Contract Report

Side-by-Side Evaluation of a Stressed-Skin Insulated-Core Panel House and a Conventional Stud-Frame House

Final Report

FSEC-CR-664-93
January 14, 1994

Prepared for
Office of Building Technologies
Conservational and Renewable Energy
U.S. Department of Energy
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Side-by-Side Evaluation of a Stressed-Skin Insulated-Core Panel House and a Conventional Stud-Frame House

Energy Efficient Industrialized Housing
Research Program
(A joint effort of the Center for Housing Innovation, University of Oregon, the Florida Solar Energy Center and the Department of Industrial Engineering of the University of Central Florida.)

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1.0 Executive Summary

Side-by-side energy testing and monitoring was conducted on two houses in Louisville, KY between 12 January 1993 and 5 March 1993. Both houses were identical except that one house was constructed with conventional U.S. 2x4 studs and a truss roof while the other house was constructed with stress-skin insulated core panels for the walls and second floor ceiling. Air-tightness testing included fan pressurization by blower door, hour long tracer tests using sulphur hexafluoride, and two-week long time-averaged tests using perfluorocarbon tracers. While both houses were considered to be more air-tight than average houses in the Louisville area, an average of all the air-tightness test results showed the SSIC panel house to have 22 percent less air infiltration than the frame house. Air-tightness testing resulted in a recommendation that both houses have a fresh air ventilation system installed to provide 0.35 air changes per hour continuously. Thermal insulation quality testing was by infrared imaging. Only two notable defects were found; both were in the frame house. Approximately 6 ft^2 of ceiling insulation was missing over the stairwell and air leakage was observed where a bathroom exhaust duct penetrated the band joist. Pressure differential testing resulted in recommendations to use sealed combustion appliances, and to allow for more return air flow from closed rooms. This can be accomplished by separate return ducts or transfer ducts which simply connect closed rooms to the main body with a short duct. By calculation, the conductive building load coefficient (UA) was within 2 percent for each house. When measured air infiltration results were included, the total UA was within 5 percent. The SSIC house UA was lower in both cases. By measurement, co-heating tests showed the SSIC panel house total UA to be 12 percent lower than the frame house. Short-term energy monitoring was also conducted for the two houses. A 17 day period of electric heating and a 14 day period of gas furnace heating was evaluated. Monitoring results showed energy savings for the panel house to be 12 percent during electric heating and 15 percent during gas heating. A comparison of the two monitoring periods showed that the lumped efficiency of the gas furnace and air distribution system for both houses was close to 80 percent, which was the same as the manufacturers listed Annual Fuel Utilization Efficiency. Simple regression models using Typical Meteorological Year weather data gave a preliminary prediction of seasonal energy savings between 14 and 20 percent. More accurate seasonal predictions will require additional effort. In addition to the SSIC panel house having less building air leakage, there seem to be other factors, which remain unaccounted for, which cause the panel house to use less heating energy. These factors require further investigation.

2.0 Introduction

A side-by-side evaluation was conducted to assess the heating energy-use benefits of using stressed-skin insulated-core (SSIC) panels in residential construction in Louisville, KY, U.S.A. One house was constructed as a conventional U.S. 2x4 stud-frame, and the other was constructed with SSIC panels. The SSIC wall panels were 4 feet wide by 8 feet high and 2x4 lumber was used for the vertical spline. The SSIC ceiling panels were 4 feet wide by 16 feet long and 2x8 lumber was used for the spline. Since the solid lumber splines extended between the interior oriented strand board (OSB) skin to the exterior OSB skin, they created more of a thermal short than other splining methods used with the SSIC technology. Both houses were privately financed and constructed by the same builder who has experience with both types of construction. The builder was not coached to build either house differently, better or worse, than he normally would. Each two-story house has 1200 ft^2 floor area and has the same floor plan, elevations, orientation, and nearly the same exterior colors. Both houses are heated by natural gas furnace. All the air distribution ducts are within the thermal envelope of the building. A comparison of the basic building parameters for the two houses is given in Table 1. Energy testing, and unoccupied monitoring with simulated occupancy, was conducted from January 12 through March 5, 1993.

Table 1

Thermal Envelope Parameters of the Stud-Frame (SF) and Stressed-Skin Insulated-Core (SSIC) Panel houses

Component	House Type	Construction Type	Insulation
Foundation	Both	Block stem wall and slab	R-10 to 2 foot depth
Walls	SF	2x4 stud	R-13 fiberglass batt Partial R-3.5 sheathing
	SSIC	3-5/8" EPS core panel	R-14 EPS core
Windows	Both	Double glazed, wood frame, aluminum cladding	R-2.0
Second floor ceilings	SF	2x4 truss	R-30 loose-fill cellulose
	SSIC	Flat, 7-3/8" EPS core panel	R-29 EPS core

Both houses were designed to have a conductive thermal transmittance (UA) equal to each other. Calculations, using the as-built configuration and thermal transmission data from (ASHRAE 1989), showed that the SSIC panel house conductive UA equaled 265 Btu/hr-°F and the frame house conductive UA equaled 271 Btu/hr-°F, a difference of only 2%.

Five days of building diagnostics testing was performed on each house. The testing assessed thermal insulation quality by infrared imaging, building envelope and air distribution system air-tightness by fan pressurization and tracer gas, pressure effects inside the house due to interactions of the air distribution system, calculated versus measured building load coefficients by co-heating, and building thermal decay by cool-down.

Table 2
Measurements Made During House Monitoring

Measurement Channel	Location and/or Purpose	Sensor
Air temperature	First floor living area, 4 foot height in open air	Type T thermocouple
Mean radiant temperature	First floor living area, 4 foot height in open air	Type T thermocouple
Relative humidity	First floor living area, 4 foot height in open air	Bulk polymer, resistive
Wall surface temperature	First floor living area, 4 foot height on south wall, not over framing member	Type T thermocouple
Air temperature	Second floor hall, 6 foot height in open air	Type T thermocouple
Air Infiltration	First and second floors, open air	Passive perfluorocarbon tracer (PFT's)
Gas energy-use	Natural gas consumption by furnace	Gas meter with electronic output
Electric energy-use	Heater on dedicated circuit for simulated internal gains	Watt-hour monitor
Electric energy-use	Whole house electric use monitored at load center	Watt-hour monitor

Four weeks of short-term energy-use monitoring was conducted—two weeks of electric heating energy-use monitoring and two weeks of gas heating energy-use monitoring. The houses were unoccupied during monitoring but internal heat gains due to people and equipment were simulated by computer control. The internal gain profile was taken from a study conducted in the Northwest for the Bonneville Power Administration by the Pacific Northwest Laboratories (Pratt 1989). In addition to house energy-use data, data from house dry bulb temperature, mean radiant temperature, south wall surface temperature, and relative humidity were continuously monitored. The monitoring plan is described in Table 2. In order to increase measurement accuracy, all thermocouples were made from special calibration wire from the same spool. Passive perfluorocarbon tracer gas sources and samplers were deployed to measure the time-averaged house air exchange rates (Dietz 1986). A weather measurement station was installed on top of one of the houses and continuously monitored the channels listed in Table 3. A photograph of the two houses, with the weather station on top of the SSIC panel house, is shown in Figure 1.

Table 3
Weather Station Measurements

Measurement Channel	Sensor
Radiation shielded air temperature	Type T thermocouple
Relative humidity	Bulk polymer, resistive
Vertical solar irradiance	Silicon pyranometer
Horizontal solar irradiance	Silicon pyranometer
Wind speed	Helicoid propeller anemometer
Wind direction	Lightweight vane

Figure 1 Photograph of the two test houses; weather station installed on top of the SSIC panel house on the right. The middle house separates the two test houses and was not part of the test.

3.0 Results

3.1 Energy Testing/Building Diagnostics

Infrared scanning indicated that the thermal insulation quality of both houses was good. Few defects were found which would have a significant impact on energy use. The stud-frame house had two insulation defects that are worth noting. One defect involved a ceiling area over the stairwell, approximately 6 ft^2, where the blown-in insulation was missing. The other defect became apparent only after infiltration was forced by the blower door—an air leak occurred where the exhaust duct in the first floor bathroom penetrated the band joist and was not completely sealed. Examination of a photograph of that same penetration, taken during construction, revealed that a worker had attempted to seal the gap, but he did not get it sealed well enough. These defects were not fixed.

Air-tightness was evaluated for the building envelopes and the air distribution systems. Blower door and tracer gas tests indicated that the envelope of the SSIC panel house was more air-tight. The tracer gas tests, using SF_6 and a specific vapor analyzer, showed that both houses had an increase in air infiltration when the air distribution system was operating. However, duct leakage to the outdoors was less than the blower door could measure accurately. Figure 2 gives a summary of these results. Also included in Figure 2 are results from the perfluorocarbon tracer (PFT) time-averaged infiltration measurements taken during the electric and gas heating monitoring periods. The averaging period was 17 days for electric heating and 21 days for gas heating. PFT results showed higher infiltration for the frame house compared to the panel house

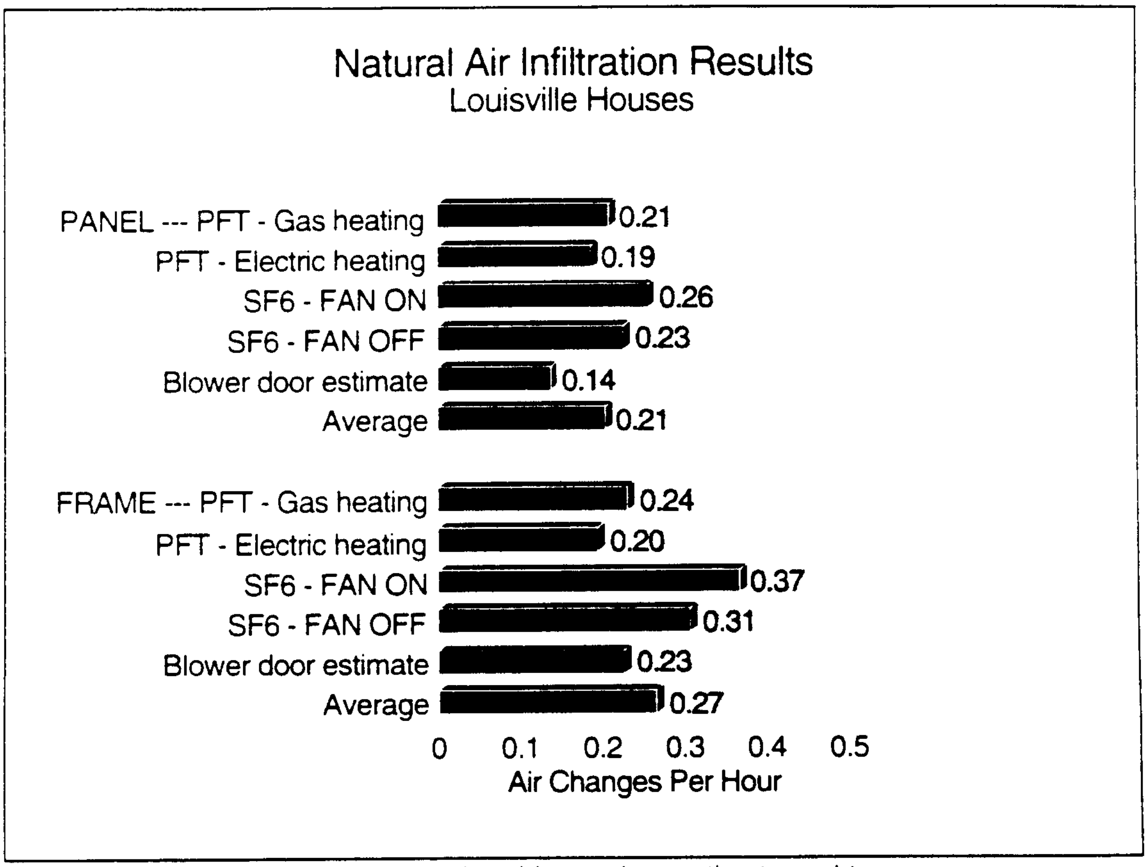

Figure 2 Natural air infiltration results - blower door estimate and tracer gas

and higher infiltration for the gas heating monitoring period compared to the electric heating monitoring period. During the gas heating period, the influence of the naturally aspirated (not sealed combustion) furnace, and the movement of air by the air distribution system, may have contributed to higher infiltration. The average outdoor temperature during the gas heating period was about 6.5°F lower which may have driven more stack-effect infiltration. The wind speed was similar for both periods. Because of the variation in natural air infiltration, as measured by the three methods, the results are somewhat inconclusive in an absolute sense, however, they are consistent in a relative sense in that the panel house was always tighter and air infiltration was always greater when the furnace fan was operating. Both houses were considered to be more air-tight than average houses in the Louisville area. an average of all the air-tightness test results yielded a natural infiltration rate of 0.27 for the frame house and 0.21 for the SSIC panel house. Recommendations from the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE), in their Standard 62-1989, indicate that houses should have at least 0.35 air changes per hour or 15 ft^3/min of ventilation air per occupant. Based on that, a whole-house fresh air ventilation system should be considered for both the frame and panel houses. For the Louisville climate, an exhaust-only ventilation system providing at least 0.35 air changes per hour, or about 60 ft^3/min for these particular houses, may be the most cost-effective. This may be accomplished by installing a two speed exhaust fan in the attic which is ducted to each bathroom and to the outdoors. The fan could run on low speed constantly, and be manually switched to high speed by occupants. A humidistat control could also be linked to the high speed mode. A 100 ft^3/min, 48 W fan would use about 420 kW-hr per year to operate continuously. At $0.08/kW-hr the cost would be $34/yr. Many people have questioned why it is recommended to seal a house tightly and then install a fan to ventilate it. The answer is that relying on random leaks in the building and unknown pressure forces due to wind and temperature does not assure adequate ventilation at all times, and it may lead to over-ventilation and high energy bills. In addition, leaky duct systems, in certain instances, can cause pressure imbalances which can cause combustion appliances to malfunction. This can lead to health and safety problems.

A series of measurements were taken to evaluate pressure differentials within the building, and between the building interior and the outdoors. The impact of building pressure differentials can affect occupant health and safety, building durability, and energy-use. Since both houses have gas furnaces inside the conditioned space, occupant health and safety could be affected if negative pressures caused the furnaces to back-draft. Pressure measurements taken between the utility closet and the outdoors showed pressures between -2.0 Pa and -5.7 Pa. These measurements were taken with the furnace fan on, and the kitchen and bath exhaust fans on; a clothes dryer, which will be installed inside the house, would have increased the exhaust flow. Since the utility closet has two 6" ducts connecting it to the ventilated attic to provide combustion air and dilution air, a recommendation is made that the utility closet doors be weather stripped to better seal the furnace, and gas hot water heater, from the main body of the house. Or better yet, use sealed combustion appliances. Additional pressure differential measurements taken between closed rooms and the main body of the house, with the furnace fan and exhaust fans on, showed that the main body depressurized to about -5 Pa while the closed rooms pressurized to between 3 and 10 Pa. These pressure differentials would cause increased infiltration in the main body and increased exfiltration in the closed rooms, resulting in increased energy-use (Cummings 1992). In a cold climate, if warm moist air is forced through the building shell due to pressurized rooms, moisture may condense inside the building shell and cause material degradation. A recommendation is made to allow for more return air flow from closed rooms by separate return ducts or transfer ducts which simply connect closed rooms to the main body with a short duct.

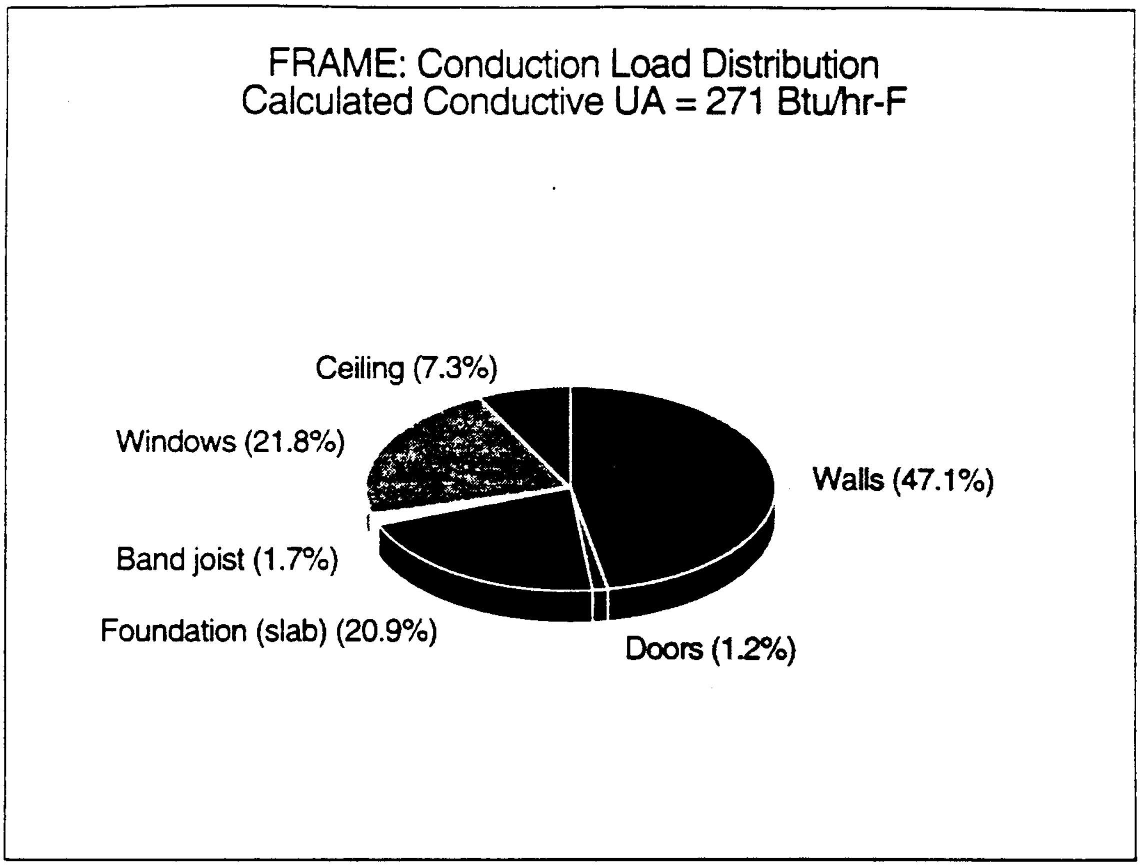

Figure 3a Conduction heating load distribution and calculated conductive UA for the stud-frame house

Figure 3a shows the calculated conductive thermal transmittance, or conductive UA, and conduction heating load distribution for the stud-frame house. Figure 3b shows the same for the SSIC panel house. Both houses had nearly the same distribution and the calculated conductive UA's were within 2% of each other—the panel house was lower. When the measured infiltration UA was included, from the average of all air tightness testing results shown in Figure 2, the total building UA for the panel house was 5% lower than that of the frame house. Air infiltration made up 15% and 12% of the total heating load for the frame and panel houses, respectively. In order to determine the as-built total UA, a co-heating test was performed. Figure 4 displays the inside to outside temperature difference of each house and the energy used to hold that temperature. The measured UA for the SSIC panel house was 19% lower than that of the stud-frame house, for the one-night co-heating test. A more accurate estimate of the as-built building UA is presented with the electric heating monitoring results. That UA is calculated by a linear

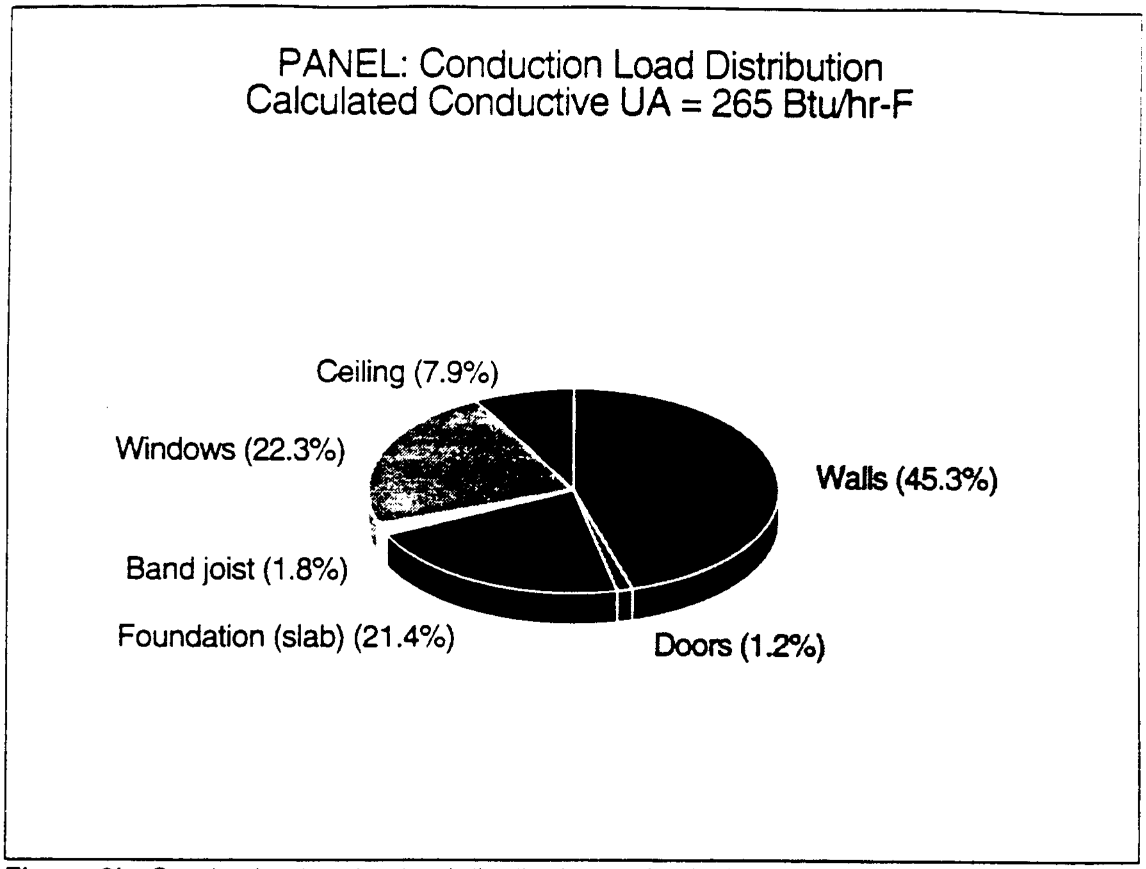

Figure 3b Conduction heating load distribution and calculated conductive UA for the SSIC panel house

regression of, in effect, 17 nights of co-heating data.

An evaluation of the temperature decay of each house was made, starting at sundown, by letting the house temperature fall with no internal heat source. The two buildings appear to have similar thermal capacitance. The drop in inside temperature as a function of time is shown for each house in Figure 5. The time constant for the stud-frame house was 8 hours compared to 10 hours for the SSIC panel house. The panel house cooled more slowly due to its lower conductive heat loss rate and lower infiltration rate. In a follow-on test, where the houses were heated up at the same energy input rate, the panel house heated up more quickly.

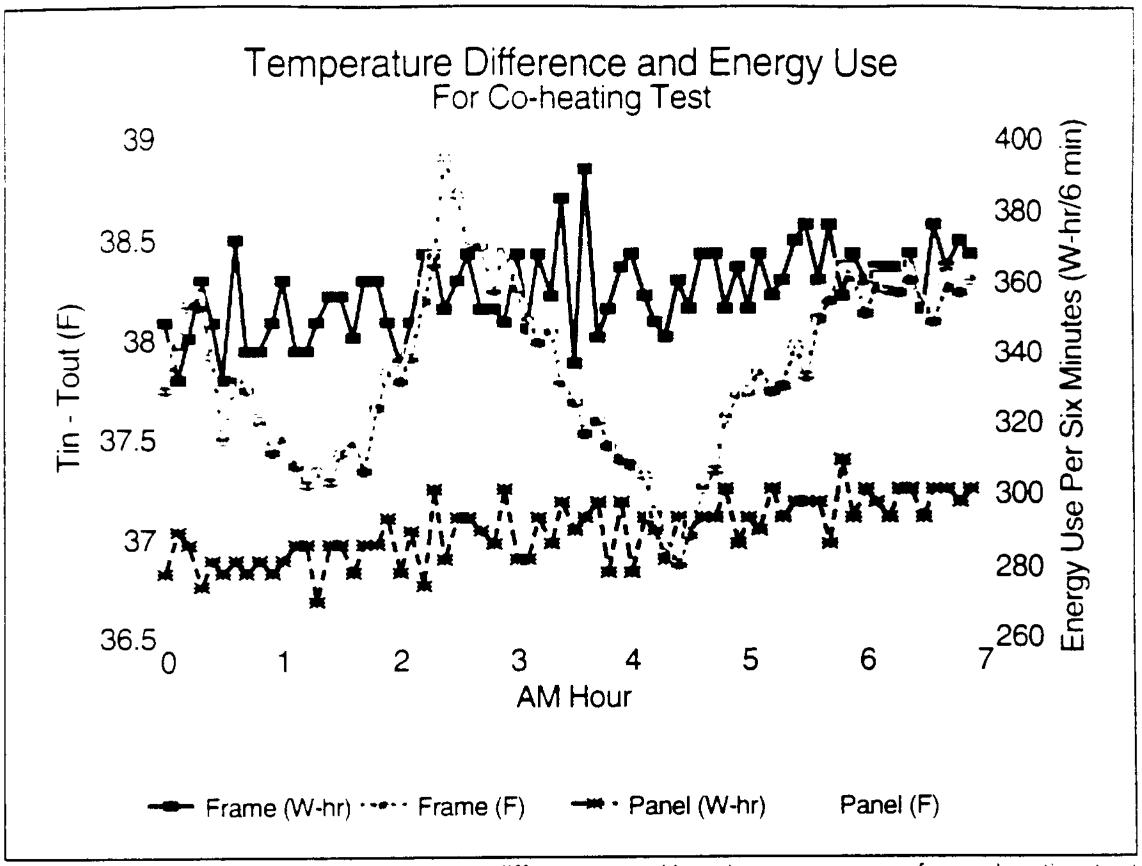

Figure 4 Inside to outside temperature difference and heating energy-use for co-heating test

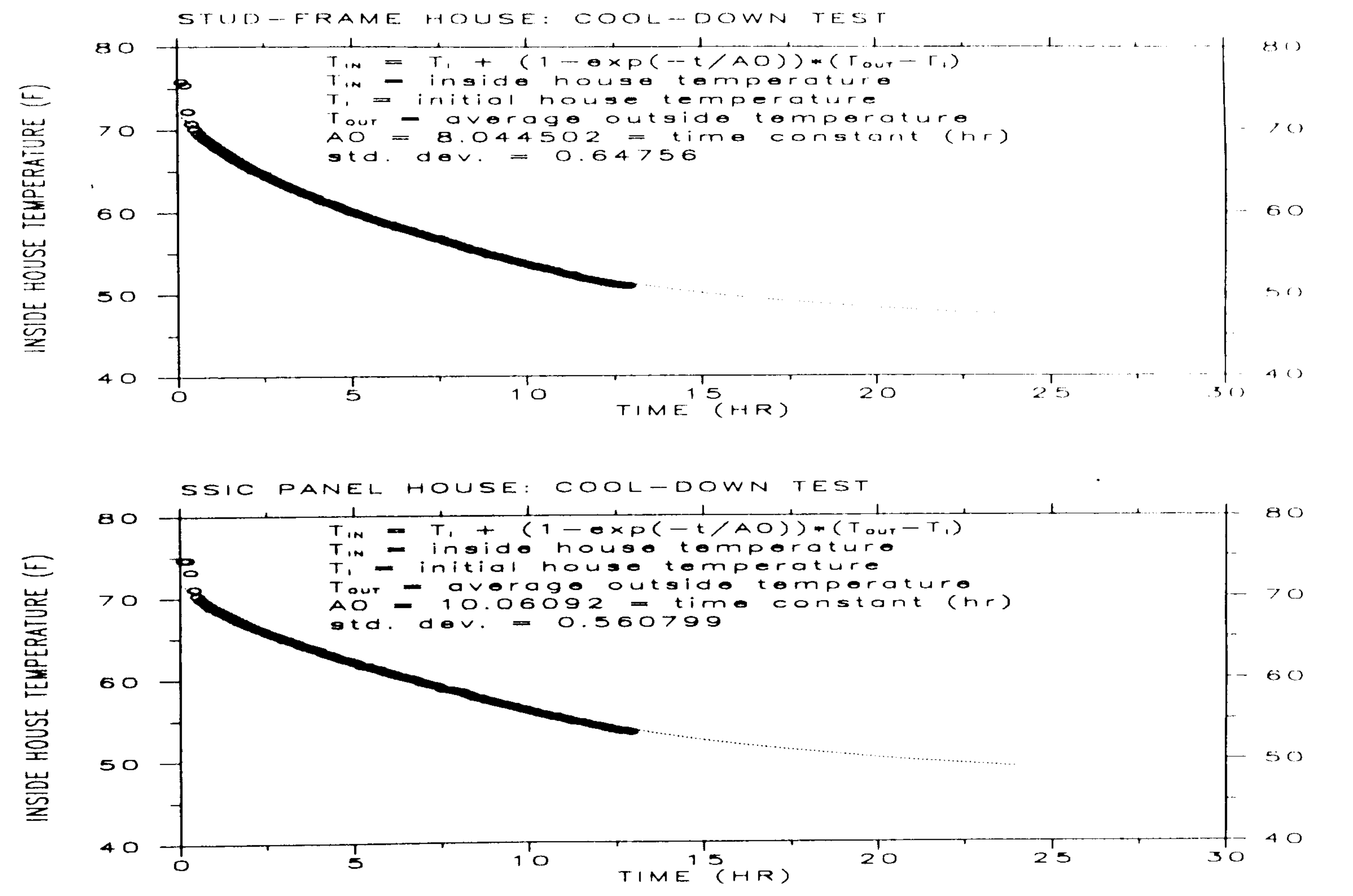

Figure 5 House temperature decay during thermal capacity cool-down test

3.2 Energy-use Monitoring

Two periods of energy-use monitoring, one for electric heating and one for gas heating, were included in the monitoring plan in order provide a more accurate comparison of the thermal envelopes of the two houses, and to calculate a total heating system and air distribution system efficiency. Electric heating eliminated the additional measurement uncertainties associated with the gas furnace and the increased air infiltration effects and leakage of the air distribution system. Since electric heating efficiency is 100%, the difference in measured building UA between the electric heating and gas heating monitoring should be due mainly to the gas furnace efficiency and infiltration/leakage effects caused by the air distribution system.

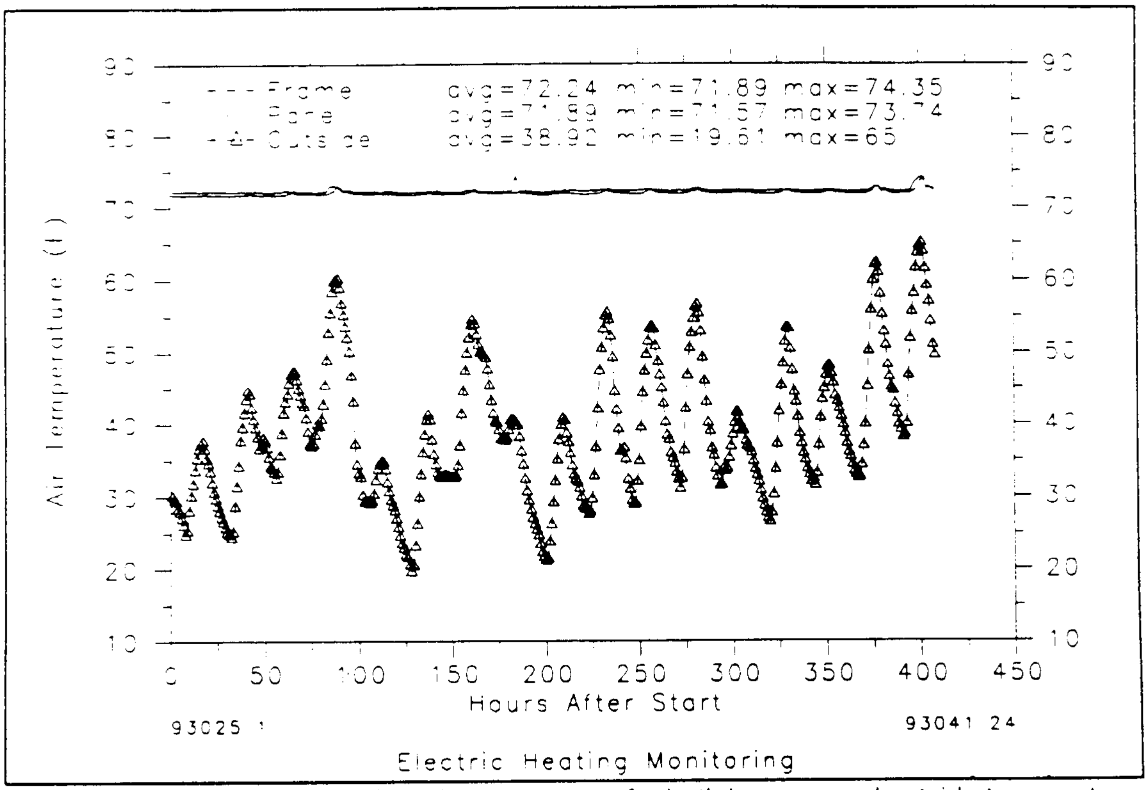

Figure 6a Hourly averages of inside temperature for both houses, and outside temperature, during the electric heating monitoring period

A total of seventeen consecutive days of electric heating energy-use monitoring was completed between 25 January and 10 February 1993. The houses were heated with six 1300 W electric heaters placed throughout the house. The heaters were turned on and off by computer control based on temperature feedback from thermocouples. Data was collected every six seconds and averaged or totalized and stored every 6 minutes. Figure 6a shows hourly averages of inside temperature for both houses and outside temperature. Temperatures typically did not vary more

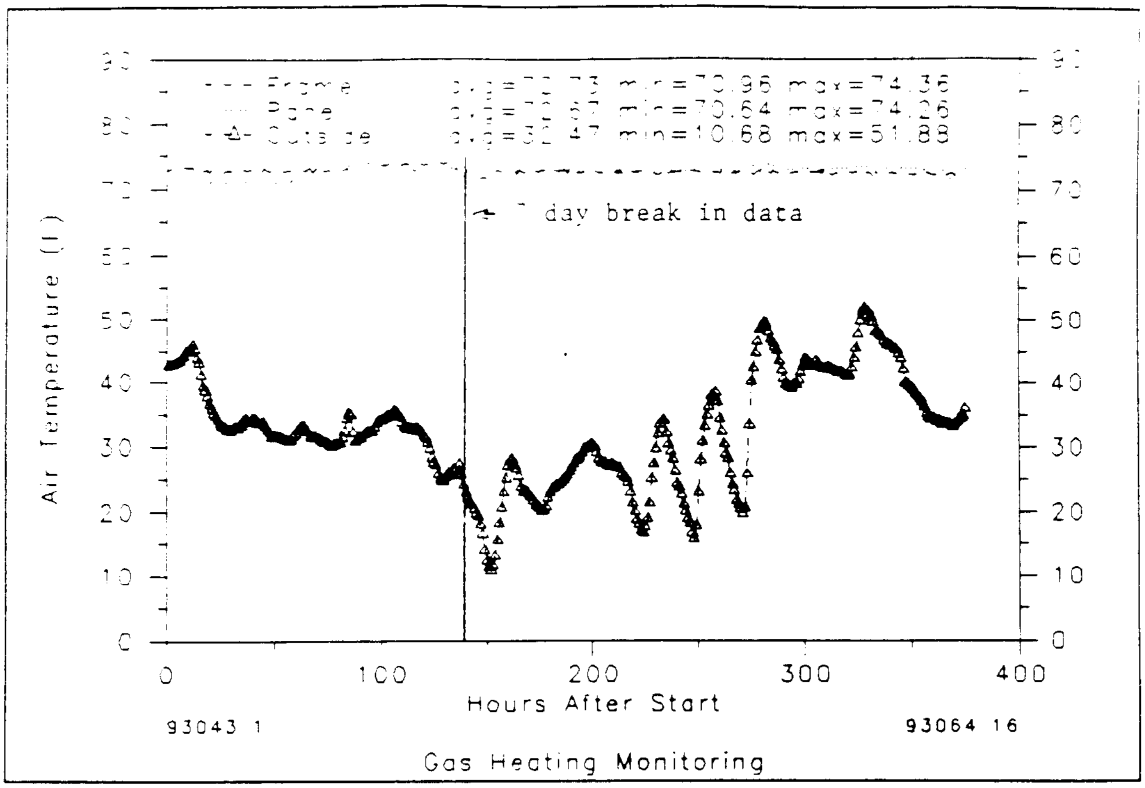

Figure 6b Hourly averages of inside temperature for both houses, and outside temperature, during the gas heating monitoring period

than 0.5°F within the house and between houses. Outdoor temperature for the entire period averaged 39°F.

A total of 21 days of gas heating energy-use monitoring was conducted between 12 February and 5 March 1993. For a seven-day period, 17 February to 23 February, there was a gap in gas meter data for the stud-frame house due to a meter failure. Hence, only 14 days of gas heating monitoring were analyzed. The electronic-ignition, gas furnaces were turned on and the thermostats were adjusted to minimize the control dead-band and to keep each house as close as possible to 72° F. Figure 6b shows hourly averaged temperatures for the inside of each house and for the outside. The temperature in each house, and between houses, typically did not vary more than 1.5°F. Outdoor temperature during the entire period averaged 33°F.

Table 4a

Daily Summary of House Interior Conditions and Weather Conditions - Electric Heating Monitoring Period

Day of Electric Monitoring Period	Frame House Tair (F)	Frame House Twall (F)	Frame House Tmrt (F)	Frame House RH (%)	Panel House Tair (F)	Panel House Twall (F)	Panel House Tmrt (F)	Panel House RH (%)	Frame-Panel Difference Tair (F)	Frame-Panel Difference Twall (F)	Frame-Panel Difference Tmrt (F)	Frame-Panel Difference RH (%)	Weather Conditions Tair (F)	Weather Conditions RH (%)	Weather Conditions WS (mph)	Weather Conditions Irr,ver (W/m2)
93025	72.2	68.4	69.8	35.0	71.7	68.2	69.4	36.8	0.5	0.3	0.3	-1.8	31.2	45.0	3.2	118.2
93026	72.2	68.5	69.8	33.5	71.8	68.2	69.4	35.5	0.4	0.3	0.3	-1.9	33.9	42.0	2.5	117.3
93027	72.2	69.2	70.0	34.6	71.9	68.8	69.7	36.4	0.3	0.3	0.3	-1.8	40.2	44.8	3.4	115.6
93028	72.4	69.9	70.5	36.3	72.1	69.4	70.2	38.0	0.3	0.5	0.3	-1.7	48.5	44.0	5.8	110.7
93029	72.1	68.6	69.8	34.6	71.8	68.5	69.7	36.0	0.3	0.1	0.0	-1.5	31.9	41.1	6.3	101.6
93030	72.1	68.3	69.6	30.7	71.8	67.8	69.5	31.8	0.3	0.6	0.2	-1.1	29.8	35.7	4.2	125.9
93031	72.1	69.1	70.1	32.1	71.9	68.5	69.8	32.8	0.2	0.5	0.2	-0.7	43.0	38.9	6.7	110.9
93032	72.3	69.2	70.0	33.0	71.9	68.9	69.9	34.5	0.4	0.3	0.1	-1.5	38.2	42.6	6.9	124.1
93033	72.1	68.4	69.6	29.0	71.7	68.2	69.5	31.2	0.4	0.2	0.1	-2.2	30.3	36.2	4.2	126.3
93034	72.2	69.0	70.0	29.3	71.8	68.8	69.8	31.5	0.4	0.2	0.2	-2.2	39.7	30.6	1.9	108.9
93035	72.2	69.3	70.1	30.3	71.9	69.1	70.0	32.4	0.4	0.2	0.1	-2.1	41.3	35.4	3.2	122.7
93036	72.3	69.3	70.2	30.6	71.9	69.0	70.1	32.7	0.3	0.3	0.1	-2.1	42.9	34.4	1.7	90.6
93037	72.2	68.9	69.9	30.9	71.9	68.5	69.9	32.7	0.3	0.5	0.0	-1.8	36.2	56.5	3.9	78.5
93038	72.2	69.2	70.0	30.7	71.9	69.0	69.9	32.7	0.3	0.2	0.1	-2.0	38.3	50.0	2.1	118.2
93039	72.2	68.8	70.0	31.6	71.9	68.8	70.0	33.7	0.3	0.0	0.0	-2.0	39.7	62.8	2.8	73.7
93040	72.3	69.4	70.4	32.6	72.1	69.4	70.3	34.6	0.3	0.1	0.1	-2.1	45.5	53.2	2.4	93.2
93041	72.7	70.4	71.0	34.4	72.3	70.2	70.8	36.4	0.4	0.3	0.2	-2.1	51.3	49.5	1.9	103.6
averages:	72.2	69.1	70.0	32.3	71.9	68.8	69.9	34.1	0.3	0.3	0.2	-1.8	38.9	43.7	3.7	108.2
maximums:	72.7	70.4	71.0	36.3	72.3	70.2	70.8	38.0	0.5	0.6	0.3	-0.7	51.3	62.8	6.9	126.3
minimums:	72.1	68.3	69.6	29.0	71.7	67.8	69.4	31.2	0.2	0.0	0.0	-2.2	29.8	30.6	1.7	73.7

Table 4b

Daily Summary of House Interior Conditions and Weather Conditions - Gas Heating Monitoring Period

Day of Gas Monitoring Period	Frame House Tair (F)	Frame House Twall (F)	Frame House Tmrt (F)	Frame House RH (%)	Panel House Tair (F)	Panel House Twall (F)	Panel House Tmrt (F)	Panel House RH (%)	Frame-Panel Difference Tair (F)	Frame-Panel Difference Twall (F)	Frame-Panel Difference Tmrt (F)	Frame-Panel Difference RH (%)	Weather Conditions Tair (F)	Weather Conditions RH (%)	Weather Conditions WS (mph)	Weather Conditions Irr.ver (W/m2)
93043	72.8	70.2	71.7	34.5	71.3	69.1	70.1	36.7	1.5	1.1	1.6	-2.2	41.3	82.6	4.6	3.7
93044	72.7	69.6	71.5	31.6	70.9	68.5	69.7	34.1	1.7	1.1	1.8	-2.6	33.2	71.8	5.9	7.4
93045	72.8	69.7	71.6	29.5	71.4	68.9	70.1	32.3	1.3	0.8	1.5	-2.8	31.7	62.0	4.7	9.8
93046	73.5	70.2	72.3	27.8	72.1	69.5	70.8	31.4	1.3	0.7	1.5	-3.5	31.7	68.6	2.9	16.0
93047	73.9	70.7	72.7	28.6	72.8	70.3	71.4	31.2	1.1	0.5	1.3	-2.6	33.7	76.8	5.8	12.1
93055	72.4	69.6	70.9	19.7	73.1	70.9	71.3	20.7	-0.7	-1.2	-0.4	-1.1	20.1	38.5	5.3	120.2
93056	72.8	69.3	71.4	18.6	72.9	70.1	71.3	20.3	-0.1	-0.8	0.0	-1.8	23.5	64.6	5.0	19.9
93057	72.6	69.3	71.3	20.4	73.1	70.3	71.6	22.5	-0.5	-1.0	-0.3	-2.2	28.0	74.0	4.7	33.1
93058	72.6	70.4	71.3	19.9	73.3	71.5	71.8	21.7	-0.7	-1.1	-0.5	-1.9	25.2	46.2	2.8	275.7
93059	72.6	70.5	71.3	19.5	73.3	71.6	71.8	21.6	-0.8	-1.1	-0.5	-2.1	27.7	46.9	1.7	275.4
93060	72.5	70.8	71.4	20.4	73.3	71.7	72.0	22.8	-0.8	-0.9	0.6	-2.4	36.7	48.0	2.1	247.3
93061	72.5	69.8	71.4	23.1	73.2	70.8	71.9	25.8	-0.7	-0.9	0.5	2.7	41.6	67.6	1.8	18.0
93062	72.4	69.8	71.2	28.8	73.2	70.9	72.0	29.6	-0.8	-1.1	0.7	0.8	45.7	90.0	2.5	13.3
93063	72.3	69.5	71.2	30.2	73.1	70.7	71.8	30.9	-0.8	-1.2	-0.6	-0.6	40.5	85.2	5.9	9.4
averages:	72.7	70.0	71.5	25.2	72.7	70.3	71.3	27.3	0.1	-0.4	0.2	-2.1	32.9	65.9	4.0	75.8
maximums:	73.9	70.8	72.7	34.5	73.3	71.7	72.0	36.7	1.7	1.1	1.8	-0.6	45.7	90.0	5.9	275.7
minimums:	72.3	69.3	70.9	18.6	70.9	68.5	69.7	20.3	-0.8	-1.2	-0.7	-3.5	20.1	38.5	1.7	3.7

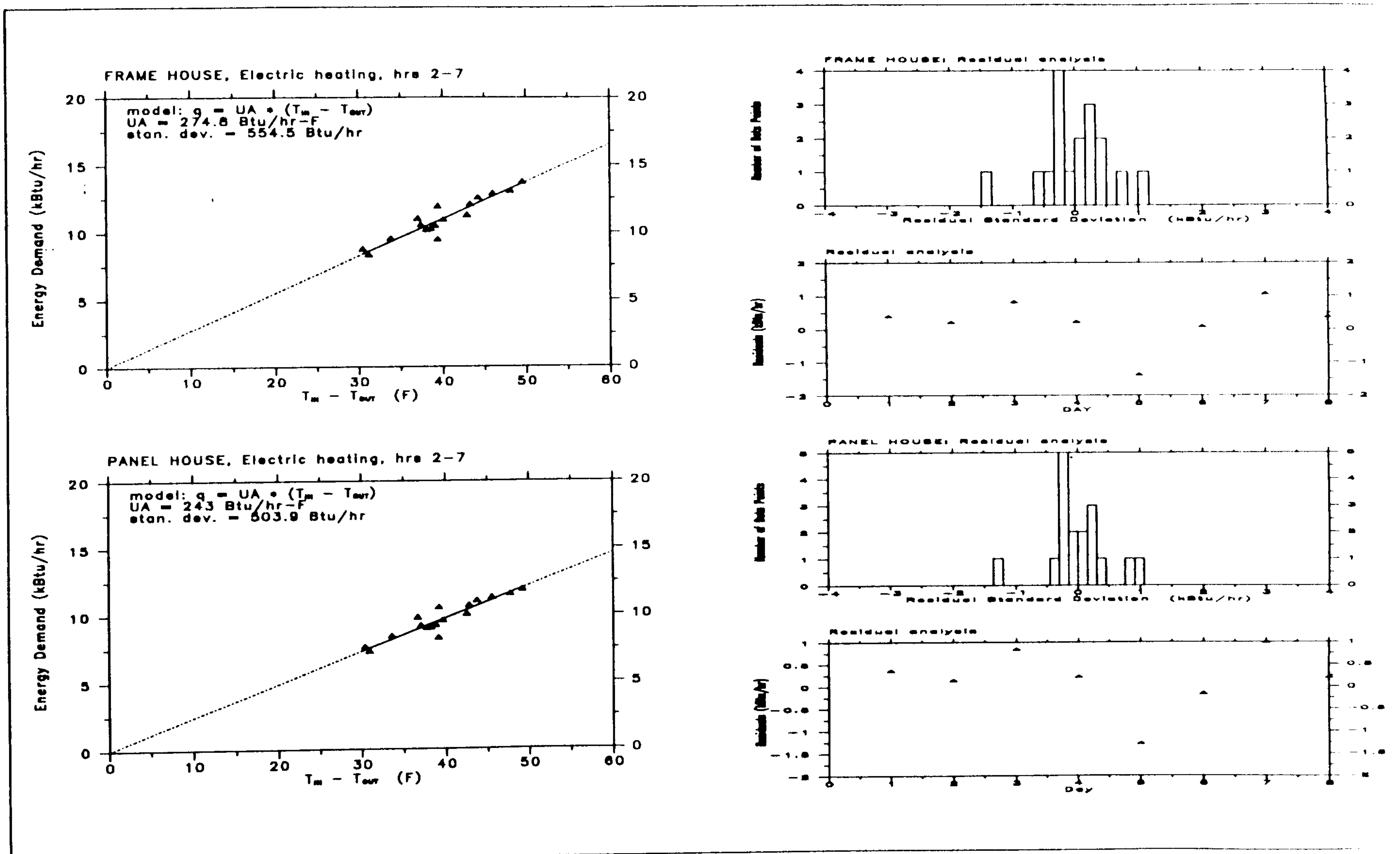

Figure 7 Linear regression of nighttime heating energy-use data as a function of temperature difference during the electric heating monitoring period, adjoining residual analysis

Tables 4a and 4b. give a concise summary of the daily-averaged data describing the indoor conditions of the two houses, as well as the differences between the houses, and the outdoor environmental conditions. The differences in air temperature, south wall temperature, and mean radiant temperature were small for both monitoring periods. Relative humidity was about 2% higher in the panel house, well within the sensor accuracy limit of ±2%.

Table 5
Measured Building UA and Heating System Efficiency

	Measured Building UA		
	Frame House (Btu/hr-°F)	Panel House (Btu/hr-°F)	Percent Difference
Electric heating monitoring (17 nights)	276	242	12.3%
Gas heating monitoring (14 nights)	352	300	14.8%
	Gas furnace and air distribution system efficiency		
	78.4%	80.7	

A linear regression of heating energy-use and inside to outside temperature difference is shown in Figure 7. The objective of the analysis of Figure 7 was to obtain a more accurate estimate of the as-built building UA than the one-night co-heating test could give. Only night hours, hours 2-7, were included in the regression to minimize the effects of solar gains and thermal capacitance. The adjoining residual analysis in Figure 7 shows acceptable normality of distribution and no significant bias error. Table 5 gives a summary of the results for both monitoring periods and the one-night co-heating test. The building UA's of 276 for the frame house and 242 for the panel house are expected to be the most accurate and repeatable results. Taking those UA values, and comparing them to those obtained from the gas heating monitoring period, yields a lumped efficiency for the gas furnace plus the air distribution system leakage and possible infiltration effects due to pressure imbalances. Those efficiencies are 78% and 81% for the frame and panel houses, respectively. Since the gas furnaces have a rated 80% Annual Fuel Utilization Efficiency, it seems that the conclusion from blower door testing, that there was no measurable duct leakage, was confirmed. All interior doors were open during the monitoring periods, hence there was little opportunity for pressure imbalance which could increase building air leakage.

Table 6
Heating Energy Savings Of SSIC Panel House Over Stud-frame House

	Percent Heating Energy Savings
Electric Heating Monitoring	
Night data	**12**
Daily data	15
Seasonal predicted	14-16
Gas Heating Monitoring	
Night data	**15**
Daily data	17
Seasonal predicted	16-20

Heating energy savings were calculated for both monitoring periods by comparing the total energy consumed by each house, less the internal gains profile. No outside lights were operable, and the gas hot water heaters were turned off, hence, all electricity and gas consumed were considered to contribute to the heating of the houses. Table 6 summarizes the heating energy savings results. The night data, hours 2-7, were expected to give the most accurate comparison of the two building thermal envelopes due to the fact that any solar gain differences between the two buildings would have no impact. Night data showed that the SSIC panel house used between 12 and 15% less heating energy than the stud-frame house. The daily data was considered to give the next level of accuracy and was primarily utilized to obtain a simple mathematical model with which to predict seasonal savings. Daily data (all 24 hours) indicated that the panel house used between 15 and 17% less heating energy. Two mathematical models were calculated by linear regression of the daily heating energy-use data. The first model included only two coefficients:

$$y = a1 * (T_{in} - T_{out}) + a2 \qquad (1)$$

where: y = heating energy-use
T_{in} = inside temperature
T_{out} = outside temperature
$a1$, $a2$ = regression coefficients

The second model included a third coefficient to pick up the impact of solar gain:

$$y = a0 * I_{hor} + a1 * (T_{in} - T_{out}) + a2 \qquad (2)$$

where: I_{hor} = horizontal solar irradiance

The analysis showed that solar irradiance had almost no impact on heating energy savings during the monitoring periods. This is supported in that the difference in energy savings predicted by both models, using the actual monitored weather data, was less than 0.2%. When the model was used to extrapolate, or predict seasonal energy savings, using Typical Meteorological Year weather data for Louisville, the difference between the models became more significant. The predicted seasonal heating energy savings ranged between 14 and 20% in favor of the panel house. However, the reader is cautioned that the preliminary models referred to here may not accurately represent seasonal savings. A more in depth approach, using a detailed energy simulation model which was "tuned" to the actual measured data (Lutz 1992), would be desirable, given additional funding. Another analysis approach could be the Short-Term Energy Monitoring/Primary and Secondary Terms Renormalization (STEM/PSTAR) method developed at the National Renewable Energy Laboratory (Subbarao 1988).

Tables 7 and 7a list the average daily energy use, the maximum daily energy use, total energy use, and the percent difference in total energy use for the periods and analysis methods described. The only difference between the two Tables is the regression model employed. The model for Table 7 follows Eq.(1) while the model for Table 7a follows Eq.(2)—with a solar coefficient. Since the total heating load for both houses is not large, the absolute difference in energy use, or actual cost, is also modest even though the percentage difference is significant.

Table 7

Daily and Total Energy Use For Different Monitoring Periods and Analysis Methods

		Frame House			Panel House			
*Regression model = **a1(Tin-Tout) + a2*** Description	number of days	avg daily energy-use kwh/day	max daily energy-use kwh/day	total energy-use kwh	avg daily energy-use kwh/day	max daily energy-use kwh/day	total energy-use kwh	% diff total energy-use
Electric Heating Monitoring:								
Measured data alone, Julian Days 25-41	17	37.0	52.6	629	31.4	46.1	533	**15.2%**
Measured data applied to model, JD 25-41	17	36.6	50.4	623	31.5	43.6	536	14.0%
TMY data applied to model, JD 25-41	17	48.6	71.1	826	42.0	61.7	714	13.5%
TMY data applied to model, Nov-Mar	151	36.1	85.3	5446	31.0	74.2	4683	14.0%
Gas Heating Monitoring:								
Measured data alone, Julian Days 43-47,55-63	14	69.4	104.5	972	58.0	81.3	812	**16.5%**
Measured data applied to model, JD 43-47,55-63	14	68.0	93.9	951	56.9	78.3	797	16.3%
TMY data applied to model, JD 43-47,55-63	14	53.1	78.5	744	44.6	65.6	625	16.0%
TMY data applied to model, Nov-Mar	151	55.0	121.2	8307	46.2	100.9	6978	16.0%

Table 7a

Daily and Total Energy Use For Different Monitoring Periods and Analysis Methods

		Frame House			Panel House			
*Regression model = **a0*Ihor + a1(Tin-Tout) + a2*** Description	number of days	avg daily energy-use kwh/day	max daily energy-use kwh/day	total energy-use kwh	avg daily energy-use kwh/day	max daily energy-use kwh/day	total energy-use kwh	% diff total energy-use
Electric Heating Monitoring:								
Measured data alone, Julian Days 25-41	17	37.0	52.6	629	31.4	46.1	533	**15.2%**
Measured data applied to model, JD 25-41	17	36.6	50.6	623	31.5	43.9	536	14.0%
TMY data applied to model, JD 25-41	17	46.8	70.7	795	39.3	61.2	668	16.0%
TMY data applied to model, Nov-Mar	151	34.8	84.5	5253	29.1	73.0	4395	16.3%
Gas Heating Monitoring:								
Measured data alone, Julian Days 43-47,55-63	14	69.4	104.5	972	58.0	81.3	812	**16.5%**
Measured data applied to model, JD 43-47,55-63	14	67.9	92.2	950	56.7	78.1	794	16.4%
TMY data applied to model, JD 43-47,55-63	14	51.5	77.9	720	41.2	64.6	577	19.9%
TMY data applied to model, Nov-Mar	151	53.5	124.0	8083	43.1	107.1	6514	19.4%

Figures 8a and 8b were developed to determine if any environmental parameter was significantly correlated to energy savings, so as to produce a possible bias of the results, for example, due to the fact that the frame house has an east elevation (with no windows) exposed to the street while the panel house was located closely between two other houses. The plots of heating energy-use savings against outdoor temperature, solar irradiance, wind speed and relative humidity appeared random, and showed no clear correlations for either monitoring period, meaning that the bias of the results due to these factors would be small.

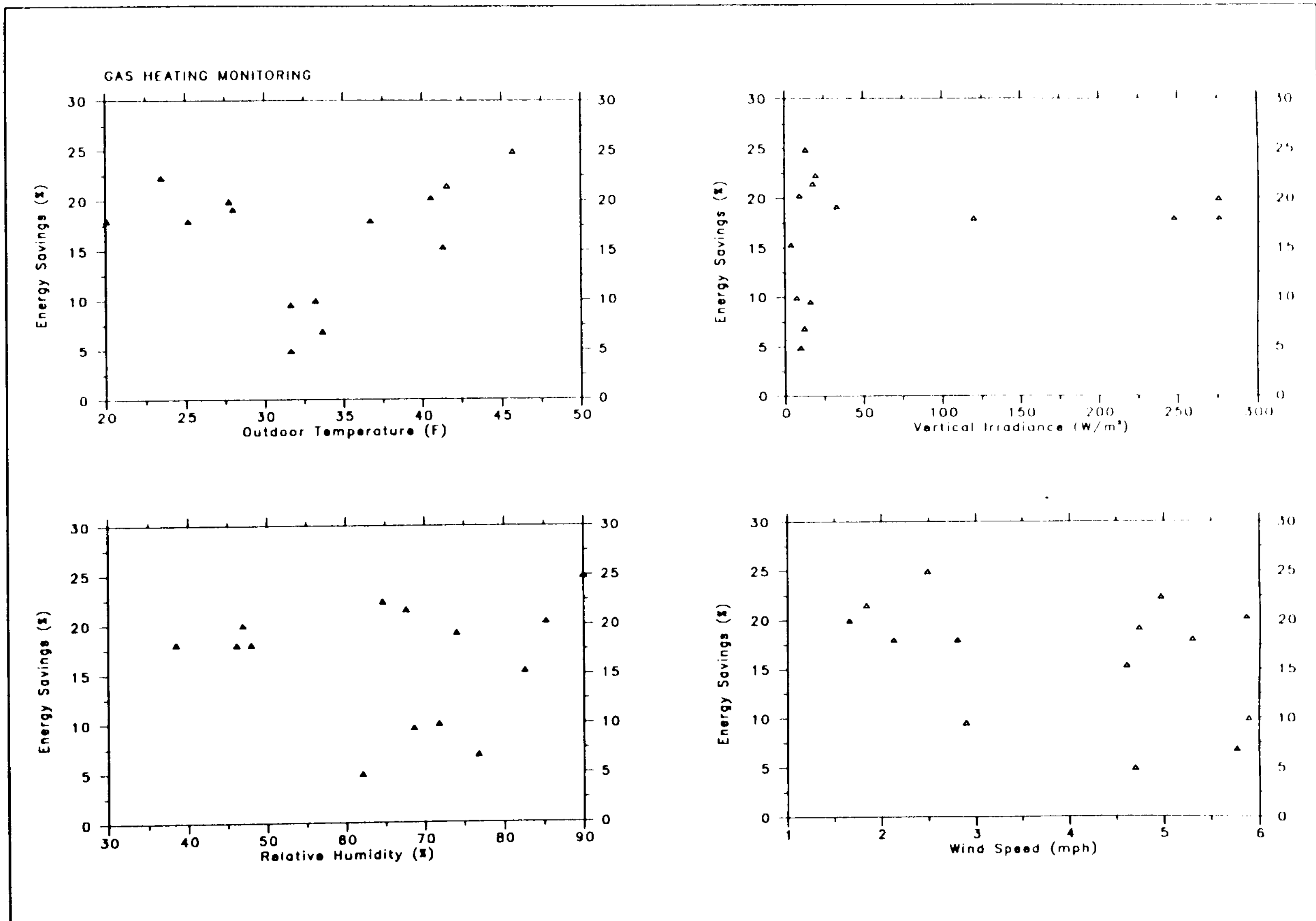

Figure 8b Heating energy savings versus outside environmental conditions during gas heating monitoring

Mostly for the readers general information, Figures 9a and 9b give an hourly-averaged time-trace of indoor and outdoor relative humidity for both houses and both monitoring periods. Figures 10a and 10b give the same time-trace for mean radiant temperature; and Figures 11a and 11b give the time-trace for south wall temperature. These plots demonstrate how similarly the two houses performed in terms of interior comfort conditions, and illustrate the validity of the test conditions.

4.0 Conclusions

Extensive energy-use monitoring was conducted comparing the building thermal envelopes of a conventional stud-frame house and an industrialized house using stressed-skin insulated core panels for its walls and ceiling. The houses were otherwise identical. By calculation, the two houses had a conductive thermal transmittance within 2% of each other. Measured co-heating data showed the total building load coefficient of the panel house to be 12% lower than the frame house. Monitored heating energy-use data, for nighttime hours only, showed that the SSIC panel house used 12% and 15% less energy than the frame house during electric heating and gas heating, respectively. Monitored energy-use for 24-hour data indicated between 15% and 17% energy savings. A preliminary effort to predict seasonal heating energy savings, using simple regression models and TMY weather data, indicated energy savings ranging between 14% and 20%. More accurate seasonal predictions would require additional effort. In addition to the panel house being more air-tight, there seem to be other factors, which remain unaccounted for, which cause the panel house to use less heating energy. These factors require further investigation.

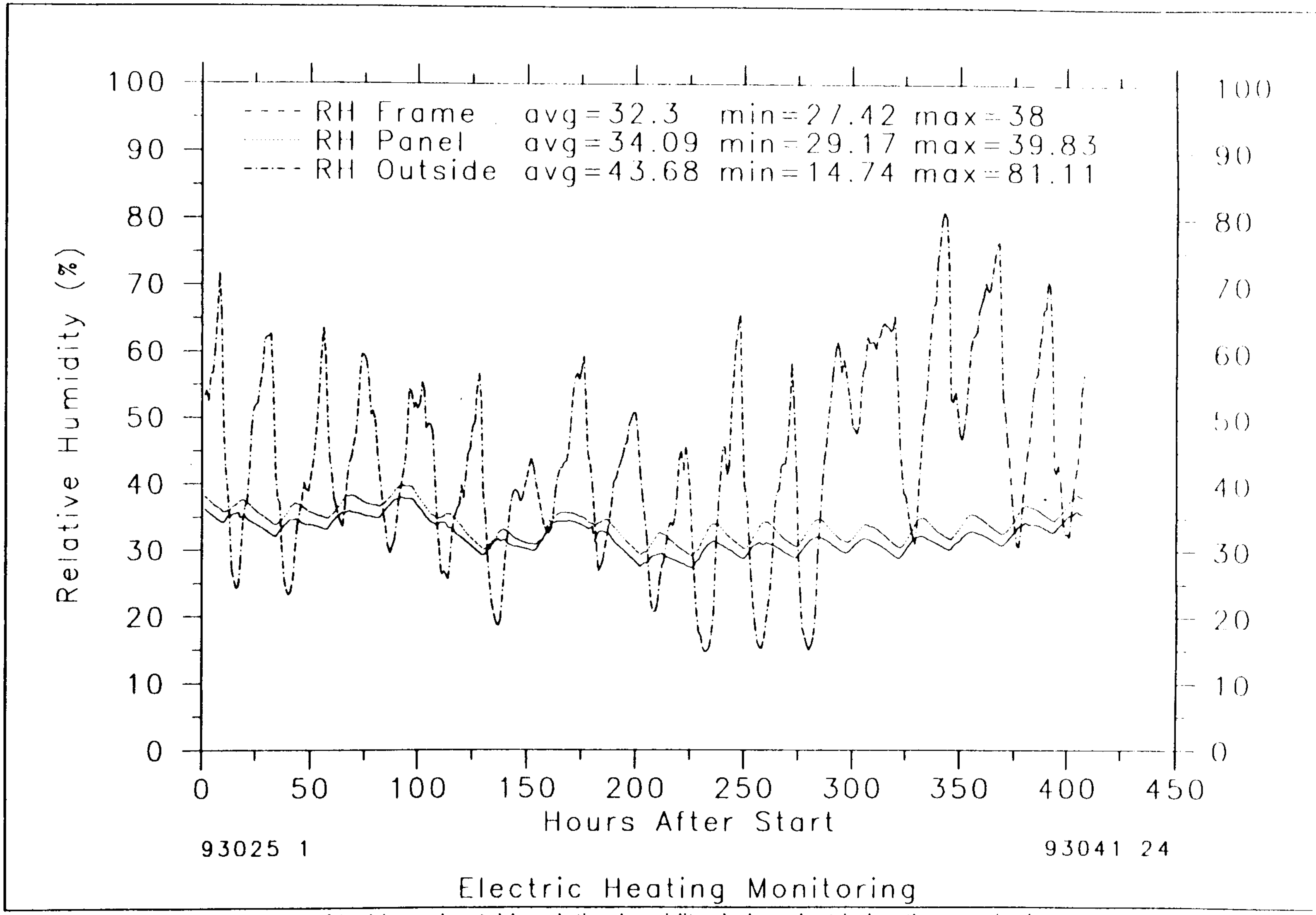

Figure 9a Hourly time-trace of inside and outside relative humidity during electric heating monitoring

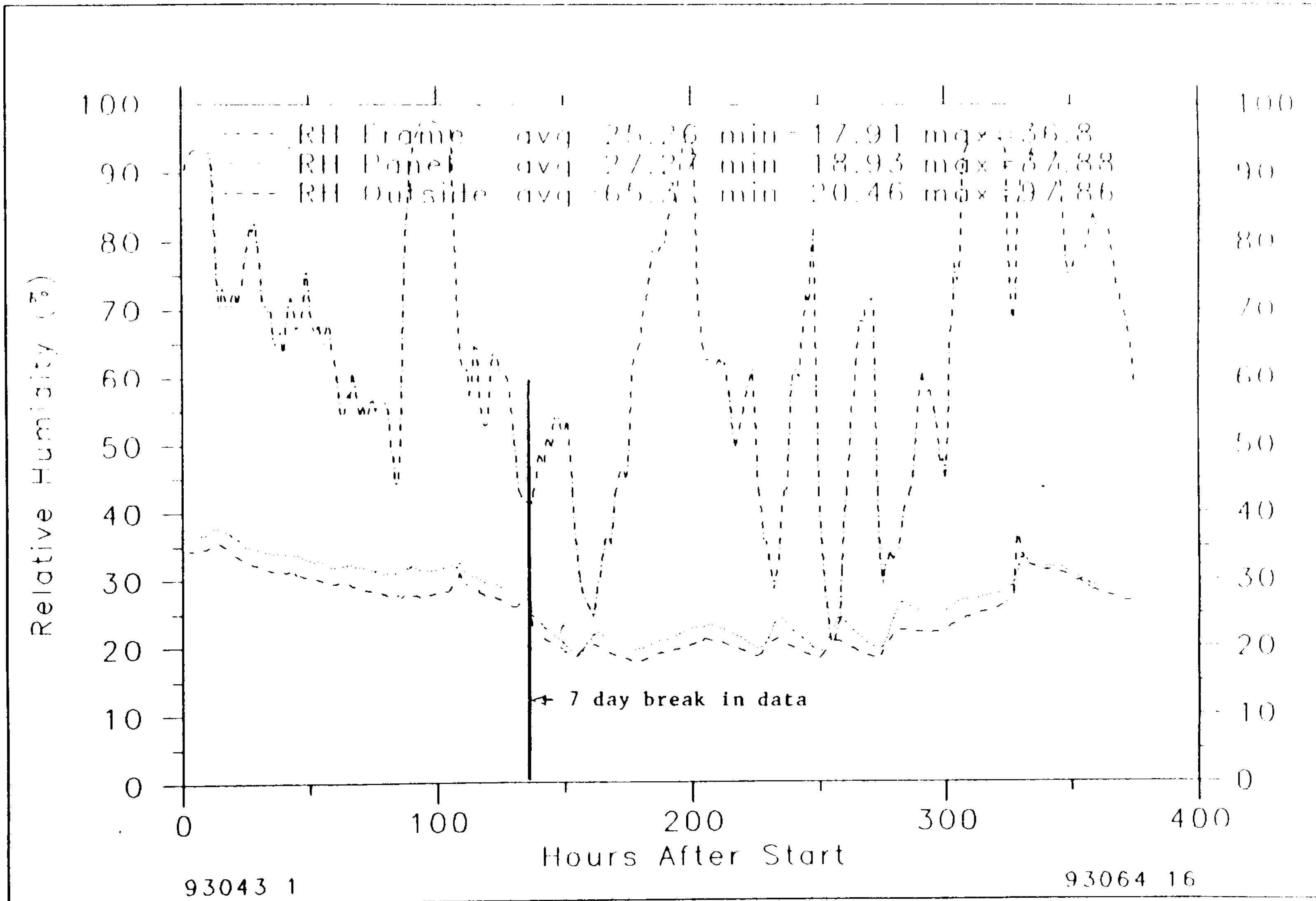

Figure 9b Hourly time-trace of inside and outside relative humidity during gas heating monitoring

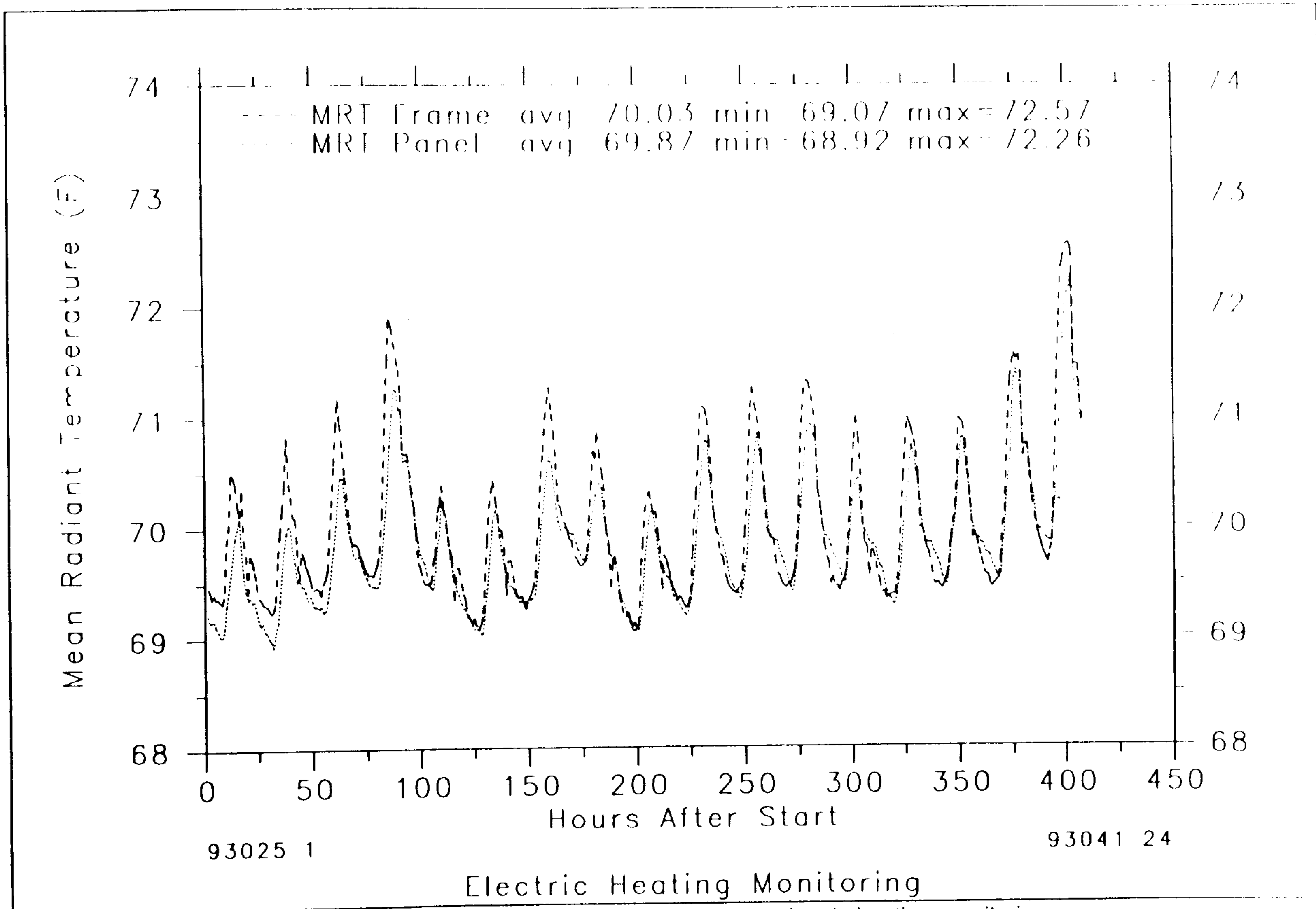

Figure 10a Hourly time-trace of inside mean radiant temperature during electric heating monitoring

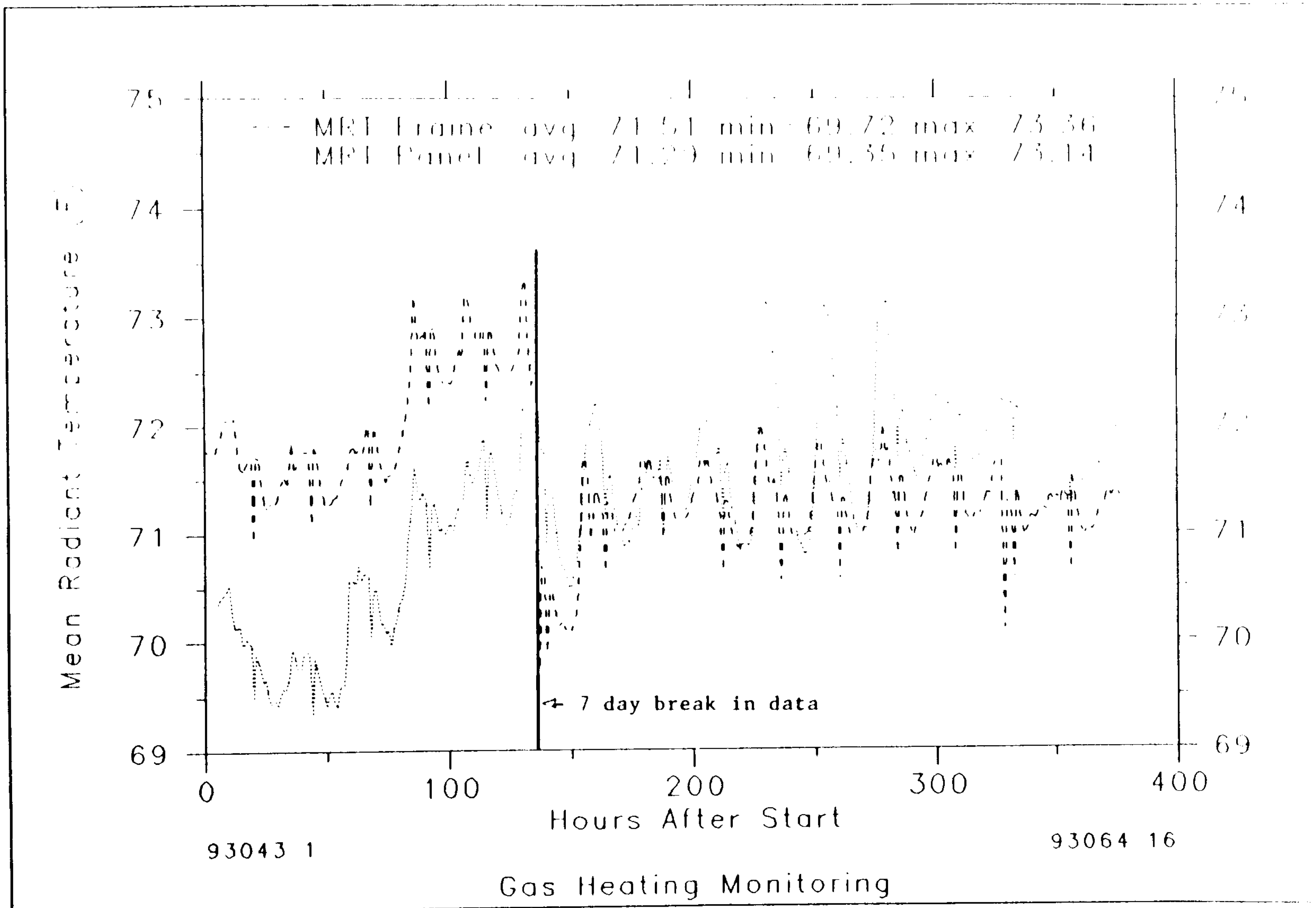

Figure 10b Hourly time-trace of inside mean radiant temperature during gas heating monitoring

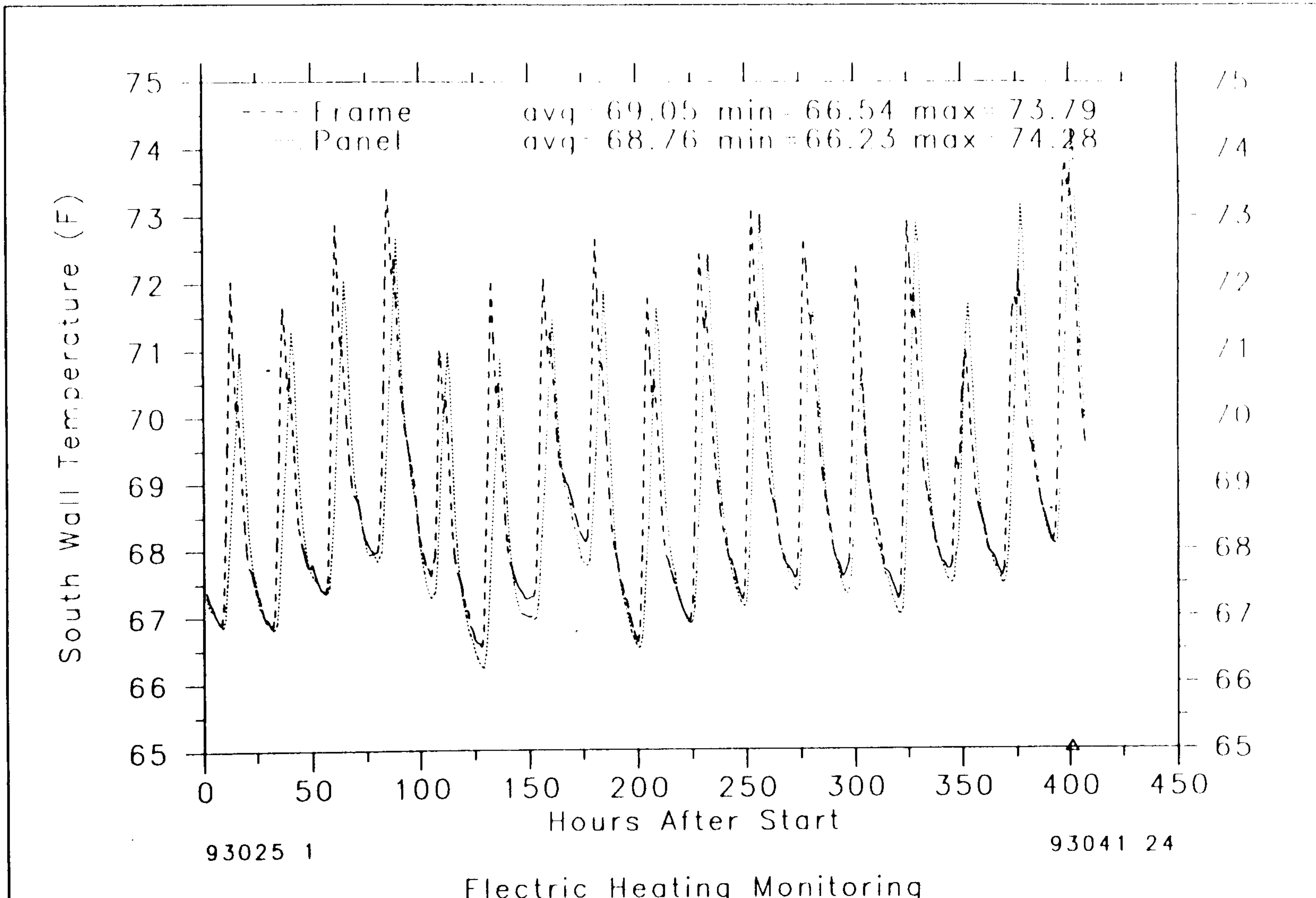

Figure 11a Hourly time-trace of inside south wall temperature (over insulated cavity) during electric heating monitoring

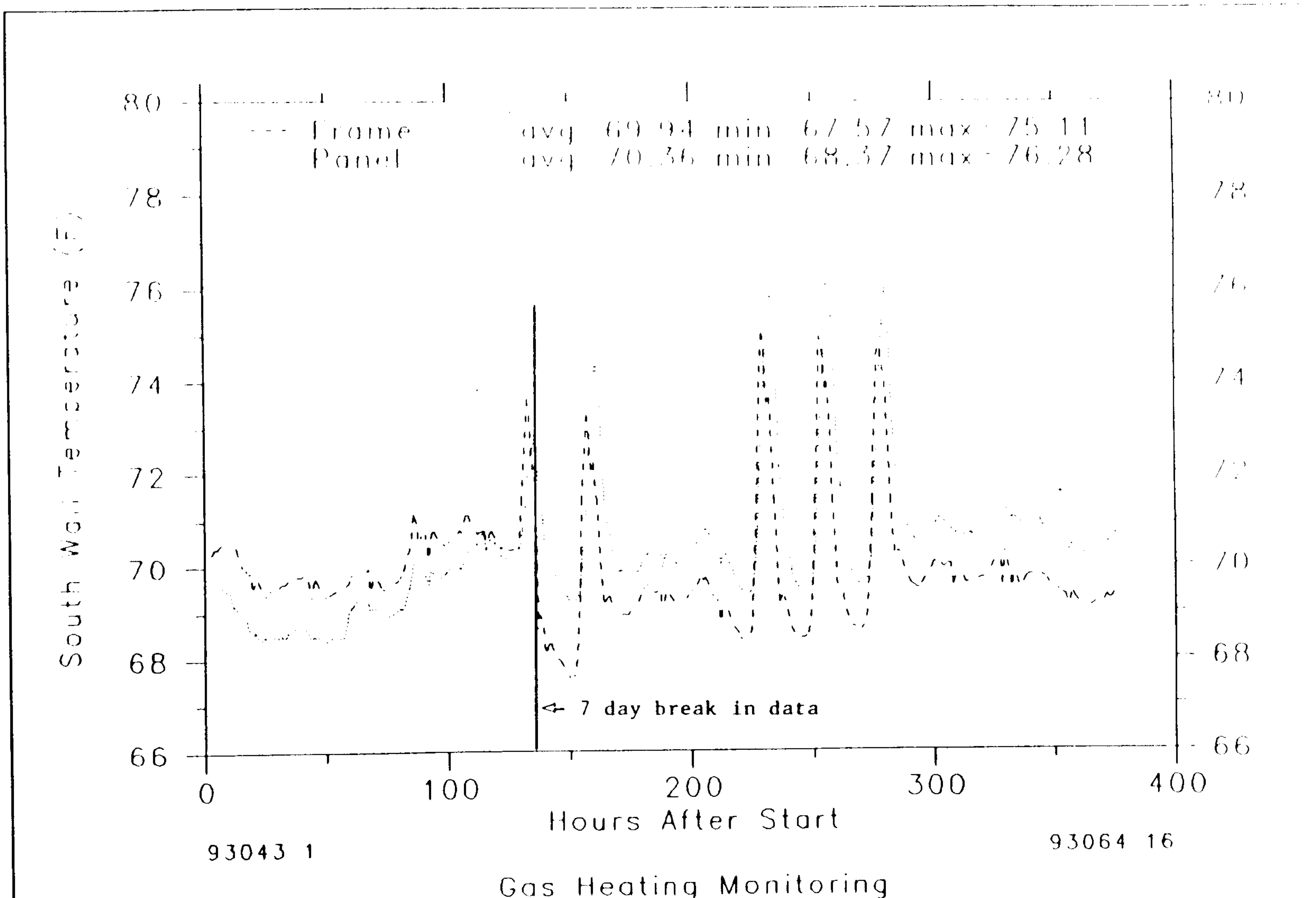

Figure 11b Hourly time-trace of inside south wall temperature (over insulated cavity) during gas heating monitoring

5.0 References

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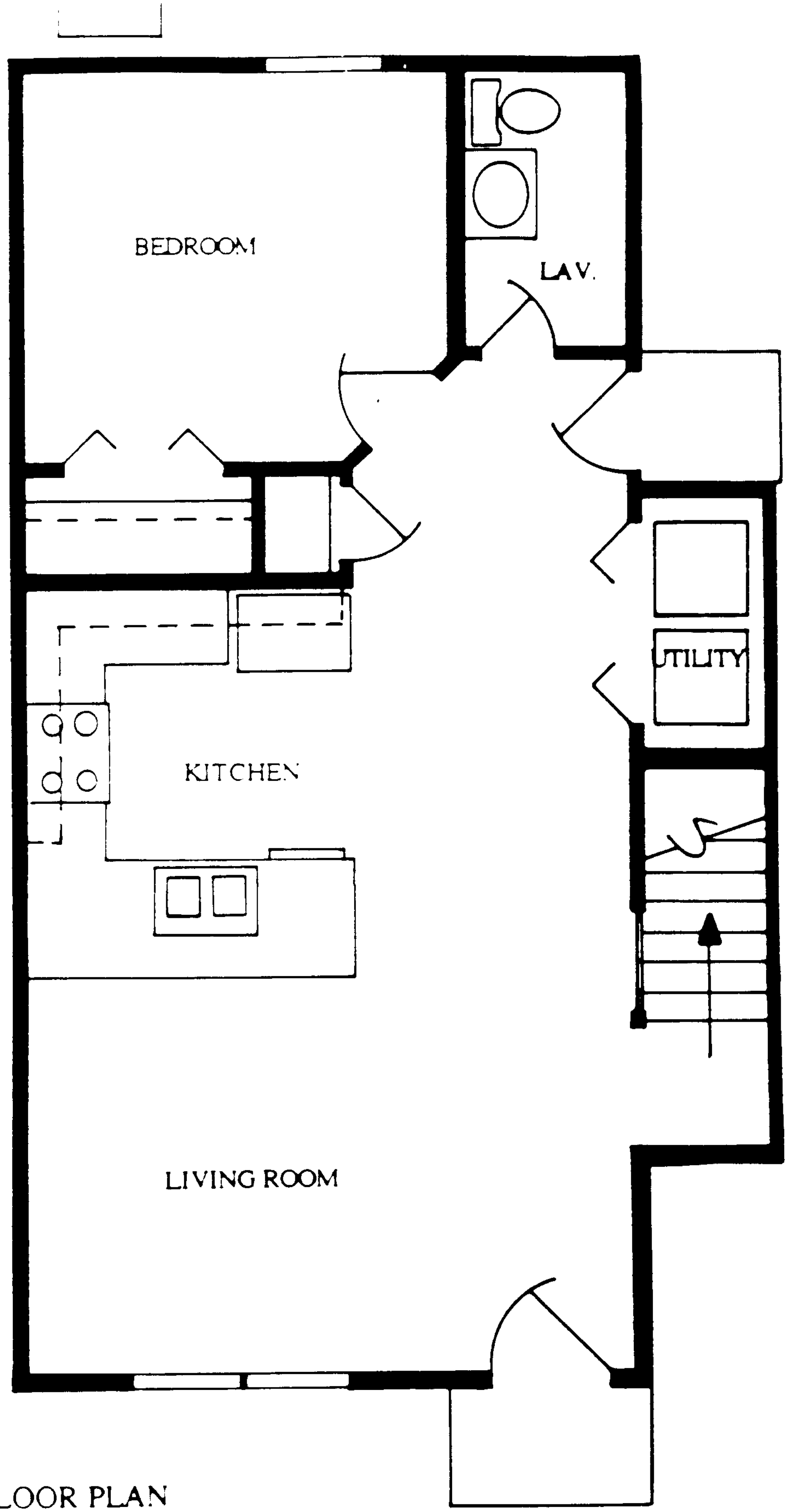
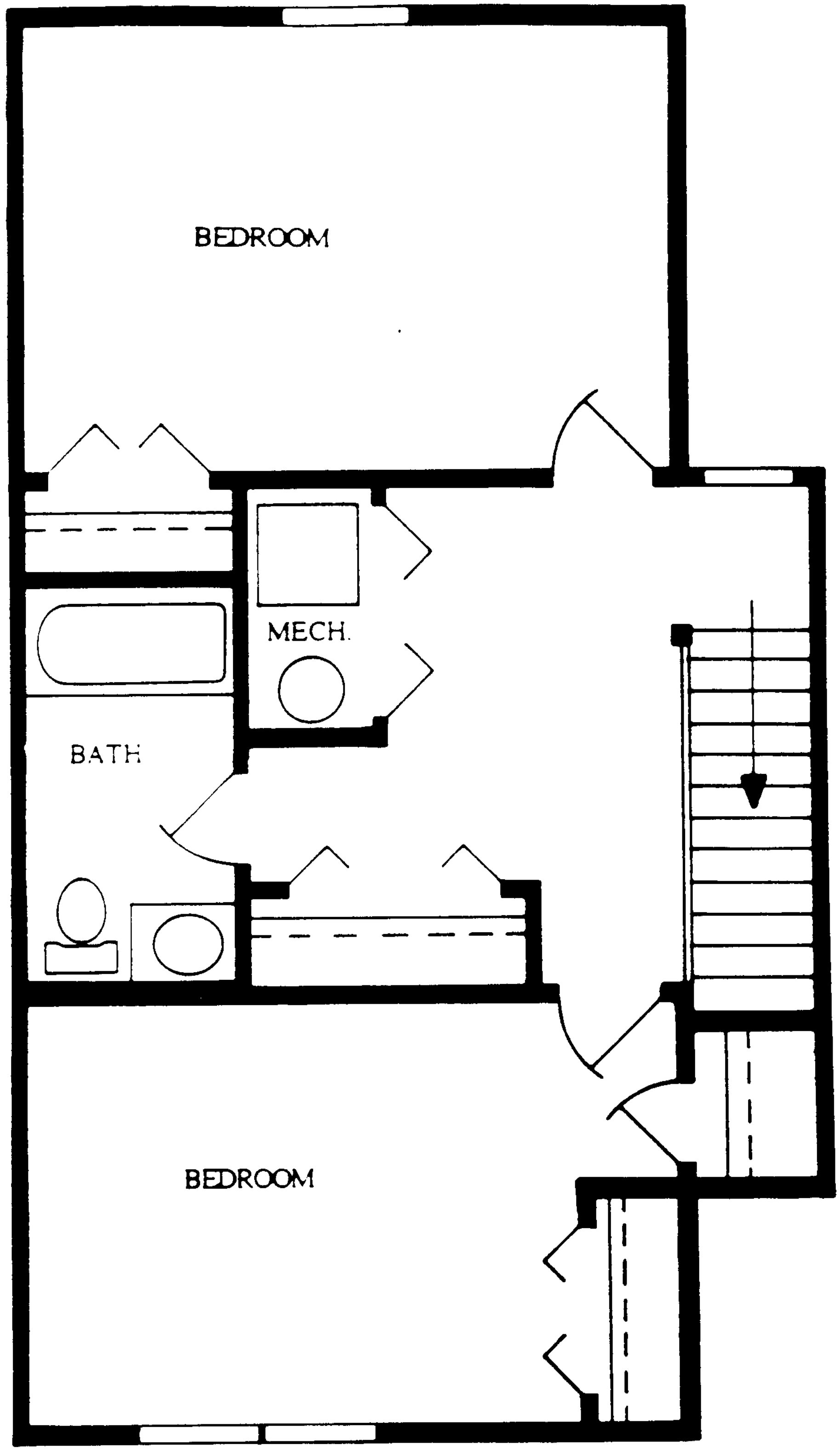
Appendix A: House Plans, Elevations, Details



FIRST FLOOR PLAN

DOVETAIL CONSTRUCTION, INC.
1302 Castlewood Dell
Louisville, Kentucky 40204 (502) 456-6641



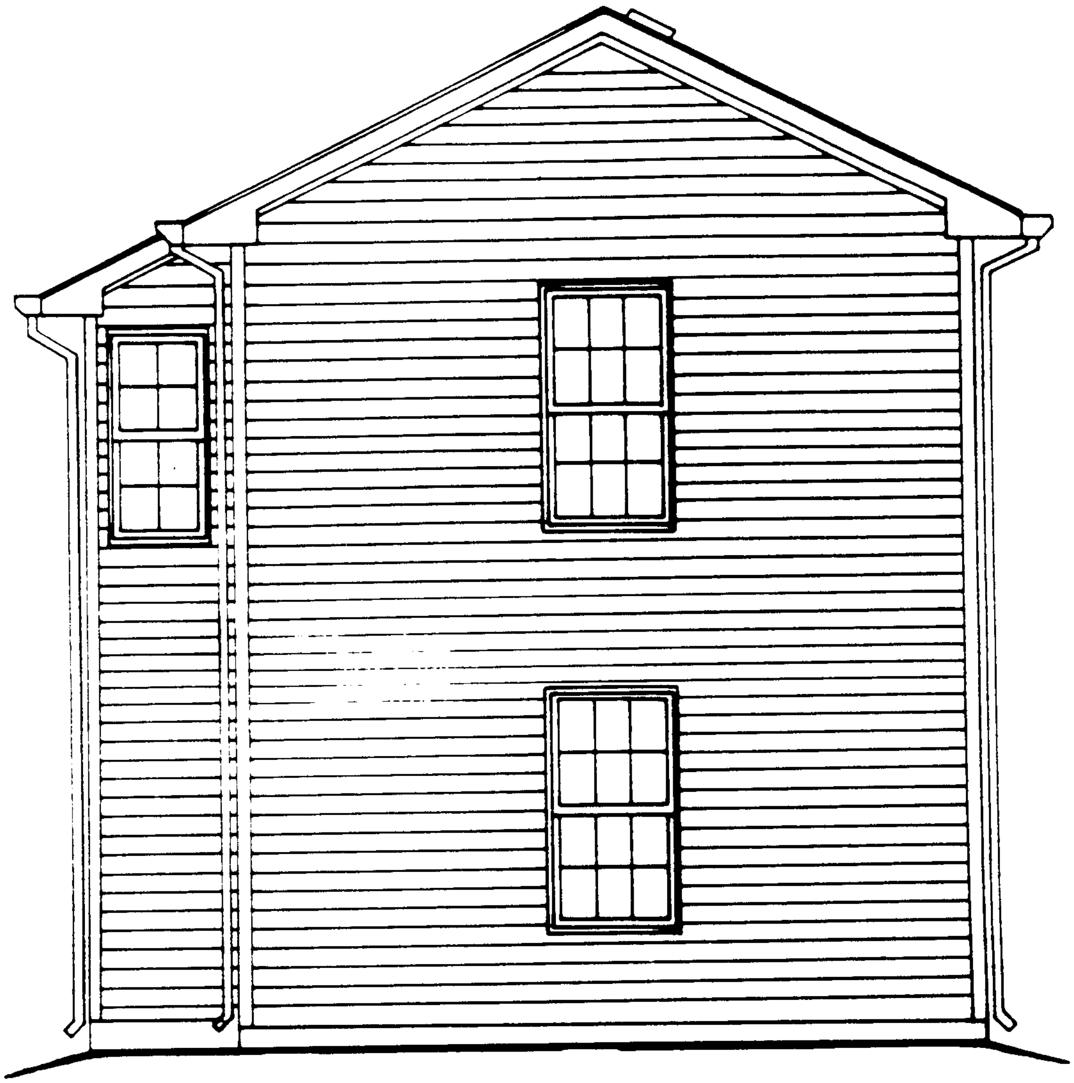
SECOND FLOOR PLAN

DOVETAIL CONSTRUCTION, INC.
1302 Castlewood Dell
Louisville, Kentucky 40204 (502) 456-6641

FRONT ELEVATION

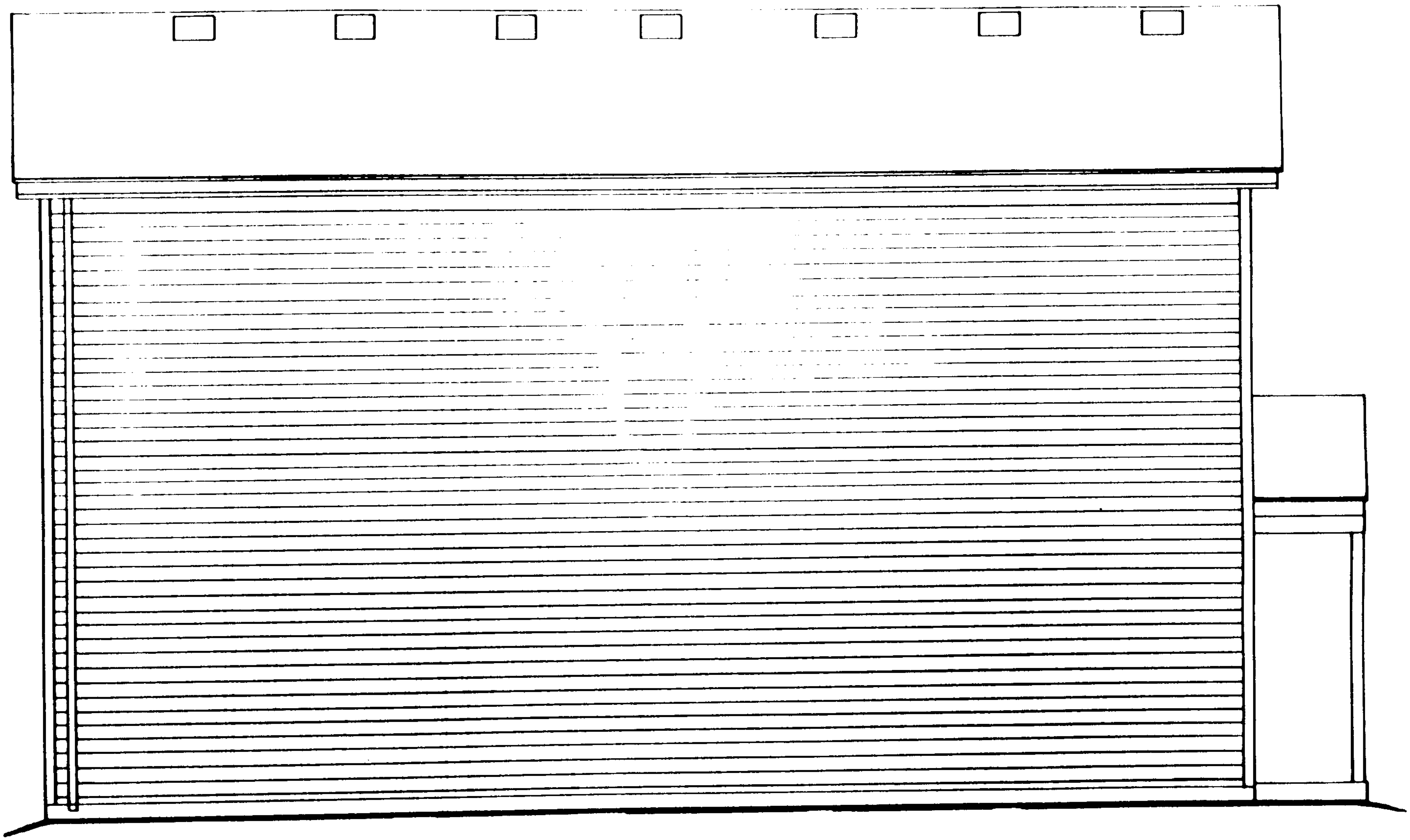
DOVETAIL CONSTRUCTION, INC.

1302 Castlewood Dell
Louisville, Kentucky 40204 (502) 456-6641



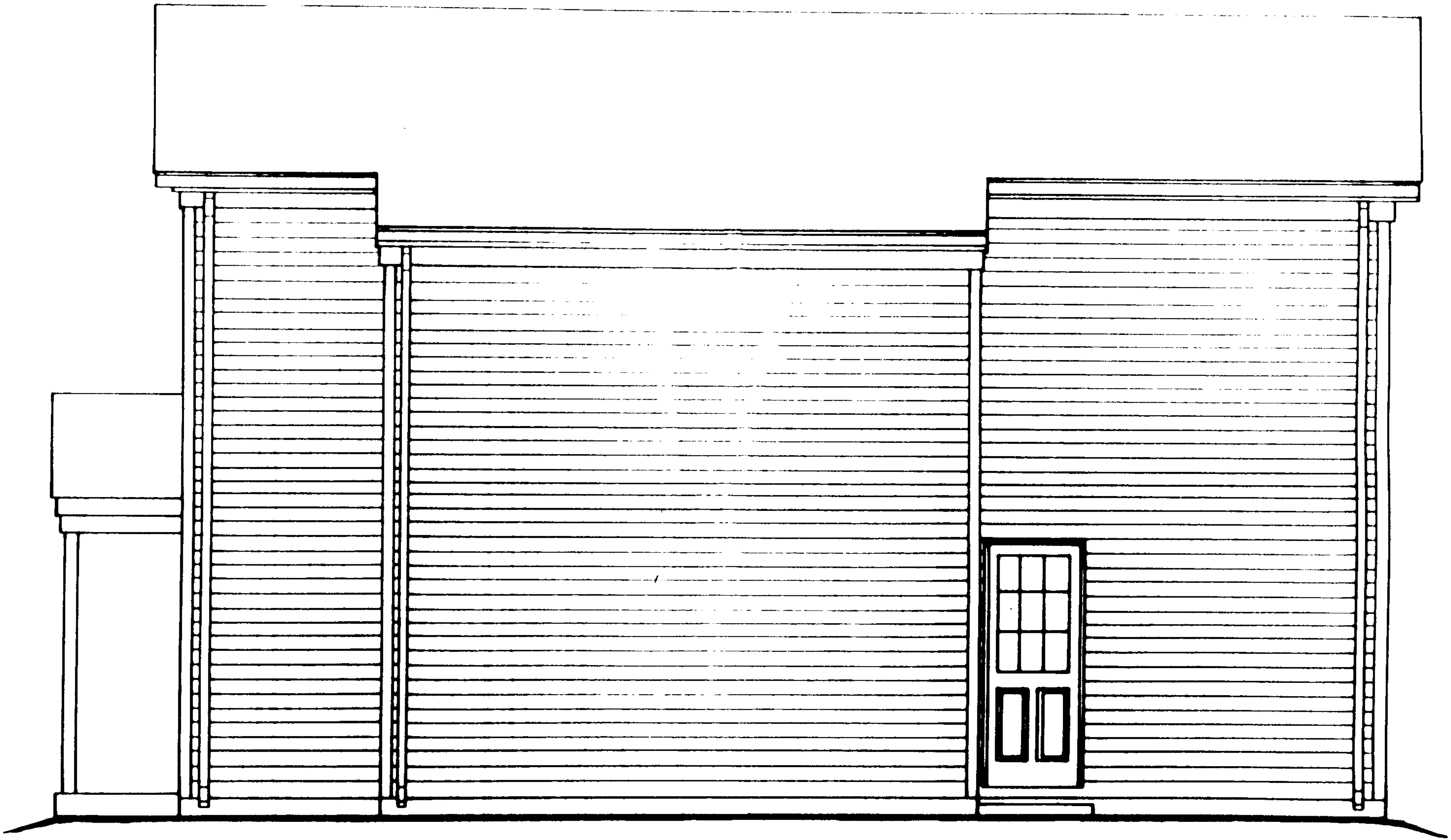
REAR ELEVATION

DOVETAIL CONSTRUCTION, INC.
1302 Castlewood Dell
Louisville, Kentucky 40204 (502) 456-6641



LEFT SIDE ELEVATION

DOVETAIL CONSTRUCTION, INC.
1302 Castlewood Dell
Louisville, Kentucky 40204 (502) 456-6641



RIGHT SIDE ELEVATION

A-6

DOVETAIL CONSTRUCTION, INC.
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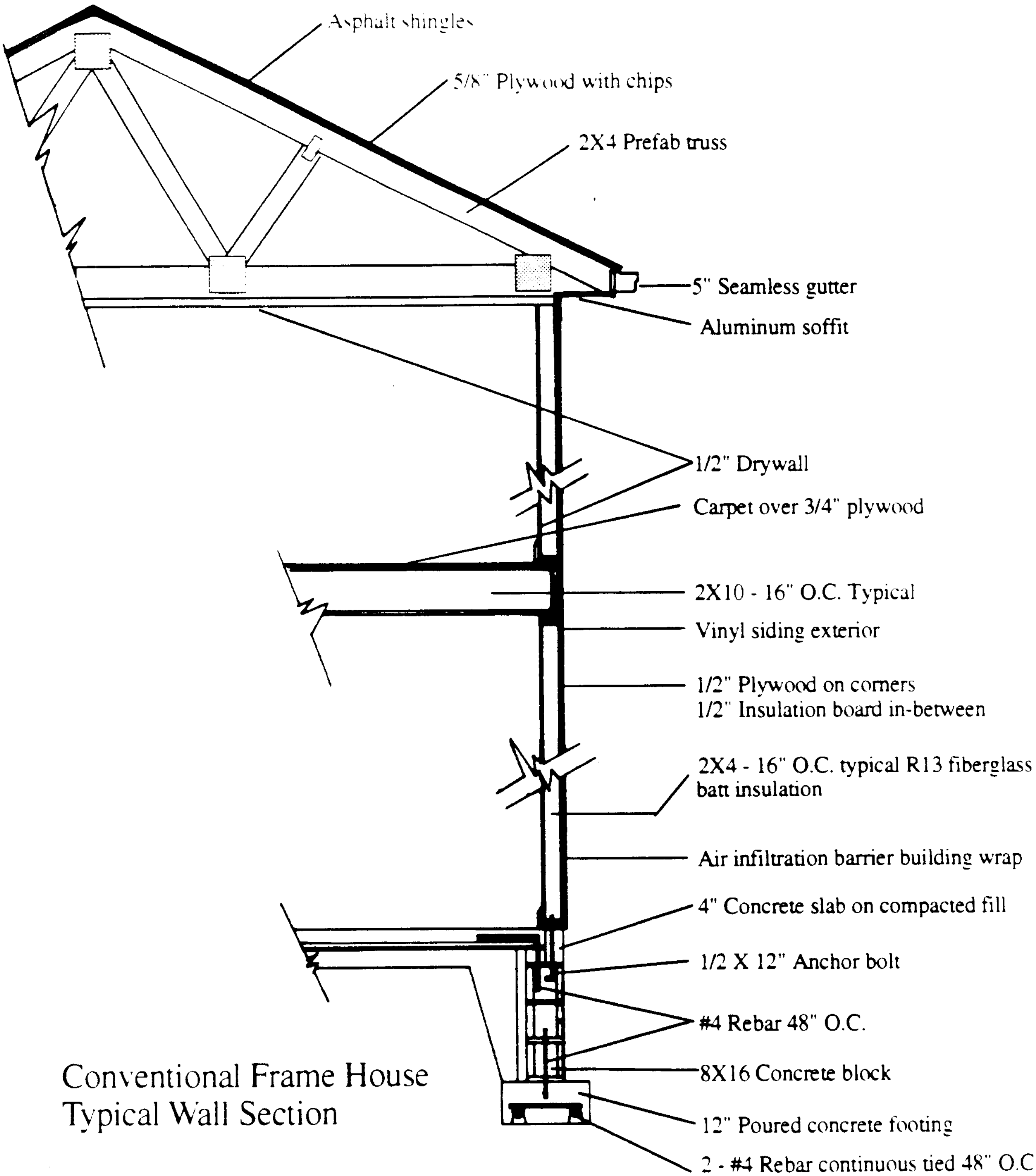
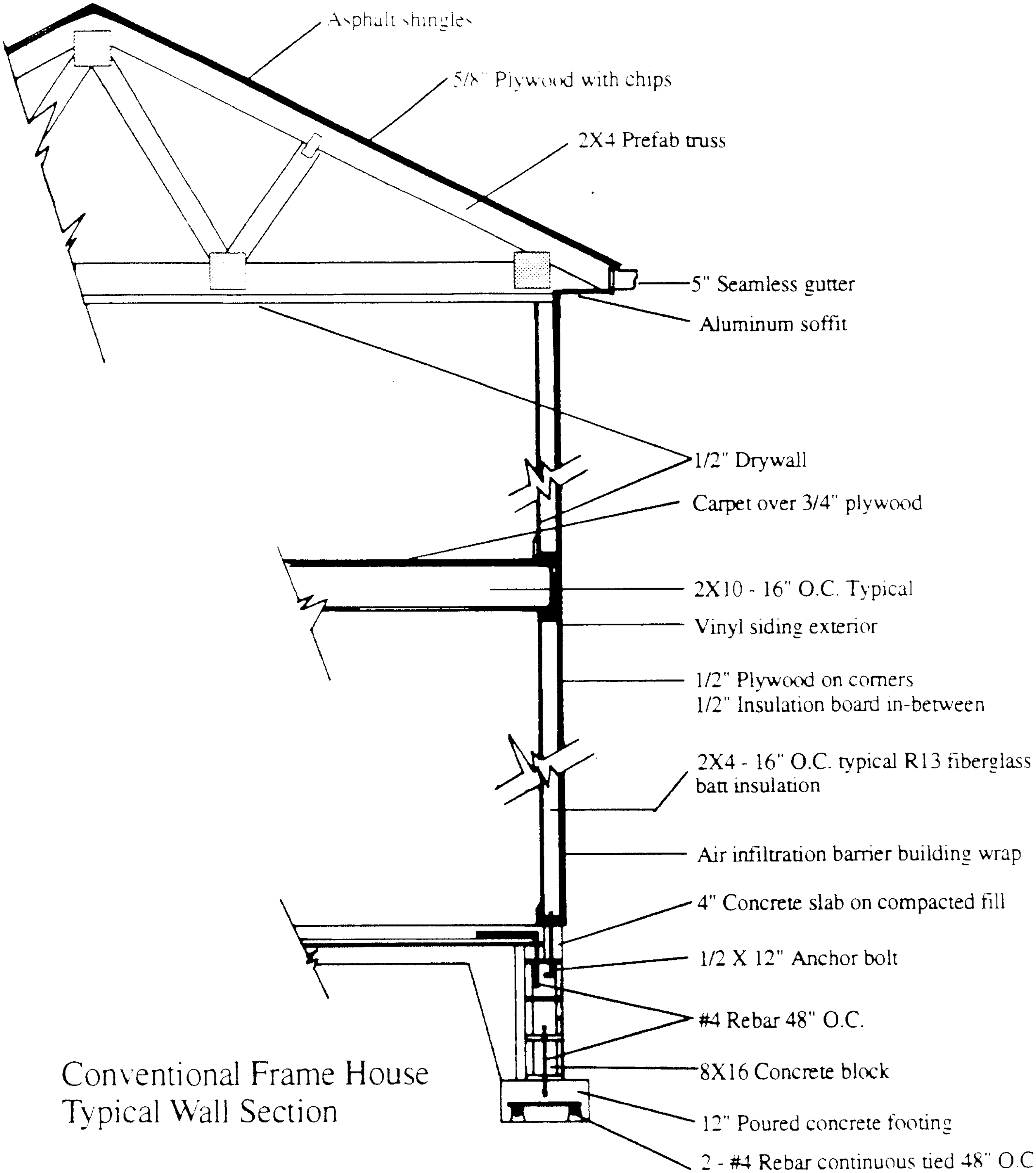


Conventional Frame House
Typical Wall Section



Conventional Frame House
Typical Wall Section