MANAGED BY UTBBATTELLE FOR THE U.S. DEPARTMENT OF ENERGY

Building 3147, Room 106
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6070
Phone: (865) 574-5207
24 h FAX: (865) 574-9338
E-mail: christianje@ornl.gov

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To: Bill Wachler
SIPA Director

From: T.W. Petrie and Jeff Christian

Subject: Heating and Blower Door Tests of the Rooms for the SIPA/Reiker Project

Introduction

The Structural Insulated Panel Association (SIPA) and Reiker, Inc sponsored an intense month of construction and test activities in the Large Scale Climate Simulator (LSCS) in the Buildings Technology Center. From January 15, 2002 through January 18, 2002 a test room from structural insulated panels (SIPs) was constructed in the LSCS. The heating and blower door tests that were conducted on it lasted until February 4, 2002. Comfort measurements were also done during this time. On February 4, 2002 the SIP test room was dismantled except for the floor. A test room of identical inside dimensions was then constructed with conventional wood framing techniques on the SIP floor. Construction continued through February 6, 2002. Heating and blower door tests were conducted on the wood-framed test room through February 12, 2002. The wood-framed test room was dismantled and all components, along with the floor, were removed from the LSCS on February 13, 2002.

This draft report summarizes the construction features of the two test rooms built by SIPA. The conditions under which the heating and blower door tests were done and the results of them are then presented and discussed. The results of the comfort measurements are reported separately except for data on the stratification of air temperatures during the heating tests.

Construction Features of the Test Rooms

Both the SIP and wood-framed test rooms sought to incorporate the major construction features of the envelope surrounding the living space of single story residences. These included a floor-to-exterior wall joint, an exterior wall-to-ceiling joint and four exterior wall corners. A window and an exterior door with required framing were also included. The crews that built the rooms were experienced in relevant construction techniques for the respective constructions.

SIP

The walls of the test room from SIPs were constructed from a sandwich of 3.5 in. of expanded polystyrene foam insulation between sheets of 0.5-in.-thick oriented strand board. The ceiling was constructed from a sandwich of 7.25 in. of expanded polystyrene foam insulation between sheets of 0.5-in.-thick oriented strand board. The floor was constructed from a sandwich of 3.5 in. of expanded polystyrene foam insulation between sheets of 0.5-in.-thick oriented strand board. The joints between SIPs at 90° were secured with long 6 in. screws. The joints between coplanar SIPs were secured with splines. A thick bead of adhesive was applied to joining surfaces before the joints between SIPs were made. The SIPs were constructed under the leadership of Charles Judd, Blue Heron Timberworks, a SIP contractor. He felt the SIP test house used best practices when the goal is airtight construction with mechanical ventilation an integral part of the whole house system design. Charles felt the SIP test room used more caulk, and sealant than is currently typical in the field. In part, this is because of the SIP construction crew uncertainty about just how tight to assemble the panels. The walls and ceiling of the SIP test room were finished on the inside with a layer of 0.5-in.-thick gypsum board. Joints in the gypsum board walls and ceiling, including the wall/ceiling joint, were taped and spackled one time with dry wall compound. No fabric air barrier was installed on the exterior of either the SIP, or the Stick test room.

Holes were routed out of the gypsum and SIPs for pairs of outlet boxes near the floor in all four walls. An extra wall outlet box was placed in the wall that had the door. The box was placed at switch height beside the door. A tenth outlet box was installed on the exterior wall to the left of the door. Foam sealant (Great Stuff) from a pressurized can was blown into each hole and the outlet boxes were set into the foam before it hardened. The same foam sealant was used around the rough openings in two walls for the window and door. No wiring chases were prerouted in the SIP panels used in this room as is done for construction with SIPs in the field. Since the wiring chase is normally bored through the foam core at the panel assembly factory, it was assumed by SIPA to not contribute to infiltration, wiring was also omitted in the SIP room except for one functional outlet.

An outlet box in the southeast corner contained a duplex receptacle. One of the two outlets in the receptacle accommodated the power cord for occasional use of a portable 1000 W radiant-type (no circulating fan) baseboard heater. The other outlet accommodated a power strip for occasional use by instruments in the room. Two lead wires went from the outlet box directly down through the floor into the conditioned room under the assembly. One was wired to the receptacle in the outlet box. The other was wired to a Reiker Room Conditioner unit. This remote controlled unit is a reversible ceiling fan and fluorescent light combined with four approximately 340 W electric resistance heaters and a blower. The control module, heaters and blower are located in the housing above the fan/light assembly. Control of all functions is accomplished with a battery-powered remote control that communicates with the control module.

2X6 Frame

The conventionally constructed room's walls and ceiling were framed with 2x6 dimensional lumber. Ceiling joists were 24 in. oc and 0.5-in.-thick gypsum board formed the ceiling. Wall studs were 16 in. oc with 0.5-in.-thick gypsum board on the interior and 0.5-in.-thick OSB on the exterior. It is recognized that 24 in. oc is the recommended DOE Building America Program method, but that outside government demonstration buildings most 2x6 frame construction is still found to be 16 in oc. Joints in the gypsum board walls and ceiling, including the wall/ceiling joint, were taped and spackled one time with dry wall compound. The floor that was constructed from structural insulated panels was reused for the wood-framed room. A layer of adhesive remained intact on the floor after the SIP walls were removed. The adhesive was soft and pliable and along with an additional continuous bead of caulk run under the bottom plate of all four walls, formed a seal between the sill plate of the wood-framed walls and the floor. The construction crew hired to build the 2x6 test room was given the discretion to assemble this test room in the same manner as they did in the field.

R-19 $h \cdot ft^2 \cdot °F$/ Btu kraft-paper-faced fiberglass batt insulation was placed between the wall studs and chinked into spaces around the window and door frames. To hold the insulation in each cavity in place, tabs on the kraft paper were stapled at the top of the cavities to the cavity side of the 2x6's. R-19 fiberglass batt insulation was placed between the 2x6 ceiling joists. R-11 fiberglass batt insulation was placed over the joists and perpendicular to them. Since no wind or rain effects were simulated during the tests, the R-11 batts were left uncovered.

Pairs of outlet boxes were placed near the floor in each stud wall and electric wire was run between each pair except for the pair in the wall with the door. The door separated that pair. The wire ran 18 inches from the floor inside the 2x6 wall through holes drilled approximately in the center of the studs. The wire was not pulled taut. In the wall with the door, an extra wall outlet box was placed at switch height beside the door. Electric wire was run between this box and the one near the floor and one stud space away. A tenth outlet box was installed on the exterior near the door. In all spaces, the insulation batts were compressed either in front or in back of the electric wiring. As in the SIP room, only the outlet box in the southeast corner of the wood-framed room was functional. The two lead wires for electricity were wired like they were for the SIP room, one to the duplex receptacle in the outlet box and the other to the Reiker Room Conditioner.

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The SIP room with outlet boxes sealed in foam did not need additional protection against infiltration. Blank cover plates were placed over the non-functional outlet boxes for tests with the wood-framed room. The blank covers were installed after measuring what felt like excessive air leakage from the as built series of 10 electric wiring outlet boxes. The effect of the cover plates on infiltration characteristics was measured during blower door tests of this room. In the infiltration tests in both rooms, the effect of the window was also determined. The door opening was used to mount the blower door in its adjustable enclosure. Hence the effect of the door itself on infiltration could not be measured. The coupling between the window/door and the opaque wall was captured in both sets of airtightness tests. We did attempt to determine the effect of the blower door enclosure on infiltration.

Windows and Doors

In each test room, the dimensions of the vinyl-clad wood frame of the double-hung window were 33.5 in. by 47.5 in. The window was installed in the north wall. Glazing consisted of two units each 27 in. by 20 in. The window’s National Fenestration Rating Council certified U-factor was 0.34 Btu/(h·ft^2·°F). In each test room, the fiberglass frame of the door was 36.25 in. by 82.5 in. The door was installed in the west wall. Glazing area of the hinged patio door was 24.5 in. by 66 in. The door’s National Fenestration Rating Council certified U-factor was 0.33 Btu/(h·ft^2·°F). The double-paned glazing in both units was high-performance, low-E and argon filled. The solar heat gain coefficient and visible light transmittance are not relevant parameters for tests inside the Large Scale Climate Simulator. The aluminum flange used to attach the window and door was caulked and mechanically fastened to the exterior sheathing on all 4 sides of the window and on jambs and the top of the door. No exterior air barrier layer was added to either of the test rooms.

Heating Systems

The inside floor dimensions of the test rooms were 10 ft 11 in. by 10 ft 11 in. Floor to ceiling height was 7 ft 6½ in., which was the maximum height that could be accommodated in the Large Scale Climate Simulator. The rooms could be described as well-insulated, add-on rooms. The baseboard heater was placed under the window on the floor. It contained a bimetallic thermostat that provided simple on/off control of the heater and yielded a ±2°F fluctuation of room air temperature about a steady average room air temperature. No scale was provided on the thermostat so desired temperature was achieved by trial-and-error. The Reiker Room Conditioner was hung from a mounting fixture in the center of the ceiling. Its remote control unit was placed at chest height on a stand about two feet away from the south wall directly across from the window. The controls for the Reiker Room Conditioner not only provided on/off functions for the fan, heater and light but also automatically modulated the four stages of heat. The Reiker Room Conditioner was capable of holding a steady temperature to ±0.6°F at 46 in. from the floor. The remote control featured a digital display of desired and actual room temperatures to the nearest 1°F.

Instrumentation

Four thermocouple measuring junctions were suspended at chest height (46 in. from the floor) in the corners of the room about two feet away from each wall. They measured the inside air temperatures (with desired temperature usually 70°F in the room) during the various tests. Four thermocouple measuring junctions were placed 3 in. away from the exterior walls at the height of the top of the window on three sides of the room to monitor the outside air temperatures (with desired test temperature usually 0°F outside the room). Temperature below the floor was held at 50°F throughout the tests and was monitored by an array of thermocouples in the air under the floor. The thermocouples are accurate to ±0.5°F. A watt transducer with 3 kilowatt capacity generated a record of power demand by the rooms. It is accurate to ±15 Watt. The watt transducer was located in the basement underneath the floor and was connected to the lead wires that served the room. Power loss through the #12 lead wires between the watt transducer and the room is estimated to be 2 Watt when 1000 Watt was being used by the baseboard heater.

Heating Tests

The advantage of testing in a climate simulator is the precise and reproducible control over imposed conditions. In order to compare the thermal performance characteristics of the two test rooms and the two methods of heating, separate tests needed to be run in each test room using heat from the Reiker Room Conditioner and the baseboard heater, respectively. Conditions were close to ASHRAE/ARI winter conditions for heating equipment performance rating: an outside air temperature of 0°F and an inside air temperature of 70°F. Basement or crawlspace temperatures are not part of the ASHRAE winter conditions. Here, an air temperature of 50°F was specified as typical of winter conditions in an unheated basement.

Table 1 shows the actual average conditions held in seven test periods each four hours long, four conducted in the SIP and three in the 2x6 frame. The seven periods were selected from a continuous record of air temperatures and watt transducer output during the course of the test program. The tests were monitored with an automated data acquisition system. Temperatures were written to a raw data file every 30 seconds and the watt transducer output was written to the file every 10 seconds. Table 1 was generated from one-minute averages of the raw data (averages of pairs of each temperature and sets of 6 watt transducer outputs) that were written to a spreadsheet for analysis.

Table 1. Steady-state power demand over four hour periods during the tests.

Heater Case (with Room)	Air Temperature			Heater Power	
	Inside	Outside	Below	Raw	Corrected[1]
Baseboard 1 (in SIP Room)	69.7°F	+0.4°F	49.9°F	768 W	780 W
Baseboard 2 (in SIP Room)	70.2°F	+0.6°F	49.9°F	746 W	755 W
Reiker 1 (in SIP Room)	69.0°F	-0.2°F	50.0°F	789 W	800 W
Reiker 2 (in SIP Room)	69.6°F	+0.5°F	49.8°F	815 W	826 W

Ratio Reiker/Baseboard (all combinations)					1.03, 1.06, 1.06, 1.09
Baseboard 3 (in Wood-Framed Room)	68.9°F	+0.3°F	49.9°F	820 W	850 W
Baseboard 4 (in Wood-Framed Room)	69.8°F	-0.7°F	50.0°F	834 W	840 W
Reiker 3 (in Wood-Framed Room)	68.0°F	-0.1°F	49.9°F	856 W	883 W
Ratio Reiker/Baseboard					1.04, 1.05

[1] Corrected to uniform 70°F inside, 0°F outside and 50°F below

Inside air temperatures, reported as the 4 hour average in Table 1,were measured at a height of 46 in. from the floor. The average at this height, the air temperatures outside and below the room and the raw heating power were obtained over the respective four hour periods by simply averaging the data that were reported at one minute intervals. Figures 1 and 2 show examples for the Reiker Room Conditioner in the SIP Room and the baseboard heater in the wood-framed room, respectively, of the time variations that are inherent to the inside temperature and raw power with the two methods of heating. The Reiker Room Conditioner clearly exhibits smaller fluctuations because its control method was more sophisticated than the one for the baseboard heater. The Reiker fan also generated considerably more air mixing within the test room space.

There is also a variation with height that is inherent to the inside temperature with the radiant-type baseboard heater. Figure 3 shows the significant stratification in air temperature from floor to ceiling with the baseboard heater and the complete absence of stratification with the Reiker Room Conditioner, in both the high speed fan and medium speed fan configurations for these tests. The average air temperature in the room with baseboard heating is 0.99 times the measured temperature at 46 in. above the floor. This small correction for inside temperature is included in the “Corrected Heater Power” data in the last column of Table 1.

In order to make cross comparisons it was necessary to adjust for the different vertical temperature stratification that resulted from each of the tests. The raw data was all adjusted to reflect inside uniform air temperature of 70 F. Heat loses through both the floor and walls were adjusted. The same floor was used in both rooms. Its air-to-air R-value was estimated to be 17.25 $h \cdot ft^2 \cdot °F/Btu$. Heat flow rate through the floor was calculated using this R-value and air temperatures 3 in. above and below the floor. For the baseboard-heated room, due to stratification, air temperature 3 in. above the floor was 0.914 times the measured temperature at 46 in. above the floor. Subtracting floor heat flow from raw heating power left heat flow through the walls, window, door and ceiling. An R-value was calculated for the room except for the floor using average air temperature in the room and outside air temperature. This is an experimentally determined value that averages out the effects of significantly different areas and R-values for the ceiling, walls, door, and window, as well as different infiltration rates.

The corrected power requirement for each case is shown in the last column of Table 1. The corrected power is for the following conditions: uniform inside air temperature of 70°F; outside air temperature of 0°F; and, air temperature below the floor of 50°F. Corrected heat flow rate through the floor was calculated using the floor’s R-value, floor area, 70°F above the floor and 50°F below the floor. Corrected heat flow rate through the rest of the room was calculated using the rest of the room’s R-value, its area, 70°F inside the room and 0°F outside the room. The sum is the corrected power requirement in Table 1.

Two conclusions can be made from Table 1. One conclusion is that the SIP had better thermal performance than the 2x6 wood-framed room. The average of the Baseboard 1 and Baseboard 2 corrected powers for the SIP room is 768 W. The average of Baseboard 3 and Baseboard 4 corrected powers for the wood-framed room is 845 W. The SIP room required 9.2% less power to heat. The other conclusion is obtained from the ratios of corrected power for the Reiker Room Conditioner and baseboard heating that are shown in Table 1. The Reiker Room Conditioner required 3% to 9% (average of 5%) more power to heat these rooms than did the radiant baseboard heater. One consequence of air movement by the fan in the Reiker Room Conditioner is that there is no stratification. The other is that the air movement increases the rate of heat transfer with the surfaces. Since Figure 3 shows that both the high fan speed and the medium fan speed eliminate stratification entirely, perhaps the fan speeds are higher than they need to be.

Blower Door Tests

Software controlled blower door tests were done on both the SIP and the wood-framed test rooms. The apparatus was a Model 3 Minneapolis Blower Door Fan with Automatic Pressure Test (APT) hardware controlled by Tectite Version 2.1.9.7 software. The door opening in each room was used for the vinyl and aluminum enclosure that adjusts to install the blower door fan in most door openings. Because of the very low flow rates of air leakage, tests were run with the blower-door frame installed normally and with the blower-door frame well taped to the frame of the door in each room. This was to test for the effect of the blower door enclosure.

The APT system allows up to 10 pressures to be programmed for a test. The software seeks each pressure in order of specification. When the fan speed had been adjusted to achieve each target pressure, we specified that 200 measurements of flow rate and room pressure be made and averaged. The software stored the averages and other test parameters in a file for later analysis. We input the data into a spreadsheet so we could combine results from more than one test at the same conditions.

For whole houses, the usual pressure range that is tested is a magnitude of 15 to 50 Pa below atmospheric pressure. We tested at slightly higher magnitudes for both the SIP room and the wood-framed rooms in order to get larger flow rates. We were not able to go below 35 Pa with the SIP room because it was so airtight. It is well known that flow rates through openings in building envelopes obey a power law relationship (2001 ASHRAE Handbook Fundamentals, Chapter 26):

$$Q = C(\Delta P)^n \qquad (1)$$

where,

Q	is the flow rate, cfm
C	is the flow coefficient, cfm at 1 Pa
ΔP	is the pressure difference, Pa
n	is the exponent, generally between 0.6 and 0.7 in building depressurization tests.

Equation 1 is a straight line on a log-log plot. The best fit (least squares) straight line from tests at the same conditions allows CFM_{50} to be specified for each test. CFM_{50} is the leakage at a depressurization of 50 Pa. This is an extreme pressure for infiltration because it corresponds to a wind speed of 20 miles per hour, but it usually is within or close to the pressures that were actually tested. It allows a comparison of leakage results at a common depressurization.

Table 2 lists CFM_{50} for all the configurations of the SIP and wood-framed rooms that were tested. Comparing the level of the leakage rates for the SIP and wood-framed rooms, the SIP room is much more air tight, 8-9 cfm. Taping the blower-door frame was essential for tests on the SIP room. It appears to be about half of the leakage. It was not as important to tape the blower-door frame for the wood-framed room because there appears to be scatter in results for it. With the blower-door frame taped and the window and outlets also taped, the leakage is 121 cfm. With the blower-door frame not taped but the windows and outlets taped, the leakage is less, 115 cfm, instead of more as was expected. Any insight to the effect of putting blank covers over the open outlet boxes is also lost in the scatter. No matter what things are done to seal components, the leakage in the wood frame test room remains at 115 to 125 cfm. The CFM_{50} for the SIP test room was almost 15 times less leaky than that measured in the wood-frame.

Table 2. Leakage rates at a pressure of 50 Pa from blower door tests on the SIP and wood-framed rooms.

Room from Structural Insulated Panels	CFM_{50}
Blower door frame normally installed; window uncovered	16
Blower door frame normally installed; window covered	15
Blower door frame well taped; window uncovered	9
Blower door frame well taped; window covered	8
Room with conventional wood framing	
Blower door frame normally installed; no blanks on outlets; window uncovered	130
Blower door frame normally installed; outlets covered; window uncovered	116
Blower door frame normally installed; outlets covered; window covered	115
Blower door frame well taped; blanks on outlets; window uncovered	126
Blower door frame well taped; outlets covered; window uncovered	125
Blower door frame well taped; outlets covered; window covered	121

A common use of results from blower door tests is to estimate leakage area for wind-driven infiltration. One of the estimates of leakage area that is often used is the Lawrence Berkeley Laboratory effective air leakage area (LBL ELA) at 4 Pa. It extrapolates the results of the blower door tests to estimate leakage rate at 4 Pa. A smooth crack (discharge coefficient of 1) is then assumed and a calculation is made of the area to allow the leakage at 4 Pa. Figure 4 is a log-log plot of results of whole house blower door tests on two wood-framed whole houses with floor area of 1094 ft^2 and the current results for the 119 ft^2 rooms with no tape over room components (but the blower door enclosure well-taped). The results are extrapolated to 4 Pa by the equations shown in the legend.

The leakage per unit floor area for the SIP room compared to the wood-framed room retains the relationship shown in Table 2 that showed that the SIP room is almost 10 times less leaky. Leakage per unit floor area for the wood-framed room is very similar to leakage per unit floor area for the whole houses. The leakier of the two houses was a so-called “blitz” house for a Habitat for Humanity building project. A blitz house is built very quickly to get a project started with enthusiasm and could be expected to be leakier than one more carefully built. The other house was built for a side-by-side comparison to a house with a different exterior wall construction method. It could be expected that construction for it was done carefully so as not to prejudice the comparison.

Even though the leakage per unit floor area for the wood-framed room is about the same as for the two whole houses, the slope of the leakage with pressure is steeper. The values of the exponent for the wood-framed room and for the SIP room are larger than the 0.6 to 0.7 range that is usually seen with whole houses and is seen for the two Habitat for Humanity houses. This indicates that the cracks in these rooms present a longer path for air leakage than cracks in whole houses. A sharp sudden crack has an exponent of 0.5. A long path for a leak, like through a porous medium, has an exponent of 1.0.

The importance of the slope is seen in Table 3, where the LBL ELA values for the four cases are listed. They are also divided by their respective floor areas and presented as leakage fractions. For wood-framed construction, in the units of in.^{2}/ft^2, a leakage fraction of 0.0003 is considered typical of tight construction. A leakage fraction of 0.0005 is considered typical of average construction. The larger exponent for the wood-framed room compared to the whole houses makes the leakage per unit floor area at 4 Pa for the wood-framed room fall below the values at 4 Pa for the whole houses. Leakage fraction also appears to be marginally smaller for the wood-framed room compared to the two houses. No results for SIP houses were available for comparison to the SIP room. By comparison to the wood-framed room, the SIP room is extraordinarily air tight. These results show that with care a very near air tight construction is possible with SIPs.

Table 3. LBL ELA and leakage fractions for two whole houses and the wood-framed and SIP rooms.

Building	LBL ELA (in^2)	Leakage Fraction (in^2/ft^2)
Habitat for Humanity Blitz House (1094 ft^2)	60	0.00038
Habitat for Humanity Project House (1094 ft^2)	49	0.00031
Wood-Framed Room (119 ft^2)	4.6	0.00027
Room from Structural Insulated Panels (119 ft^2)	0.40	0.00002

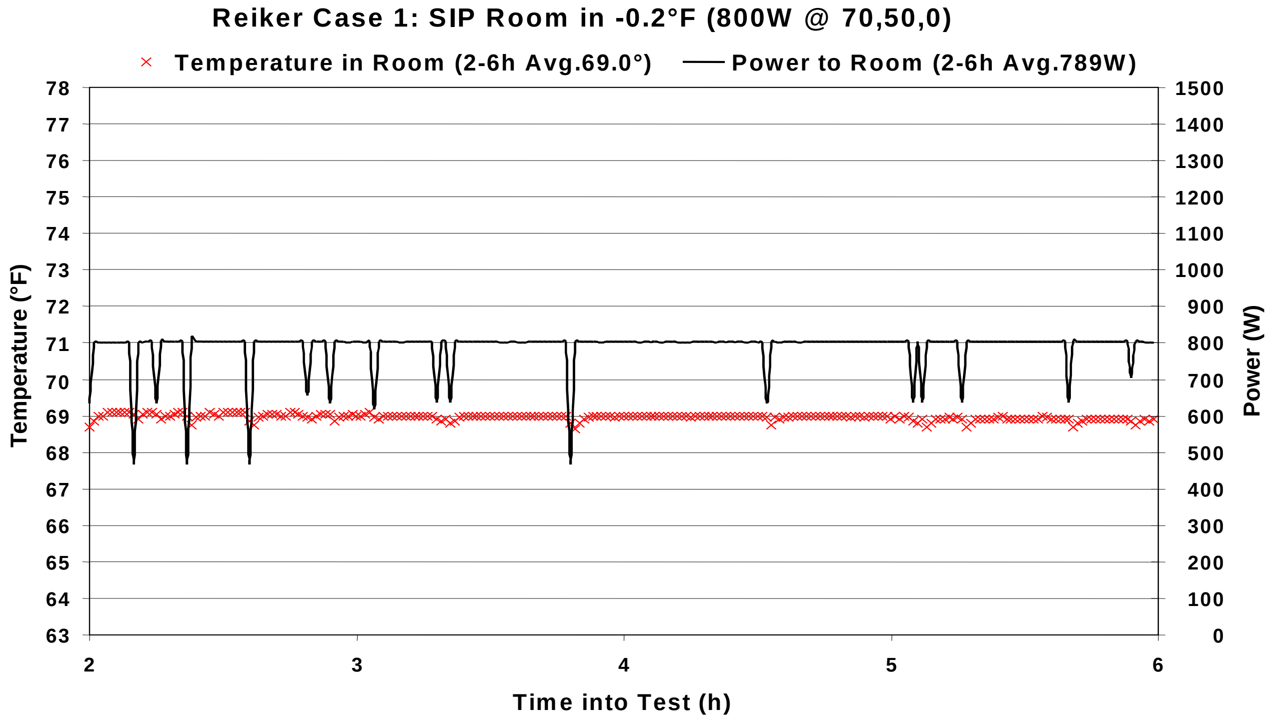

Figure 1. Example of Variation in Air Temperature and Heating Input Power for the Reiker Room Conditioner in the Room from Structural Insulated Panels.

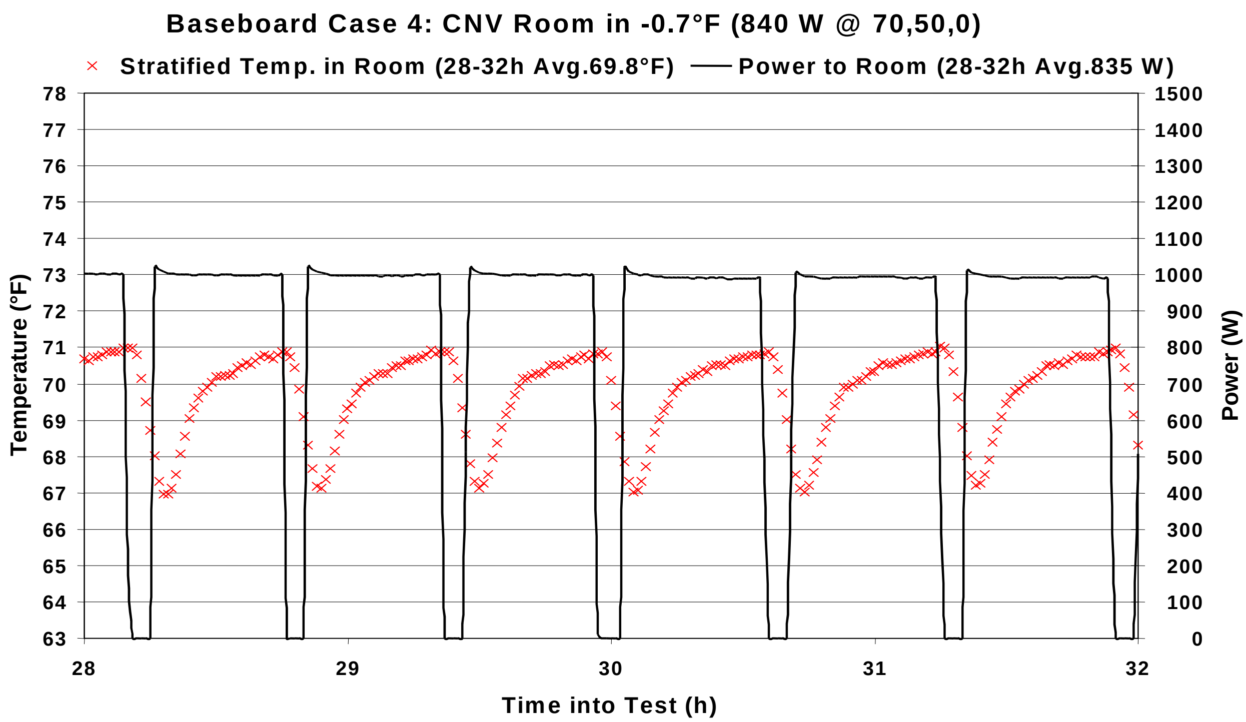

Figure 2. Example of Variation in Air Temperature and Heating Input Power for the Radiant Baseboard Heater in the Wood-Framed Room.

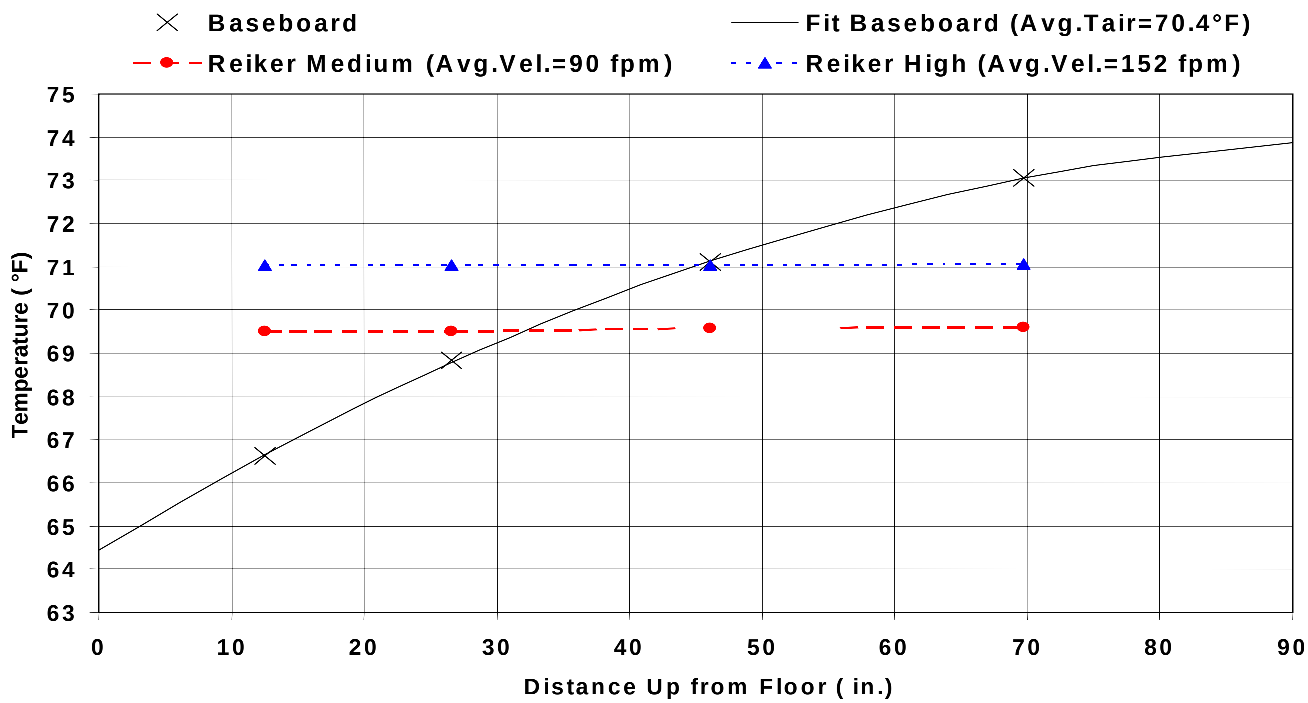

Figure 3. Stratification of Air Temperature from Floor to Ceiling of the Room from Structural Insulated Panels.

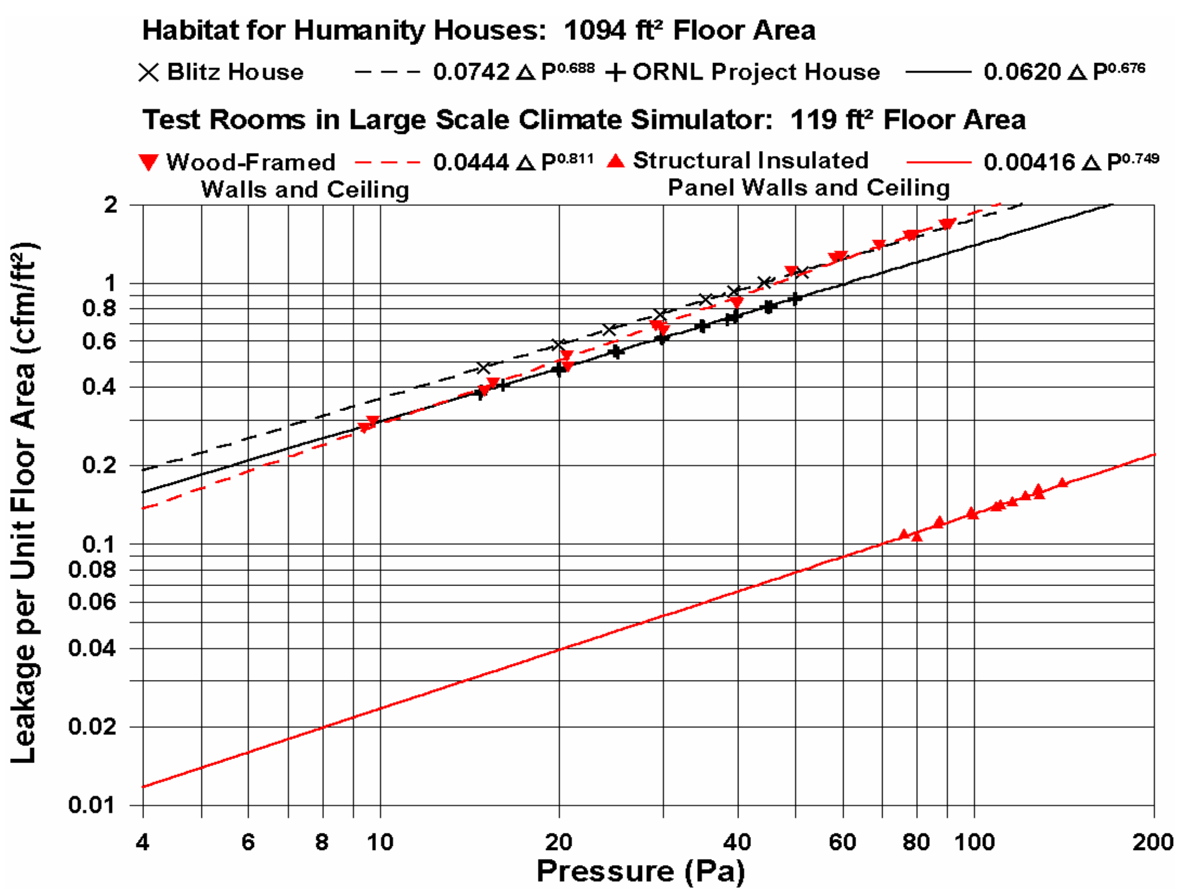

Figure 4. Blower Door Test Results for Whole Houses and the Test Rooms.