals) negative pressure is created. The fan exaggerates the existing leakage paths in the house and the measured flow across the blower orifice can be related to a variety of different standards. Air Changes per Hour at 50 Pascals (ACH50) is a common measurement that reflects the actual measured airflow at a 50 Pascal differential pressure.

Additionally, there are two measurements that are commonly used to rate a building's air tightness that are not directly measured from the blower door test, these include Natural Air Changes per Hour (ACH natural) and Estimated Leakage Area (ELA). ACHnatural is a relation between the tested ACH50, house characteristics (number of stories, exterior shielding e.g., trees and other buildings), and the area of the country. ELA is a value that represents the total leakage area as if it were combined into one opening, typically expressed in square inches. This number is extrapolated from the measured blower door test results.

Blower Door Test Results

The blower door results are virtually identical for the two houses, as the difference between the two is only 3.6 percent indicating that both steel-framed and wood-framed homes have approximately the same leakage rate. The Estimated Leakage Area (ELA) of the steel-framed house was 7.6 percent higher than that of the wood-framed house. The air tightness of both homes was average by today's construction standard (when compared to a general database of building tightness measurements.) 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.

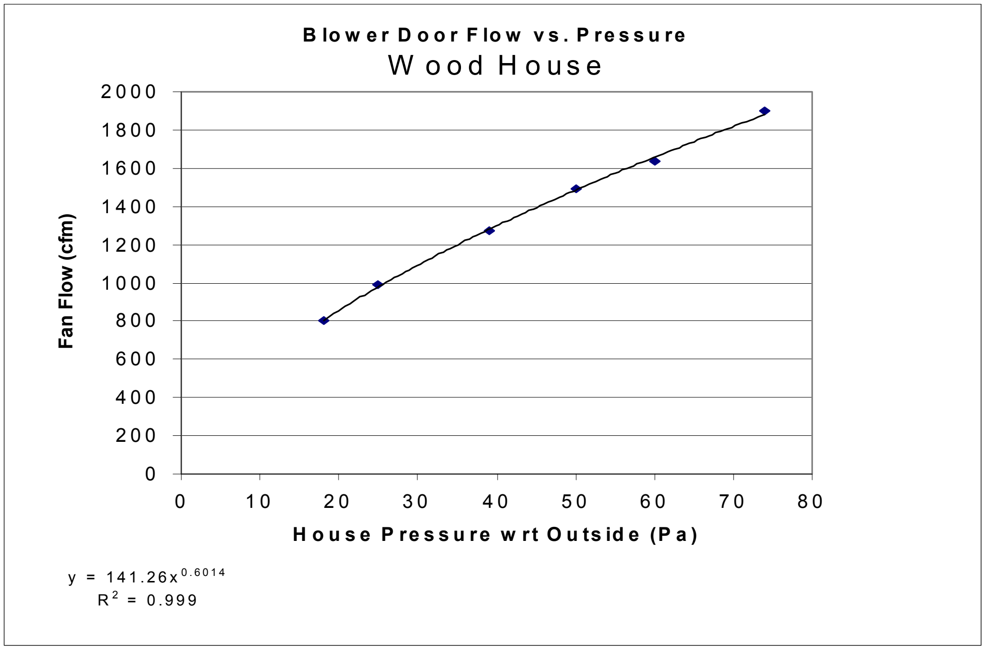

Figure B1. Blower Door Flow vs. Pressure (Wood House)

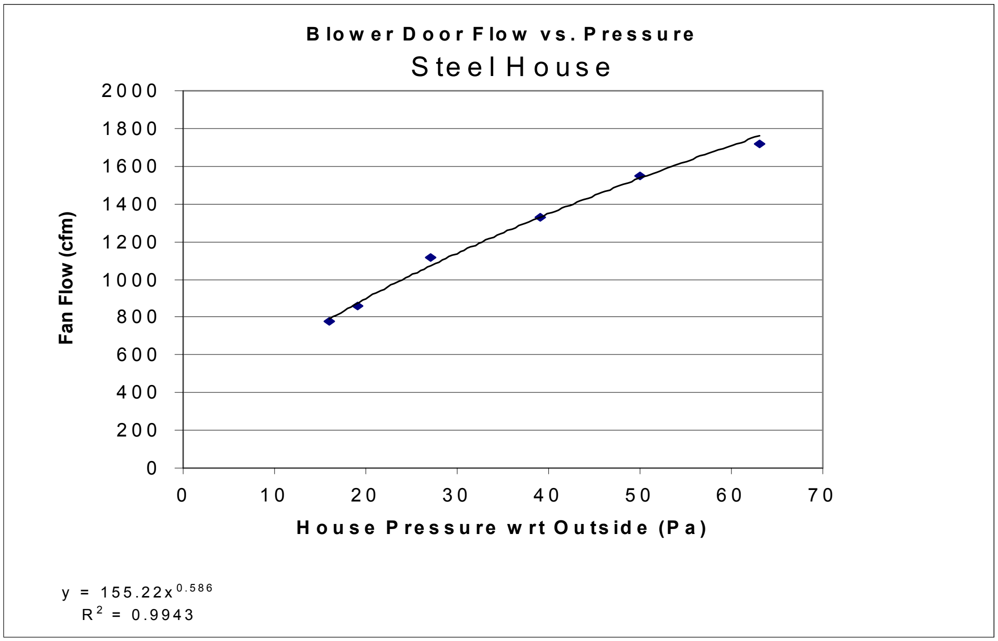

Figure B2. Blower Door Flow vs. Pressure (Steel House)

APPENDIX C

DUCT LEAKAGE TEST

DUCT LEAKAGE TEST

Air leakage in a forced air distribution system can dramatically affect both comfort and energy consumption in homes. Duct leakage causes conditioned air to escape to places it doesn’t belong. If ducts leak within the conditioned space, it will most likely be over-conditioning space within wall cavities or between floors resulting in poor distribution and potential comfort issues. If the leakage occurs to unconditioned space, comfort issues are compounded by direct loss of conditioned air to the outside resulting in wasted energy. Pressure testing forced air distribution systems can accurately determine how much leakage is occurring and where the conditioned air is going.

The test consists of two measurements; the first is the total duct leakage. This includes the leakage to both conditioned and unconditioned space. Testing is performed by sealing all registers and returns and pressurizing the system at the air-handling unit. Leakage is measured over a calibrated orifice at 25 Pascals. The measured flow is the total leakage.

Since air that leaks into conditioned space is not a direct loss of energy, a second test of duct leakage to the outside is also an indicator of duct tightness. Testing is performed similar to the total duct leakage test with the addition of a blower door (see Appendix B) setup. The blower door pressurizes the house to 25 Pascals with respect to the outside, the same pressure as the ducts. Airflow across the duct orifice now reflects the leakage to the outside.

APPENDIX D

HOUSE PICTURES

Figure D2. Steel Framed House
Insulated Attic Rafters and Floor

Figure D3. Wood Framed House
Insulated Attic Rafters and Uninsulated Floor

Figure D3. Conditioned Attic with Ventilation

Figure D4. Front of Subject Houses (steel left, wood right)

Figure D5. Back of Subject Houses (steel right, wood left)