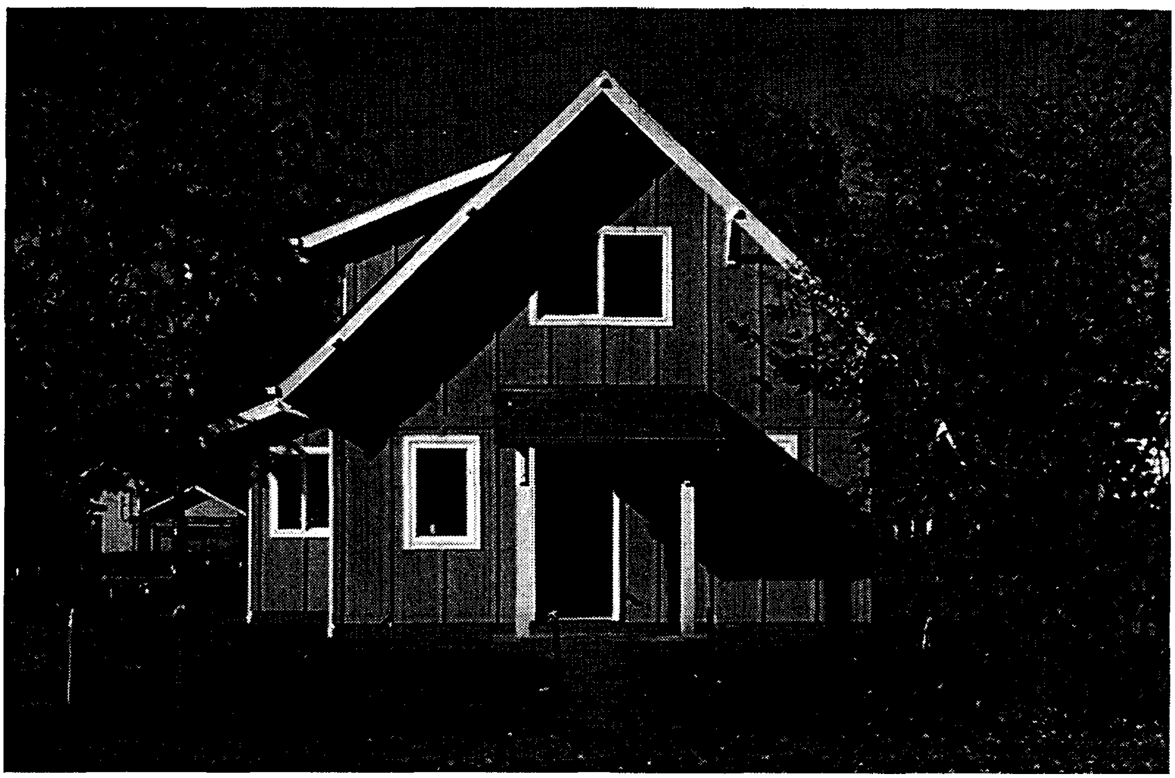
University Housing Thermal Testing Report



Center for Housing Innovation
University of Oregon

University Housing Thermal Testing Report

Energy Studies in Buildings Laboratory
Center for Housing Innovation
University of Oregon
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1.0 EXECUTIVE SUMMARY

The Energy Studies in Buildings Laboratory performed thermal diagnostic tests between November 1993 and January 1994 on six apartments in three duplexes utilizing panelized wall strategies. The objective of the testing was to assess the thermal performance of each of the six apartments and its respective panelized system. The panelized wall strategies included open panels, closed panels, and Stressed Skin Insulating Core (SSIC) panels. The building diagnostic tests included fan de-pressurization tests, smoke leakage testing, thermographic imaging, and coheating tests to determine overall thermal transmittance (UA). Short-term monitoring of the six units was performed for a period of 13 days to measure electrical consumption, comfort criteria, and weather data. Energy monitoring of three units is ongoing.

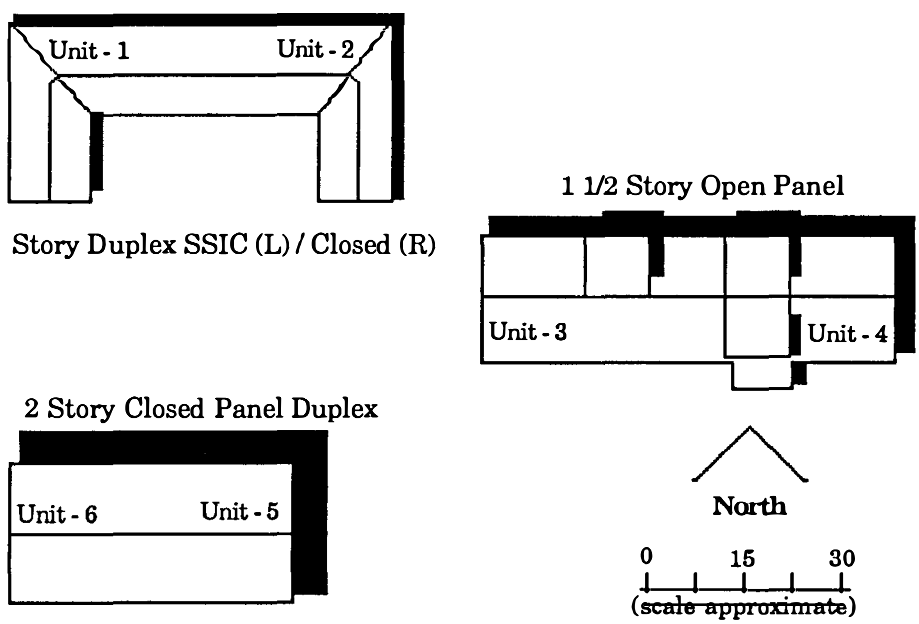

Figure 1-1.
Site Plan University Housing Units

The three duplexes were constructed in the fall of 1993 by the University of Oregon to provide student family housing. The duplexes were designed by the Center for Housing Innovation to investigate the architectural implications of the three panelized strategies of open panels, closed panels and SSIC panels. Open panels are shipped to the site sheathed on the exterior and with windows and siding installed. Insulation and the interior finish are installed on the site. Closed panels are shipped to the site with siding, sheathing, windows, insulation, vapor barriers, gypsum board and electrical chases installed. SSIC panels are shipped to the site as a sandwich of oriented strand board (OSB) on the interior and exterior with a core of expanded polystyrene (EPS); interior and exterior finishes are applied in the field. The six units of housing varied in size, configuration and orientation.

Results of the fan de-pressurization tests indicate that the 1 1/2 story open panel units were the least airtight followed by the 2 story closed panel units, the 1 story SSIC panel unit, and the 1 story closed panel unit, respectively. (See Figure 4-1 for a comparison of air changes per hour.) The average air changes per hour at 50 pascals (ACH_{50}) for the open panel units was 76% higher than the average ACH_{50} of the SSIC unit and the three closed panel units. In addition, the average specific leakage area (SLA) of the open panel units was 57% higher then the average SLA of the SSIC and Closed panel units (see Figure 4-3). Neither ACH_{50} or SLA measurements account for differences in design, such as the window crack length. To account for differences in design, the effective leakage area (ELA) was normalized to account for differences in window and door crack length as well as for differences in configuration. Normalized ELA results (see Figure 4-4 and Figure 4-5) support results of ACH_{50} and SLA indicating the open panel units were the least airtight.

Fan de-pressurization results suggest that a higher level of airtightness is more easily achieved in actual construction with closed panels and SSIC panels. However, because this study involved the use of three duplexes of different size and configuration further study must be performed to verify this conclusion. Despite normalization of results for configuration and design differences, the differences in airtightness may remain a reflection of differences in size and complexity of the units.

The results obtained by the thermographic imaging showed that Units 3 and 4 had the most significant problems with insulation in the walls and ceiling. Units 3 and 4 were constructed of open panel walls with insulation installed on site.

Both Units 1 and 2 had significant areas of missing or improperly installed insulation at the transition of vaulted insulation to flat roof insulation over the bathroom. This transition occurred within the overall roof envelope, so workers may have been more careless in installing this insulation. For the most part, thermal defects relating to missing or improperly installed insulation correspond to installation at the site whether in Units 1,2,3 or 4. These results suggest that a higher level of quality control is achievable in the factory when installing insulation. In addition, these results also suggest that roof panels with factory installed insulation would have resulted in fewer thermal defects in the overall envelope.

Coheating tests to establish an overall thermal transmittance value (UA) indicated the 2 story closed panel units had the lowest overall conductance, followed by the 1 story SSIC unit, the 1 story closed panel unit, and the 1 1/2 story open panel units respectively, (see Figure 4-10). When the coheating results were adjusted to account for heat loss due to infiltration and normalized by theoretical UA to account for differences in design, the 1 story SSIC unit, the 1 story closed panel unit, and the 1 1/2 story open panel units did not perform as well as predicted by theoretical UA values. The problems associated with insulation detected in the thermographic imaging may be the cause of the poorer performance of Units 1, 2, 3, and 4..

The results of short-term monitoring energy consumption indicate that the 2 story closed panel units consumed the least amount of energy as can be expected from coheating results. After the 2 story units, the 1 story closed panel unit consumed the least amount of energy followed by the west 1 1/2 story open panel unit, the 1 story SSIC unit, and the east 1 1/2 story open panel unit. The performance of Unit 3 is better than would be anticipated from coheating results. However, the short-term monitoring also measures effects of orientation to wind and sun, which is different from unit to unit.

Overall, the results of this study indicate that the units constructed of closed panels and SSIC panels were more airtight and had fewer thermal defects in wall insulation. These results suggest a link between airtightness and thermal integrity of insulation to panel type. In comparing the results of the six housing units, it is important to remember that the units are of different size, configuration and design and that the experience of the construction crews also differed. The building diagnostic tests and short-term monitoring measure the combined interaction of many building systems. Consequently, comparing the performance of one specific system is difficult. Despite efforts to normalize results for differences in design, uncertainty relating to the differences in design remains a factor.

2.0 INTRODUCTION

The University of Oregon constructed six units of student housing in three duplexes in Eugene, OR. utilizing three industrialized construction techniques: SSIC (Stressed Skin Insulating Core) panels, open panel wood frame construction, and closed panel wood frame construction. The duplexes infilled an existing residential neighborhood. The housing was designed by Don Corner at the Center for Housing Innovation at the University of Oregon. The housing units were constructed in the fall of 1993, and a series of building diagnostic tests and short-term monitoring were performed by the Energy Studies in Buildings Laboratory between November 1993 to January 1994.

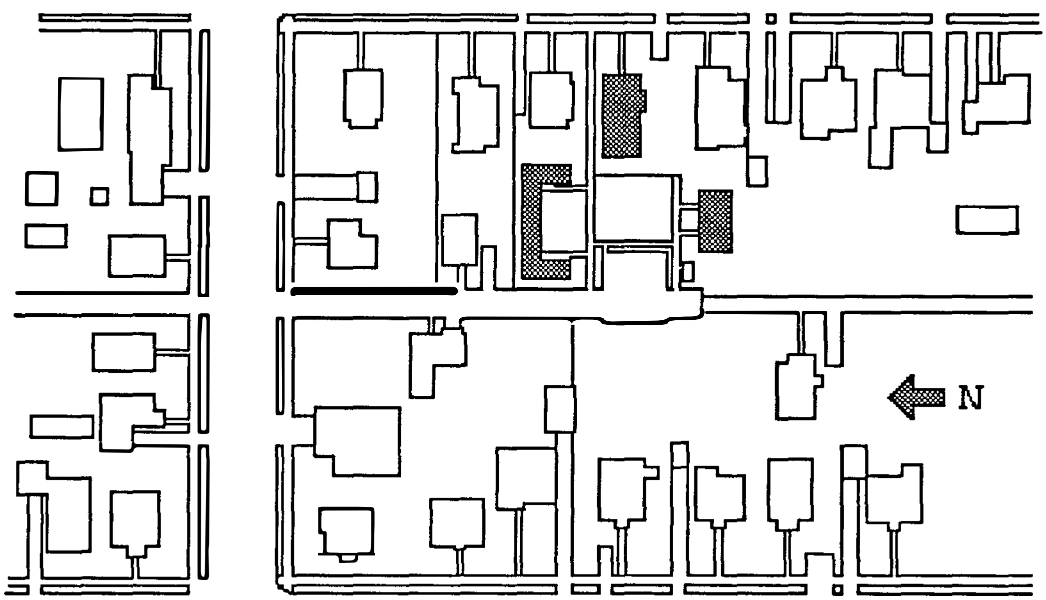

Figure 2-1
Neighborhood Plan

Unit	Construction	Floor Area	Surface Area	Volume	Crack Length of Doors and Windows
		(sq. ft.)	(sq. ft.)	(cu. ft.)	(ft)
1	1 story SSIC	674	2392	6086	146
2	1 story Closed Panel	674	2392	6086	146
3	1 1/2 story Open Panel	800	1965	5981	140
4	1 1/2 story Open Panel	868	2182	6424	188
5	2 story Closed Panel	713	1721	5552	185
6	2 story Closed Panel	713	1721	5552	185

Table 2-1
Geometric Comparison of Six Units

The building diagnostic tests included fan de-pressurization tests to determine airtightness, smoke leakage testing to identify areas of leakage, coheating tests to determine the building thermal transmittance value (UA), and thermographic imaging to identify areas of heat loss due to conductance and infiltration.

In addition to the series of building diagnostics, all the units underwent a 13 day period of short-term monitoring. Along with electrical meter readings, each unit was instrumented with sensors to measure the humidity, dry bulb temperature, and mean radiant temperature. A weather station was installed at the site on top of Unit 5 which collected data for ambient dry bulb temperature, relative humidity, mean radiant temperature, wind speed and direction and vertical and horizontal radiation.

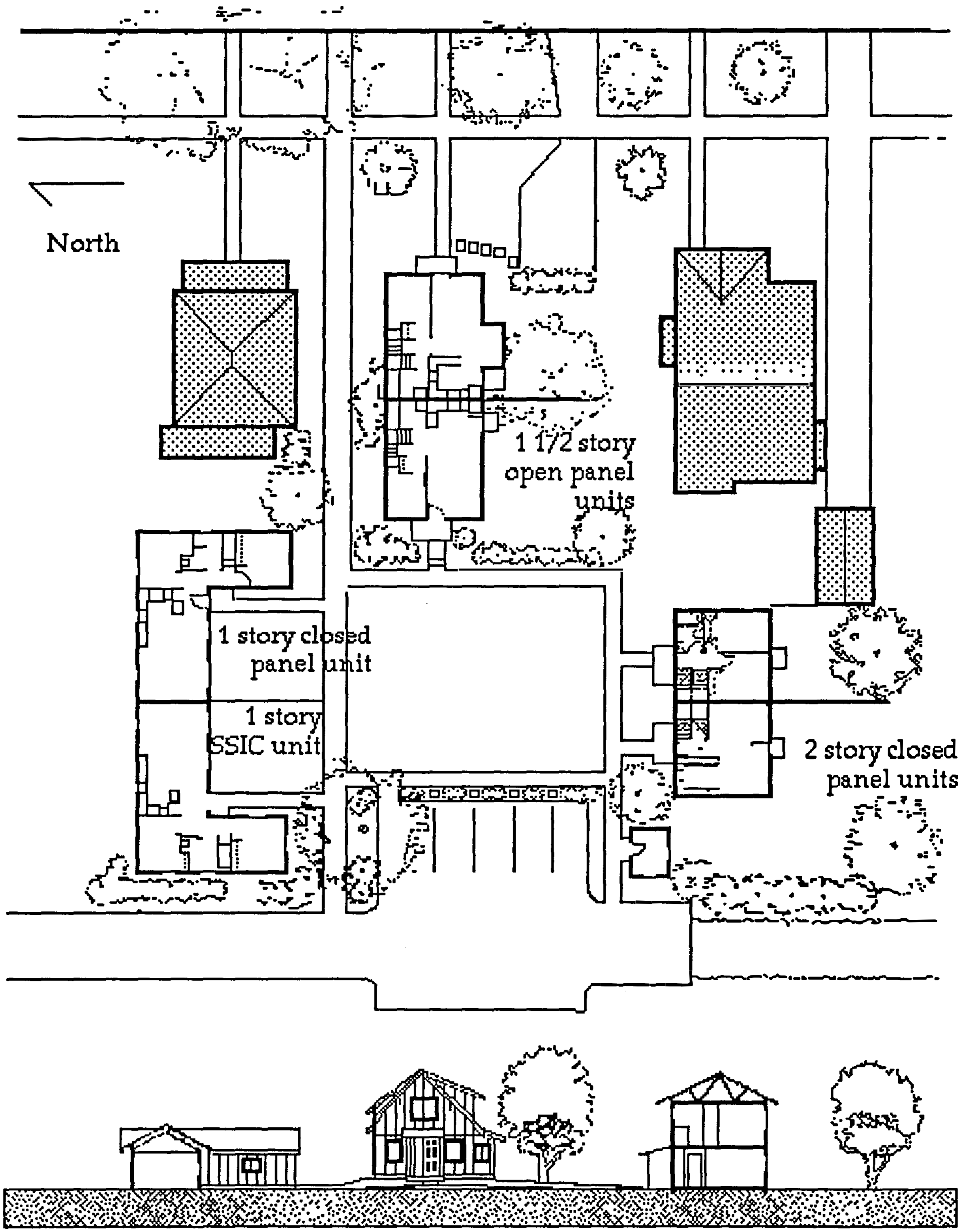

Figure 2-2
Site Plan and Section

Description of Units

The duplex units differ in size and configuration, as indicated in Figure 2.2 and Table 2-1. However, each unit has been designed to meet Bonneville Power Administration's Super Good Cents energy performance levels. All units feature R5 insulation under the slab, R15 insulation around the slab perimeter, R38 insulation in the vaulted ceiling and R49 insulation in the flat ceiling, vinyl U -.34 (R -2.94) low-e argon-filled windows, U-.19 (R5.26) doors, R4 insulation around the pipes, bimetallic controls for stack ventilation, and insulated headers. Each unit does differ in the ratio of window aperture to floor area and the amount of thermal mass. In addition, the manufactured walls all have an insulation value of R26 except for the 1 story SSIC unit which has an insulation value of R23. Heat is provided through electric resistance baseboard heaters.

		Insulation R Value			
Unit	Construction	Wall	Slab on Grade	Slab Perimeter	Roof
1	1 story SSIC	23	R5 under 4"concrete slab	R15	R38 Vaulted / R49 Flat
2	1 story Closed Panel	26	R5 under 4"concrete slab	R15	R38 Vaulted / R49 Flat
3	1 1/2 story Open Panel	26	R5 under 4"concrete slab	R15	R38 Vaulted / R49 Flat
4	1 1/2 story Open Panel	26	R5 under 4"concrete slab	R15	R38 Vaulted / R49 Flat
5	2 story Closed Panel	26	R5 under 4"concrete slab	R15	R49 Flat
6	2 story Closed Panel	26	R5 under 4"concrete slab	R15	R49 Flat

Table 2-2
Component R Values

Unit Construction

Unit 1

Unit 1 is the west unit of the 1 story duplex. The construction of Unit 1 features SSIC wall panels with R23 insulation. The SSIC panels included an interior and exterior skin of oriented strand board (OSB). Wiring chases were predrilled in the factory. Exterior siding and 15# asphalt felt were installed on site. Gypsum wall board was also installed on site. In addition, the interior was finished with a layer of vapor barrier paint. The roof, a 6:12 pitch, is primarily formed of manufactured parallel chord trusses with R38 batt insulation. The roof area over the bathroom and hallway, 24% of the total roof area, was constructed as a flat roof with R49 insulation. R49 batt insulation was lapped from the flat roof to the vaulted roof. The slab-on-grade foundation is 4" of concrete over 2" of sand resting on R5 extruded polystyrene and a 6 mil vapor barrier above a sub grade of 4" of minus 3/4" crushed gravel. At the slab's edge, R15 extruded polystyrene insulates the slab to its depth of 28 inches. At the bottom of the slab edge, the extruded polystyrene is turned outward at a right angle from the slab for 4 inches. In addition, the party wall between Unit 1 and Unit 2 is constructed of an 8" thick, grout-filled concrete masonry unit (CMU) to a height of 8 feet. The party wall is traditionally framed above the CMU.

Unit 2

Unit 2 is the east unit of the 1 story duplex and is identical in size and configuration to Unit 1. However, the walls are constructed of manufactured closed panels with R26 insulation instead of SSIC panels with R23 insulation. The closed panel walls are composed of an exterior skin of 5/8" T-11 siding with 1"x 2" battens at 24" o.c., 5/8" celotex blackcore polyisocyanurate foil face, 15# asphalt felt 2x6 stud framing at 24" o.c., with high-density fiberglass batt insulation, 5/8" gypsum board applied in the factory and a vapor barrier paint. The closed panel units also featured a gasket similar to a sill barrier at the panel-to-panel joints; however, often these "gaskets" were removed to facilitate connection of panels. The wire chases are predrilled in the factory. The roof insulation and foundation construction are identical to Unit 1.

Unit 3

Unit 3 is the west unit of the 1 1/2 story duplex. The walls consist of manufactured open panels. The open panels are identical in construction to the closed panels. However, all the wiring, installation of high-density batt insulation, and hanging of gypsum board is performed in the field. The foundation is of the same construction as for Units 1 and 2. The roof is formed of manufactured trusses with panelized dormer panels framed and sheathed in the factory. Unit 3 also has a combination of vaulted R 38 roof insulation (42%) and flat R 49 roof insulation (58%). The second floor is formed by the bottom chord of the manufactured trusses and 2 x 8 framing at 24" o.c. under the dormers. The truss system is secured to the top of the open panels as in platform construction. Unit 3 also has two doors instead of one as in Units 1 and 2.

Unit 4

Unit 4 is the east unit of the 1 1/2 story open panel duplex. Unit 4 is identical in construction to Unit 3. However, Unit 3 differs in geometry and size due to the addition of a south facing bay which acts as a breakfast nook. The breakfast nook increases the amount of surface area and window area as compared to Unit 3.

Units 5 and 6

Units 5 and 6 are identical in construction and geometry. Unit 5 is the east side of the duplex and Unit 6 is the west. The walls are manufactured closed panels identical to the closed panels of Unit 2. The foundations are also identical in construction as all the other units. The roof is constructed of manufactured trusses, and the insulation is entirely of R49 batt insulation for flat roof construction. The second floor is constructed of prefabricated floor cassettes which act as a platform for the second floor walls. Units 5 and 6 share an 8-inch, grout-filled CMU party wall on the ground floor for thermal mass. The party wall on the second floor is traditionally framed.

Ventilation Devices

All six units have features to allow ventilation. These features include user controlled slotted vents in designated windows, referred to as BPA vents. Ventilation is also provided through ceiling vents operated by bimetallic controls for stack ventilation and bathroom vents operated by timers. All of the ceiling vents, BPA vents and bathroom vents were closed and taped for fan depressurization and coheating tests.

Field Construction

As in all construction, field work always presents unforeseen variables. These variables include changes in construction crews and changes to wiring. Erection of the manufactured panels in the field was not performed by the same construction crew. The closed panels were erected by the general contractor supervised by a representative of the panel manufacturer, whereas the open panels were erected by a crew from the panel manufacture and supervised by the general contractor. Erection of the different panel systems by crews of varying experience adds another variable in the comparison of panel performance. In addition, the gypsum board on some closed panels had to be removed to make field modifications. Furthermore, one SSIC panel was not delivered and was replaced with traditional framing. These variables must be considered when comparing the performance of the panel systems.

3.0 METHODOLOGY

A series of building diagnostics and building monitoring tests was performed to establish the energy and comfort performance of the six units. The objective of the testing was to assess the thermal performance of each of the six apartments and its respective panelized system.

Properties of air infiltration and thermal transmittance were established for each of the six units with testing in two different modes: with the passive vents covered and uncovered. The results in this report correspond to taped conditions in order to provide a more direct assessment of the performance of the building construction.

In addition, the units were instrumented to measure total electrical consumption and electrical consumption for space heating. Comfort criteria were measured with ambient air temperature probes, mean radiant temperature probes, and a relative humidity meter. In order to correctly predict the thermal performance, a weather station was installed on top of Unit 5, measuring the ambient weather condition at the site.

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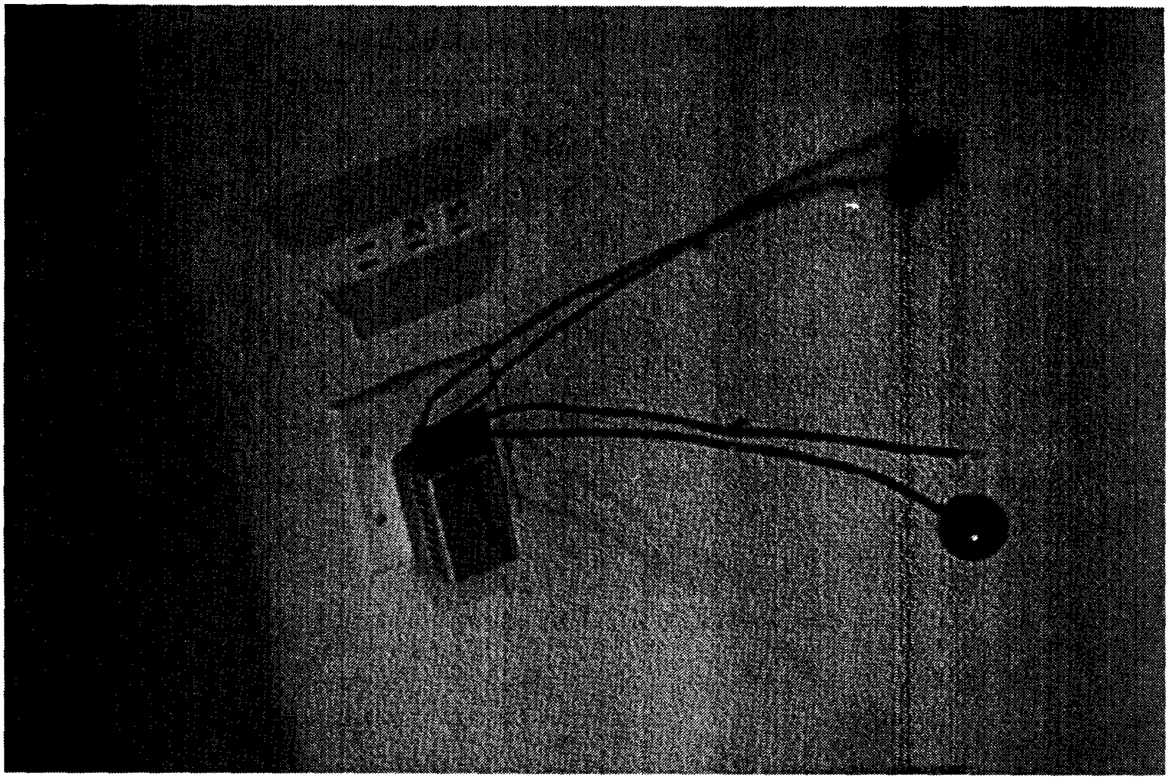


Figure 3-1
Photograph of Ambient Temperature, MRT and RH Instrumentation

3.1 AIR INFILTRATION

Fan De-Pressurization Testing

Infiltration testing was performed by fan de-pressurization (Blower Door Testing). A Minneapolis Blower Door Model 3 was used to obtain airflow rates at negative house pressure differentials. A log- log plot of multipoint test data was created, and a line of best fit was drawn. From the line of best fit data, the airflow rate at 50 pascals, CFM_{50} and the airflow rate at 4 pascals, CFM_4, were determined to establish air changes per hour at 50 pascals (ACH_{50}) and effective leakage area (ELA). In order to provide a more direct comparison of the performance of the panel systems, the effective leakage areas were normalized to account for differences in building geometries and design.

Smoke Testing

In addition to fan pressurization tests, air leakage was visually inspected by smoke testing. Smoke tests were performed by pressurizing the house to +20 Pa relative to the outside pressure using the fan pressurization equipment. Leakage paths were then established using a titanium tetrachloride smoke pencil. Major and minor leakage areas of infiltration were noted based on visual examination of the speed and quantity of escaping smoke.

3.2 THERMAL TRANSMITTANCE (UA)

Thermographic Imaging

Thermal insulation quality and air leakage pathways were evaluated using the Inframetrics 600L IR system. The model 600L IR does real-time analysis of static or dynamic thermal patterns. The scanner includes an electronic control module which can be used to interface with the scanner to adjust variables such as surface emittance. The system features an infrared camera with closed circuit cooling, a VCR and a 4" color monitor. One thorough scan of the thermal envelope was performed from the inside for each unit. The scans were done with the house in a thermally undisturbed state, i.e., the heating system had been at the same setpoint for at least 24 hours and the house was operated normally. The resulting images for all the units were recorded on 3.5 hours of videotape for later analysis.

Coheating Tests

Overall thermal transmittance (UA) was determined for each unit with a coheating test. The test uses five electrical resistance heaters controlled and monitored by a CR 21X data logger and IBM 386 to maintain the house at a constant temperature for a period of 24 hours. Electrical energy consumption is monitored using infrared optical meter sensors for the duration of the test.

The units were divided into five thermal zones, each controlled by a copper-constantan thermocouple. These thermocouples were connected to the CR-21X and IBM 386 which in turn controlled a relay that switched the heaters on or off depending upon whether the temperature in the zone drifted below or above the control point of 75°F. Interior temperatures at five locations as well as the ambient outdoor air temperature were monitored constantly. The monitoring was done for a period of 24 hours, but the data for analysis was taken from 3:00 am to 5:30 am. Data was recorded every 6 seconds and then either averaged or totaled for 6-minute intervals.

The coheating data was also normalized to account for differences in building geometry and design. The contribution due to infiltration, estimated using fan pressurization results, was deducted from the total UA. Next, theoretical UA values were calculated using ASHRAE Fundamentals. The resultant UA was divided by the theoretical UA values to normalize the data.

3.3 SHORT-TERM MONITORING

Energy consumption was monitored for a 13-day period between December 20, 1993, and January 2, 1994, while the units were unoccupied. Data was collected on site with two sets of the following data acquisition equipment: A Campbell Scientific CR10 datalogger, an AM416 Relay Multiplexer, and a SDM-SW8A Switch Closure Input Module. A rechargeable battery pack was also included to provide power in the case of an electrical power failure. One datalogger was dedicated to Units 1-3, and the second datalogger was dedicated to Units 4-6. Table 3-1 describes the measurements, sensor type and sensor location for all six units. A channel schedule for the instrumentation is provided in Appendix A.2. The CR10's were programmed and accessed using an IBM 386. Data was downloaded from the Energy Studies in Buildings Laboratory using the IBM PC via a Campbell Scientific DC 112 Modem. Dedicated phone lines were ordered from the local carrier to ensure data transfer. Figure 3-2 describes the data acquisition system.

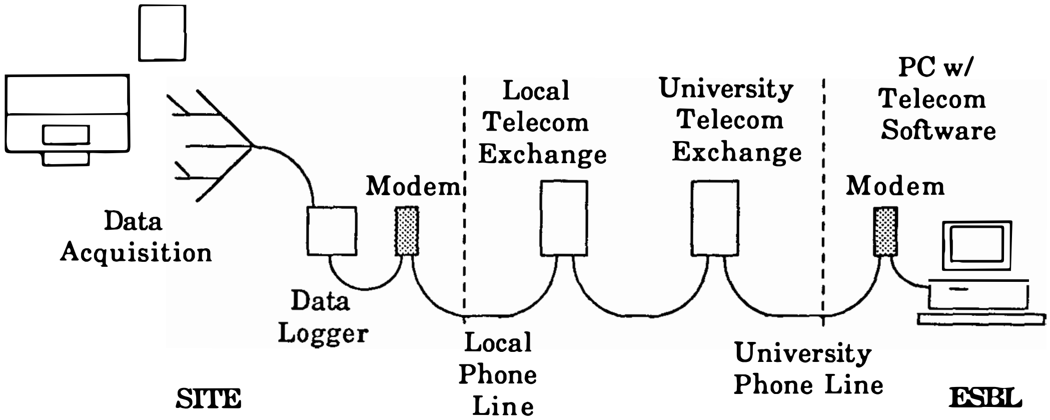


Figure 3-2
Data Acquisition

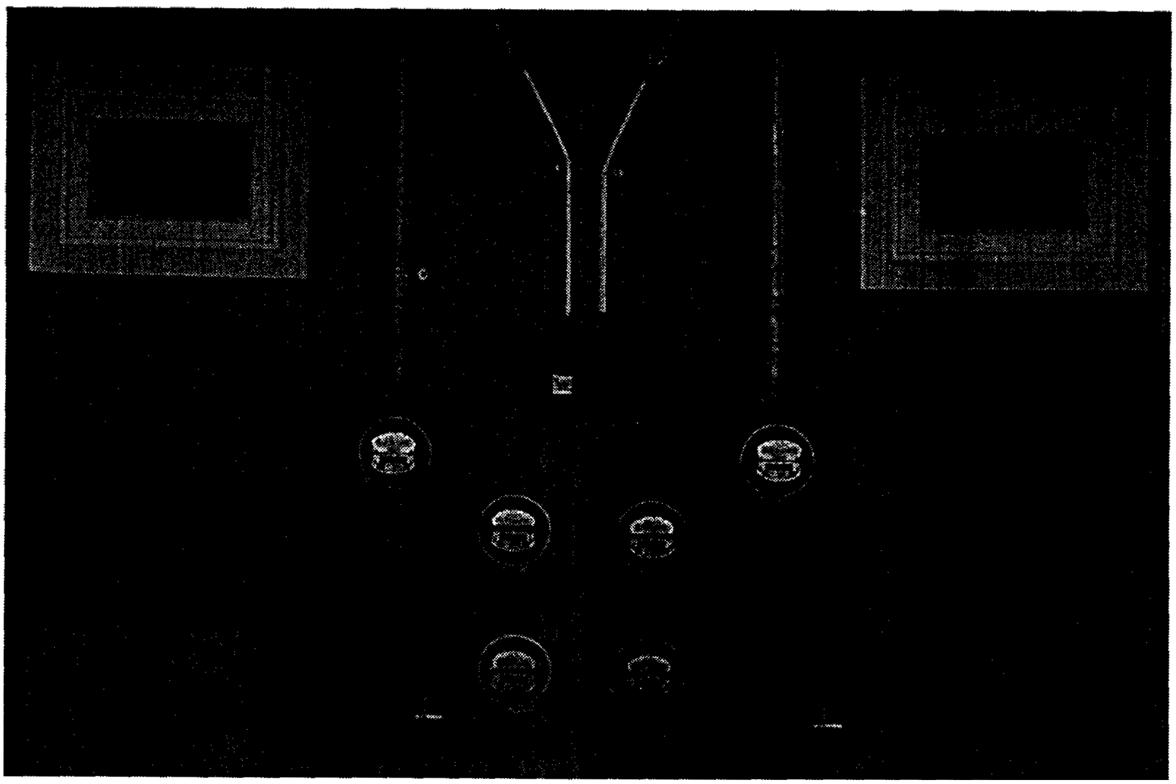


Figure 3-3
Dedicated KW-hr Meters for Total Energy Consumption and Hot Water Heating

No.	Measurement Type	Number & Location	Sensor Type
Unit 1	Air temperature	ONE, located 1'0" below vaulted ceiling in living room	T thermocouple
	M.R.T	ONE, located 1'0" below vaulted ceiling in living room	T thermocouple
	Relative humidity	ONE, located 1'0" below vaulted ceiling in living room	Bulk polymer resist
	Wall surface temp	ONE, located 4'0" above the floor on the south wall of south bedrm	T thermocouple
	Electric energy use†	TWO, one for total electric load of the unit and the other for space heating	Infrared sensor
Unit 2	Air temperature	ONE, located 1'0" below vaulted celing in living room	T thermocouple
	M.R.T	ONE, located 1'0" below vaulted ceiling in living room	T thermocouple
	Relative humidity	ONE, located 1'0" below vaulted ceiling in living room	Bulk polymer resist
	Wall surface temp	ONE, located 4'0" above the floor on the south wall of south bedrm	T thermocouple
	Electric energy use†	TWO, one for total electric load of the unit and the other for space heating	Infrared sensor
Unit 3	Air temperature	TWO, one located 1'0" below ceiling in living rm and other 2'0" below ceiling in second floor landing.	T thermocouple
	M.R.T	ONE, located 1'0" below ceiling in living room.	T thermocouple
	Relative humidity	ONE, located 1'0" below ceiling in living room.	Bulk polymer resist
	Wall surface temp	ONE, located 4'0" above the floor on the south wall of living room.	T thermocouple
	Electric energy use†	TWO, one for total electric load of the unit and other for space heating.	Infrared sensor

Table 3-1, Sensor Types and Locations

No.	Measurement Type	Number & Location	Sensor Type
Unit 4	Air temperature	TWO, one located 1'0" below ceiling in living rm and other 2'0" below ceiling in second floor landing	T thermocouple
	M.R.T	ONE, located 1'0" below ceiling in living room	T thermocouple
	Relative humidity	ONE, located 1'0" below ceiling in living room	Bulk polymer resist
	Wall surface temp	ONE, located 4'0" above the floor on the south wall of living room	T thermocouple
	Electric energy use†	TWO, one for total electric load of the unit and other for space heating	Infrared sensor
Unit 5	Air temperature	TWO, one located 1'0" below ceiling in living rm and other 2'0" below ceiling in second floor landing	T thermocouple
	M.R.T	ONE, located 1'0" below ceiling in living room	T thermocouple
	Relative humidity	ONE, located 1'0" below ceiling in living room	Bulk Polymer resist
	Wall surface temp	ONE, located 4'0" above the floor on the south wall of dining room	T thermocouple
	Electric energy use†	TWO, one for total electric load of the unit and other for space heating	Infrared sensor
Unit 6	Air temperature	TWO, one located 1'0" below ceiling in living rm and other 2'0" below ceiling in second floor landing.	T thermocouple
	M.R.T	ONE, located 1'0" below ceiling in living room	T thermocouple
	Relative humidity	ONE, located 1'0" below ceiling in living room	Bulk polymer resist
	Wall surface temp	ONE, located 4'0" above the floor on the south wall of dining room	T thermocouple
	Electric energy use†	TWO, one for total electric load of the unit and other for space heating	Infrared sensor

Table 3-1, Sensor Types and Locations (continued)

No.	Measurement Type	Number & Location	Sensor Type
Wthr Sta.	Radiation sensors	TWO, one for measuring the vertical and other for horizontal radiation	Silicon photo diode
	Wind speed	ONE, measures wind speed (m/s)	Helicoid propeller
	Wind direction	ONE, measures wind direction in degrees from 0° to 355°	Balanced vane
	Relative humidity	ONE Ambient RH	Bulk polymer resist
	Dry bulb temp	ONE Ambient DBT	T thermocouple
	M.R.T.	ONE Ambient MRT	T thermocouple

† For measuring the electric energy usage, a total of three sensors were planned in the data logger program, but only two sensors were installed. The third one to be used for measuring the electricity consumption for domestic hot water consumption was not installed.

TABLE 3-1, Sensor Types and Locations (continued)

The data acquisition equipment had a storage capacity allowing 48 hours of data storage for the university site. Hence, data was downloaded from the site every 24 hours. The data was collected from the sensors every 6 seconds and then either averaged or added every 6 minutes for final output from the data logger. The final output was further reduced to 1-hour intervals. After careful analysis of the data, graphs were plotted reflecting the performance of the apartments. The variation of relative humidity, dry bulb temperature, south wall temperature and energy consumption was recorded and analyzed.

3.4 WEATHER MONITORING

A weather station was installed on top of Unit 5, the east unit of the 2 story closed panel. Weather data collected includes ambient temperature, relative humidity, mean radiant temperature, vertical irradiance, horizontal irradiance, wind speed and wind direction.

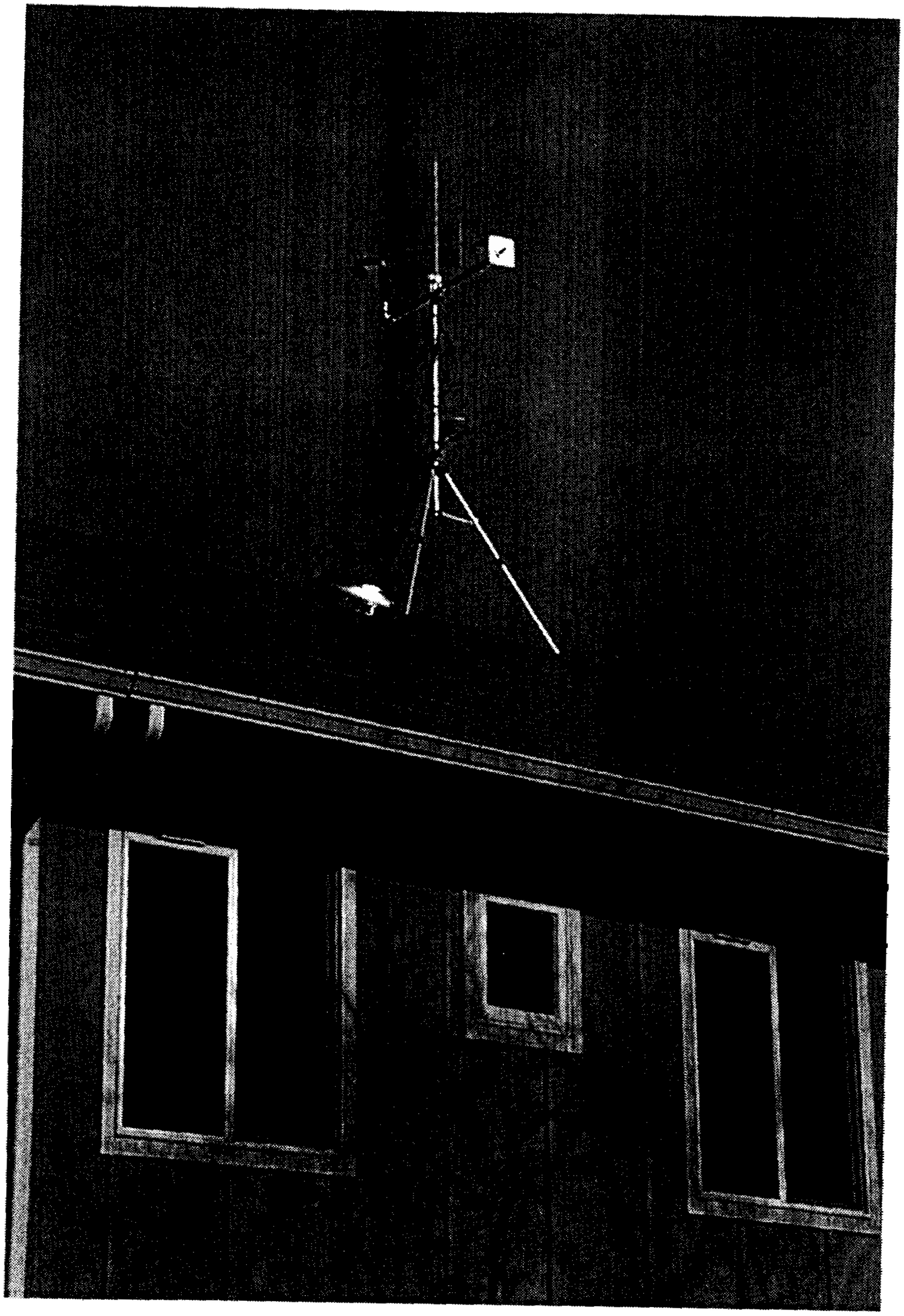


Figure 3-4
Photograph of Weather Station Mounted on Unit 5

4.0 RESULTS

The results of the building diagnostic tests and short-term monitoring of the six university housing units are presented in this section. The building diagnostic tests evaluated infiltration and thermal transmittance. The infiltration evaluation includes both fan de-pressurization and smoke leakage testing results. The thermal transmittance evaluation includes thermographic imaging and coheating results. Short term monitoring comprised 13 days of continuous monitoring of energy consumption, ambient temperature, mean radiant temperature, south wall temperature, and relative humidity as well as outside weather data.

4.1 AIR INFILTRATION

Fan De-Pressurization Testing

Fan de-pressurization tests were performed on the six units, which vary both in geometry and the number of penetrations through the envelope. Building characteristics are presented in Table 4-1. Based on the crack length of windows and doors and joint length (determinants of infiltration), one would expect Unit 1 to have the highest infiltration followed by Unit 4, Unit 2, Unit 3, and the two-story units, 5 and 6. However, air changes per hour at a house pressure of 50 pascals (ACH_{50}) determined from the fan de-pressurization tests, Figure 4-1, indicate that the 1 1/2 story open panel units (3 and 4) had the highest infiltration followed by the 2 story units (5 and 6), 1 story SSIC unit (1) and 1 story closed panel unit (2). The air changes per hour at 50 pascals (ACH_{50}) reflects the relative airtightness of each housing unit. ACH_{50} is calculated by dividing the flow rate of air per hour through the fan at a pressure differential of 50 pascals by the volume of the apartment. The test uncertainty was estimated to be 5% based on the use of digital pressure gauges and correlation of curve fit data.

Test	Surface Area	Volume	Crack Length of Windows and Doors	Joint Length	Total Crack and Joint Length
	(sq. ft.)	(cu. ft.)	(ft)	(ft)	(ft)
Unit 1 SSIC Panel	2392	6086	146	642	788
Unit 2 Closed Panel	2392	6086	146	458	604
Unit 3 Open Panel	1965	5981	140	453	593
Unit 4 Open Panel	2182	6424	188	529	717
Unit 5 Closed Panel	1721	5552	185	289	474
Unit 6 Closed Panel	1721	5552	185	289	474

Notes:

Crack length – Perimeter, feet, of window and door openings

Joint length – Perimeter feet of panel to slab, panel to ceiling, panel to panel joints

Table 4-1
Building Characteristics

The effective leakage (ELA) was also calculated area at 4 pascals, using the Lawrence Berkeley Laboratory (LBL) model (see Figure 4-2). Again, the 1 story SSIC panel unit and closed panel unit are more airtight than the open panel units. The ELA is more prone to error as the value is based on data derived at low fan pressures when measurements are more susceptible to wind and gauge error. A margin of error of 10% for ELA was estimated based on the curve fit data.

The specific leakage area (SLA) was also calculated. The SLA normalizes the ELA by floor area by multiplying the ELA in square feet by 10,000 and dividing by the floor area in square feet. A plot of the SLA, Figure 4-3, again indicates that the open panel units were the least airtight.

Unit	CFM50	ACH50	ELA	Wind Speed	SLA	Natural Infiltration (LBL)
	(cfm)	(house vol. / hr)	(sq. in)	(mph)		(air change / hr)
Unit 1 SSIC Panel	491	4.8	24	3.0	2.45	0.16
Unit 2 Closed Panel	433	4.3	21	1.9	2.19	0.15
Unit 3 Open Panel	907	9.1	39	3.4	3.38	0.34
Unit 4 Open Panel	1116	10.4	52	2.7	4.16	0.39
Unit 5 Closed Panel	616	6.7	25	2.7	2.41	0.28
Unit 6 Closed Panel	579	6.3	26	1.9	2.56	0.27

Notes:

Test conditions: All window vents (BPA vents), passive vents, and bathroom vents were taped

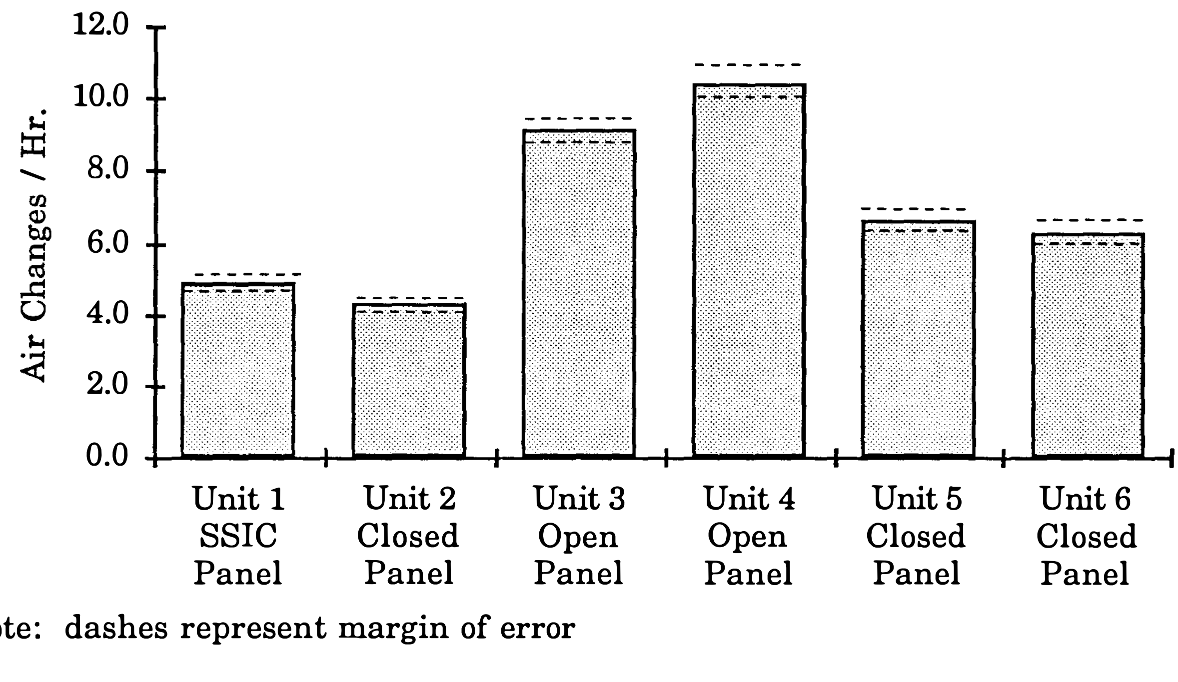
cfm - Cubic feet per minute

ELA - Effective leakage area at a specific pressure

SLA - Specific leakage area, ELA (ft) *10,000/House (ft^2)

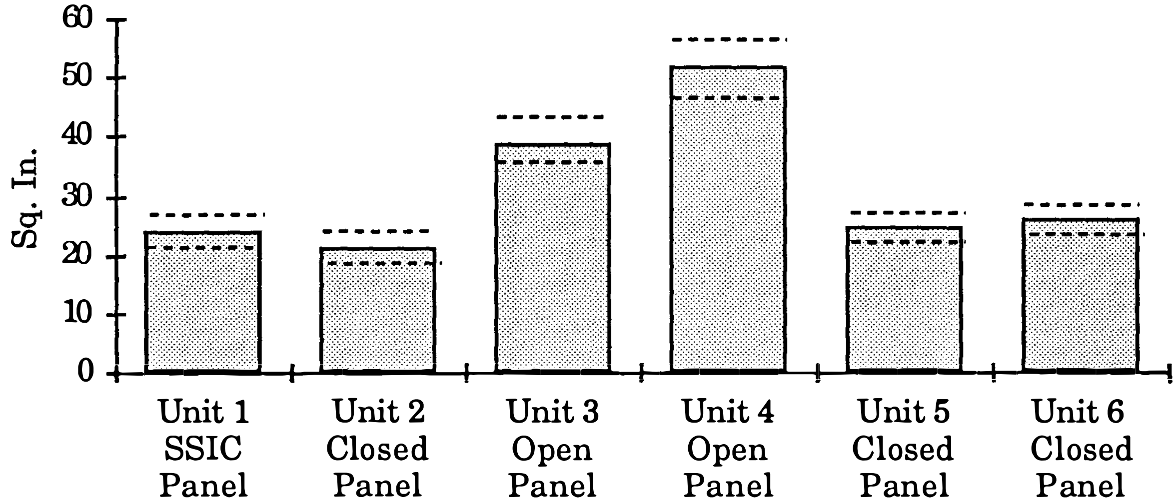
Wind Speed - represents average wind speed between 9AM and 7PM on day of test recorded at the Solar Monitoring center at the University of Oregon. .5 miles from test site. Wind measurements were taken at a height of ≈45 ft.

Table 4-2
Fan De-Pressurization Results



Note: dashes represent margin of error

Figure 4-1
Air Changes per Hour at a House Pressure of 50 Pascals



Note: dashes represent margin of error

Figure 4-2
Effective Leakage Area at House Pressure of 4 Pascals

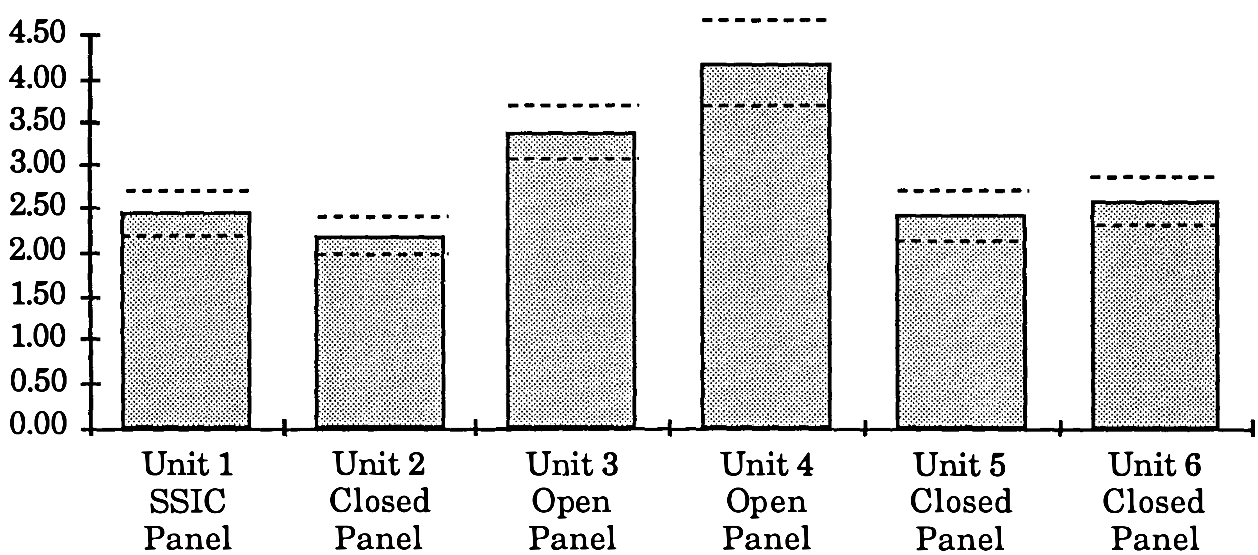


Figure 4-3
Specific Leakage Area

The ELA and SLA results reinforce the ACH_{50} data indicating performance of the closed panel Units 2, 5 and 6 and the SSIC panel unit 1 to be substantially better than the open panel Units 3 and 4. However, ACH_{50}, ELA and SLA results do not reflect differences in design, such as window and door openings and roof configuration. In order to account for differences in design, effective leakages of windows, doors, ceiling-to-ceiling joints, and penetrations through the ceiling were calculated using estimates of component leakage (ASHRAE, 23.15). Estimated leakage values for the specific components as well as joints are presented in Table 4-3. The estimated leakage areas of components were used to normalize measured ELA's. The ASHRAE data provides values only for wood windows, whereas the windows in the apartment are vinyl. Consequently, a level of uncertainty is introduced into the normalization.

Unit	Estimated Effective Leakage Area of Panel-to-Panel Joints	Estimated Effective Leakage Area of Panel-to-Slab Joints	Estimated Effective Leakage Area of Panel-to-Ceiling Joints	Estimated Effective Leakage of Windows	Estimated Effective Leakage Area of Doors
	(sq. in)	(sq. in)	(sq. in)	(sq. in)	(sq. in)
Unit 1, SSIC Panel	9.92	4.73	18.93	10.51	0.62
Unit 2, Closed Panel	2.56	4.73	18.93	10.51	0.62
Unit 3, Open Panel	4.24	5.5	12.86	7.28	1.24
Unit 4, Open Panel	4.88	6.26	16.23	11.45	1.24
Unit 5, Closed Panel	2.48	4.53	9.18	11.97	1.24
Unit 6, Closed Panel	2.48	4.53	9.18	11.97	1.24

Table 4-3
Estimated Effective Leakage Area
(continued on next page)

Unit	Estimated Effective Leakage Area of Wall Penetrations	Estimated Effective Leakage Area of Ceiling Penetrations	Estimated Effective Leakage Area of Ceiling to Ceiling Joint	Total Estimated Effective Leakage Area
	(sq. in)	(sq. in)	(sq. in)	(sq. in)
Unit 1, SSIC Panel	1.29	2.01	3.36	51
Unit 2, Closed Panel	1.45	2.01	3.36	44
Unit 3, Open Panel	1.29	2.40	4.08	39
Unit 4, Open Panel	1.13	2.40	4.08	48
Unit 5, Closed Panel	0.97	2.27	0.00	33
Unit 6, Closed Panel	0.81	2.27	0.00	32

Table 4-3 continued
Estimated Effective Leakage Area

The building components having the largest effect on the estimated leakage area were windows and doors, which are dependent upon crack length. The crack length of windows and doors varied between the units and was greatest for the 2 story units even though the 2 story units have the least surface area. The estimated leakage of windows, doors and ceiling penetrations and ceiling joints was subtracted from the measured ELA. The remaining leakage area, Figure 4-4, more closely reflects the leakage area related to the panel type and its installation in the field. Figure 4-4 indicates that the open panels were the least airtight. The factors related to panel type and installation in the field were assumed to be the following: overall panel construction, panel-to-slab joints, panel-to-ceiling joints, panel-to-panel joints, and penetrations through the panels.

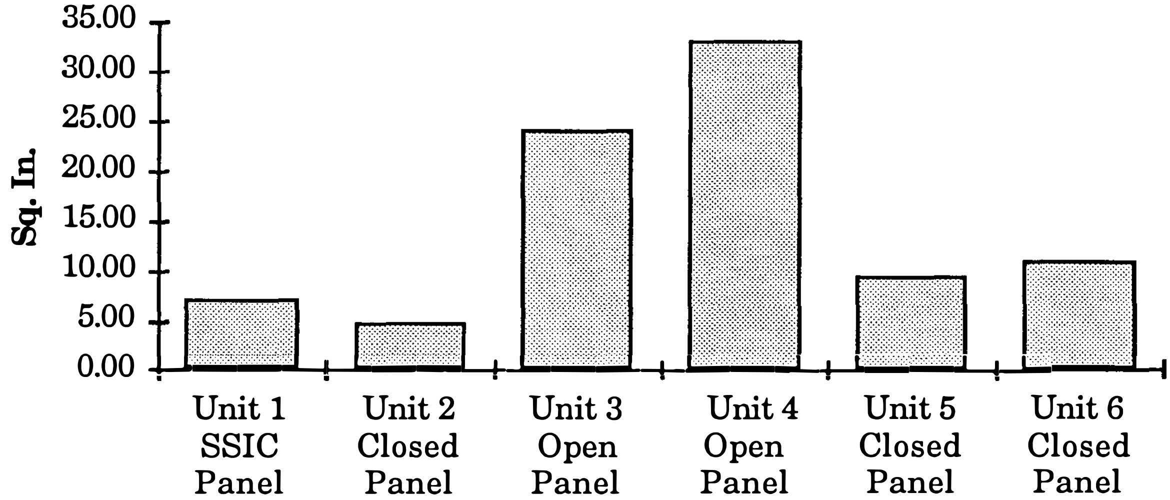


Figure 4-4
(ELA) - (Estimated Leakage Area of Windows, Doors and Ceiling Joints and Penetrations through the Ceiling)

The estimated leakage area shown in Figure 4-4 reflects the leakage area associated with panel type and panel installation. However, Figure 4-4 does not reflect differences in the size of panels and their configuration. Consequently, the estimated panel leakage area was normalized by joint length of the panels for each unit to account for differences in design. Joint length included panel-to-slab joints, panel-to-ceiling joints and panel-to-panel joints. As can be seen in Figure 4-5, even when the estimated leakage area attributable to the panel is normalized by the joint length, the 1 1/2 story open panels are still the least airtight.

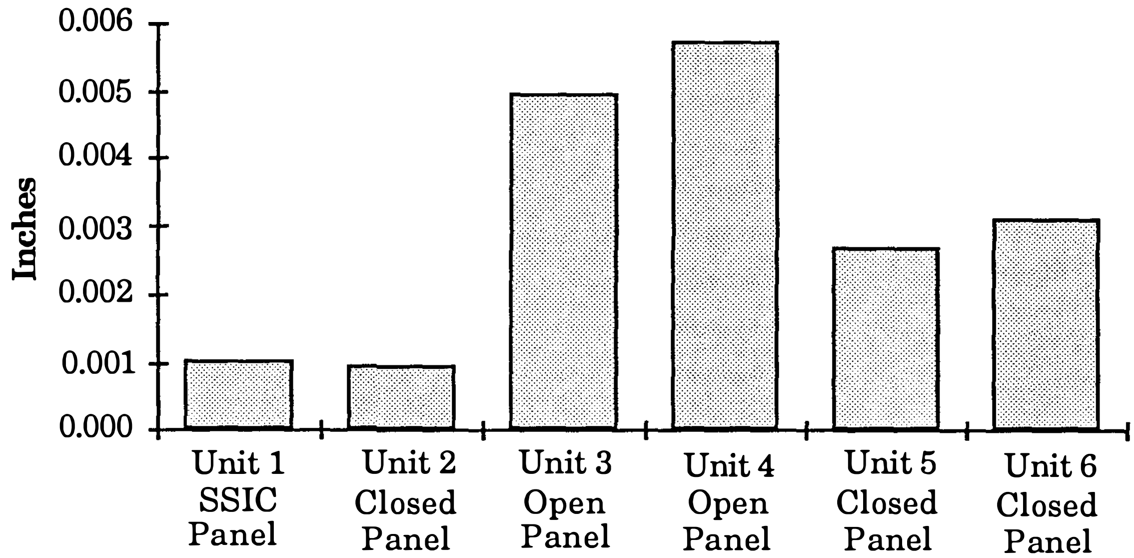


Figure 4-5
(ELA) - (Estimated Leakage Area of Windows, Doors and Ceiling joints and Penetrations through the Ceiling) Normalized by Joint Length

Overall, the fan pressurization results suggest that the SSIC panels and the closed panels may contribute to the more airtight envelopes. Analysis of the fan de-pressurization results was adjusted to account for differences in building geometry and design. However, other variables which affect the airtightness of the panel systems include the experience of the construction workers and the complexity of the design of each unit.

Smoke Testing

Smoke leakage testing using titanium tetrachloride smoke under pressurized conditions of 20 pascals was performed to identify significant areas of leakage in the University Housing units. Common leakage areas in all units include the bathroom and kitchen vents, the tops and bottoms of sliding windows, the vents on windows, and leakage into the attic space. Junction boxes and other punctures of the envelope for plumbing and electrical systems were also common areas of leakage. Units 1 and 6 exhibited leakage between the slab and wall joints. Leakage was also detected at the concrete masonry unit (CMU) party wall in Units 1 and 2 and Units 5 and 6; however, leakage was probably between units rather than to the exterior.

Unit	Room	Severe Leakage	Moderate Leakage
Unit 1	Living Room	Conduit Southeast corner on South wall	Electrical outlet not flush with wall, South wall
		Between baseboard and slab, Southeast corner	Ceiling junction box, minor leakage
		Between slab, drywall and cmu partition wall to unit 2, Northeast corner	All sliding windows, near the top and bottom end of the sliding pane, some flow along the slotted trickle vents (BPA vents)
	Kitchen	Stove vent cabinet, leakage at ceiling joint	Next to counter, between baseboard and slab, North wall
			Between baseboard and slab, North wall
			Outlet, not flush with wall, minor leakage
	Bathroom	Vent	Between baseboard and wall, West wall below heater
	South Bedroom	Junction box	Between baseboard and wall, West wall, large cracks
		2 holes in ceiling, around edges of box #1	All sliding windows, near top and bottom of sliding pane
	North Bedroom		Between Slab and baseboard, Northeast corner, small chip corner of slab
			Ceiling and light fixture joint, very minor leakage
			All sliding windows, near top and bottom of sliding pane
	Hall	Between slab and baseboard, along East wall near bedroom	
		Leakage into attic, at corner of attic door	
Unit 2	Living Room		Top and bottom joint of all sliding windows, BPA vents
	Kitchen	Vent	
	Bathroom	Vent	Top and bottom joint of all sliding windows
	South Bedroom		Top and bottom joint of all sliding windows
	North Bedroom		Top and bottom joint of all sliding windows
	General		All electrical plug joints leak mildly to moderately
	Hall		Around slot for datalogger
			Into Attic vent

Table 4-4
Smoke Leakage Testing Results

Unit	Room	Severe Leakage	Moderate Leakage
Unit 3	Living Room	All sliding windows at middle of joint	Minor leakage around door frame on West wall
	Kitchen	Stove Vent	Junction of stove box and ceiling
	Bath	Bath vent	Between baseboard and slab on East wall
	West Bedroom		Around wall sconce, west wall
			Around ceiling light
	Center Bedroom	Attic door leakage in covers	Bottom corners of both skylights
		Around ceiling Light	
	Stair	Along North wall where riser meets stair, on first stair at platforms	
	Upstairs Closet	Leakage into unit 4 around water pipes where they enter wall	
	Additional Comments	Hole through drywall at baseboard heater	Leakage between sliding plane and window frame
Unit 4	Living Room		Flow around junction box in Southeast corner of the ceiling
			Top joint of window 2 facing South
			All sliding windows near the top and bottom end of the sliding pane, some flow along BPA vents when tightly closed
	Kitchen	Vent	
	1st floor Bathroom	Ventilation fan	Moderate flow along electrical inlets
		Electrical heater inlet	
	2nd floor Bathroom	Ventilation fan	
	First Floor Bedroom	Moderate flow along electrical inlets	Top and Bottom of sliding window
			All electrical outlets
	South Bedroom	Attic access hatch, primarily in corners	Top and bottom of sliding window
		Inlet for Electrical heater	Southeast corner at baseboard
			Around pipe for hot water heater
	East Bedroom	into the inlet for electrical heaters	Top and bottom of sliding window
			Northeast corner at bedroom

Table 4-4, Smoke Leakage Testing Results (continued)

Unit	Room	Severe Leakage	Moderate Leakage
Unit 4 (cont.)	Hall		Electrical inlets and phone jack
	General	Electrical heater inlets on second floor has large hole through which a lot of air is escaping	
Unit 5		NOT TESTED	
Unit 6	Living Room	Between door and frame, lower right corner	NE corner of CMU wall
			Conduit into drywall, minor leak
	Kitchen	Vent	
		Above stove hood	
		Holes around conduit, above stove hood	
	Bath	Vent	Between linoleum and baseboard, North wall
	East Bedroom		Between Baseboard and carpet Southwest and Southeast corners
			Between ceiling and light fixtures, minor
	West Bedroom		Junction of baseboard and carpet, Southwest corner and Northwest corner of closet
	Stair/Hall	Attic hatch	
		Junction box and phone box	
		Junction of CMU wall and drywall, considerable flow	
		All corners of CMU and stair platform, big holes	

Note: BPA vents refer to slotted vents in windows provided to allow air exchange
CMU refers to concrete masonry units

Table 4-4
Smoke Leakage Testing Results (continued)

4.2 THERMAL TRANSMITTANCE (UA)

The thermal transmittance section includes results from thermographic imaging and coheating tests. The thermographic imaging, or infrared scanning, provides a qualitative assessment of heat loss through conduction and infiltration through the envelope. The coheating test provides a quantitative assessment of building conductance and heat loss due to infiltration. Theoretical UA values were also calculated as a bases to assess actual performance.

Thermographic Imaging

The results of the thermographic imaging showed that Units 3 and 4 had the most significant thermal weak spots caused by missing or poorly installed insulation in the walls and ceiling. Units 3 and 4 are open panel construction, which means that all of the insulation was installed on site. Units 1 and 2 also had substantial amounts of missing or improperly installed insulation at the interior gable wall, the transition of the flat ceiling insulation above the bathroom to the vaulted ceiling insulation. For the most part, problems related to missing or improperly installed insulation correspond to installation on site whether it was Units 1, 2, 3 or 4.

Other common problems detected by the infrared imaging include conductive and infiltration losses along panel-to-slab joints, and infiltration through the slotted vents (BPA window vents), passive vents, and electrical outlets. Thermal bridging due to studs was often detected; however, the thermally broken splines of the SSIC panel house were only detectable at building corners.

Tape	Time	Comment
Unit-1		
1	0:05:23	Missing and/or poorly installed insulation along the rafters in the northwest corner of the living room where wall and roof meets
1	0:05:50	Infiltration through electrical outlets on north wall above kitchen counters
1	0:07:41	Missing and/or poorly installed insulation at the west gable end of the living room above the kitchen
1	0:12:43	Infiltration along the frame of the entrance door to the unit.
1	0:19:29	Conductive loss through electrical outlet, north wall of northwest bedroom
1	0:22:00	Missing and/or poorly installed insulation at the south gable end of the north bedroom
1	0:27:00	Missing and/or poorly installed insulation at the north gable end of the south bedroom
1	0:31:01	Conductive/infiltration loss along all exterior corners between wall and slab on grade floor
Unit-2		
2	1:00:41	Infiltration along the frame of the entrance door to the unit
2	1:02:00	Conductive/infiltration loss through BPA trickle vents in windows
2	1:04:32	Missing and/or poorly installed insulation at the rafter and joint between north wall and roof above kitchen
2	1:08:09	Room air escaping through the electrical outlets
2	1:17:45	Conductive/infiltration loss through passive vent in bathroom
2	1:20:09	Missing and/or poorly installed insulation on the north gable end of the south bedroom
2	1:24:00	Conductive loss through passive vent
2	1:26:33	Poorly installed insulation at north gable of south bedroom

Table 4.4
Infrared Testing Results

Tape	Time	Comment
Unit-3		
2	0:01:09	Missing and/or poorly installed insulation at the northwest corner of the west bedroom near wall and ceiling joint
2	0:05:19	Missing insulation above bathtub, north wall of 1st floor bedroom
2	0:08:43	Infiltration along the frame of the entrance door next to the kitchen
2	0:12:03	Missing and/or poorly installed insulation at the top of the east skylight on the second floor.
2	0:14:02	Poorly installed insulation at the roof above the second floor landing area
2	0:16:13	Missing/ improperly installed insulation above top of west skylight
2	0:16:40	Missing insulation/infiltration south wall at knee wall and common wall
2	0:19:40	Vent pipe creates cold spot at the southwest corner of the south wall of the bedroom on the second floor
2	0:22:05	Infiltration/poorly installed insulation around electrical receptacle
2	0:24:19	Missing and/or poorly installed insulation at the north wall of storage area
2	0:25:44	Missing insulation behind water heater, 2nd floor
Unit-4		
1	1:15:36	Missing and/or poorly installed insulation at the wall-to-ceiling joint of southeast corner of the living room
1	1:18:24	Missing and/or poorly installed insulation at the wall-to-floor joint on the east side of the bay window in dining area
1	1:28:01	Missing and/or poorly installed insulation at the wall-to-ceiling joint of the northeast corner of the east bedroom
1	1:46:24	Missing and/or poorly installed insulation along the north side of the sloping roof of the second floor bathroom

Table 4.4
Infrared Testing Results (continued)

Tape	Time	Comment
Unit-4 (continued)		
1	1:52:18	Infiltration and conduction loss occurring at the wall-to-wall connection of the northeast corner of the east bedroom on second floor
1	1:59:17	Missing and/or poorly installed insulation at the southeast corner of the south bedroom on second floor
Unit-5		
2	0:27:41	Infiltration around bottom of door, south wall of living area
2	0:30:36	Poor wall-to-wall connection leading to heat loss due to infiltration and conduction
2	0:44:56	Missing and/or poorly installed insulation at the ceiling of the second floor bathroom
Unit-6		
1	0:39:10	Poor wall-to-wall connection at the southwest corner of the dining area leading to heat loss due to infiltration and conduction
1	0:40:41	Infiltration/conductive loss at top of kitchen vent
1	0:40:45	Missing and/or poorly installed insulation at the wall-to-ceiling joint of the south wall of living area
1	0:41:00	Poor wall-to-wall connection at the northwest corner of the building leading to heat loss due to infiltration and conduction
1	0:47:16	Infiltration/conduction around north panel to 2nd floor joint
1	0:48:10	Infiltration/conduction around door frame
1	0:55:45	Missing and/or poorly installed insulation at the wall-to-ceiling joint of the west wall in second floor bathroom (above bathtub)

Note: BPA vents and passive vents contribute to heat loss due to conduction and infiltration. Conductive losses along all exterior corner between walls and floor.

Table 4.4
Infrared Testing Results (continued)

Coheating Tests

Results of the coheating tests, Table 4-5, provide an estimate of heat loss due to overall thermal transmittance (UA), which includes infiltration. We would expect, based on theoretical UA, Figure 4-6, that the 1 story units would have the highest UA followed by the 1 1/2 story and the 2 story units, respectively.

Unit	Surface Area	UA Value as Measured	Estimated Infiltration Loss	UA - Infiltration UA	UA Theoretical	UA - Infiltration / Theoretical UA
	(sq. ft.)	(Btu\h F)	(Btu\h F)	(Btu\h F)	(Btu\h F)	
Unit 1 SSIC Panel	2003	174	18	156	136	1.15
Unit 2 Closed Panel	2003	180	16	164	134	1.23
Unit 3 Open Panel	1663	198	37	161	113	1.42
Unit 4 Open Panel	1862	186	46	140	129	1.09
Unit 5 Closed Panel	1478	129	28	101	112	0.90
Unit 6 Closed Panel	1478	136	27	110	112	0.98

Note: Infiltration loss was estimated by multiplying the Lawrence Berkeley Laboratories estimate of natural infiltration times the volume of each unit and by 1 hour to establish an air volume. The air volume was then multiplied by the specific heat of air and the density of air to establish the heat capacity of the air lost due to infiltration in each unit.

Table 4-5
Coheating Results

Measured results indicate the 2 story closed panel units display the lowest UA followed by the 1 story SSIC, 1 story closed panel and finally the 1 1/2 story panel units.

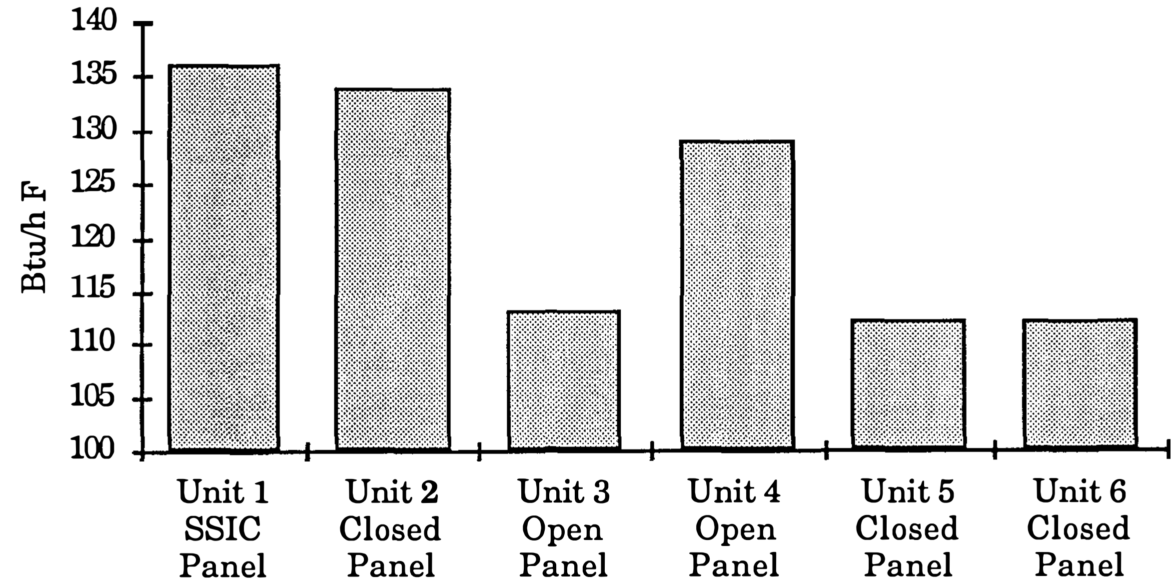


Figure 4-6
Theoretical UA Values Reflecting Differences in Design of Units.

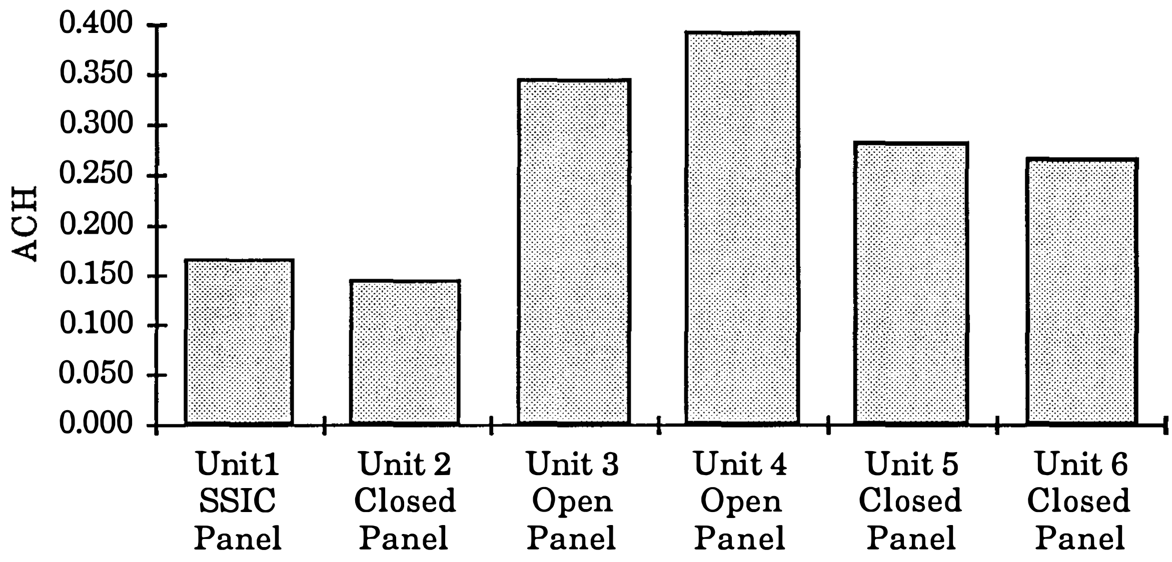
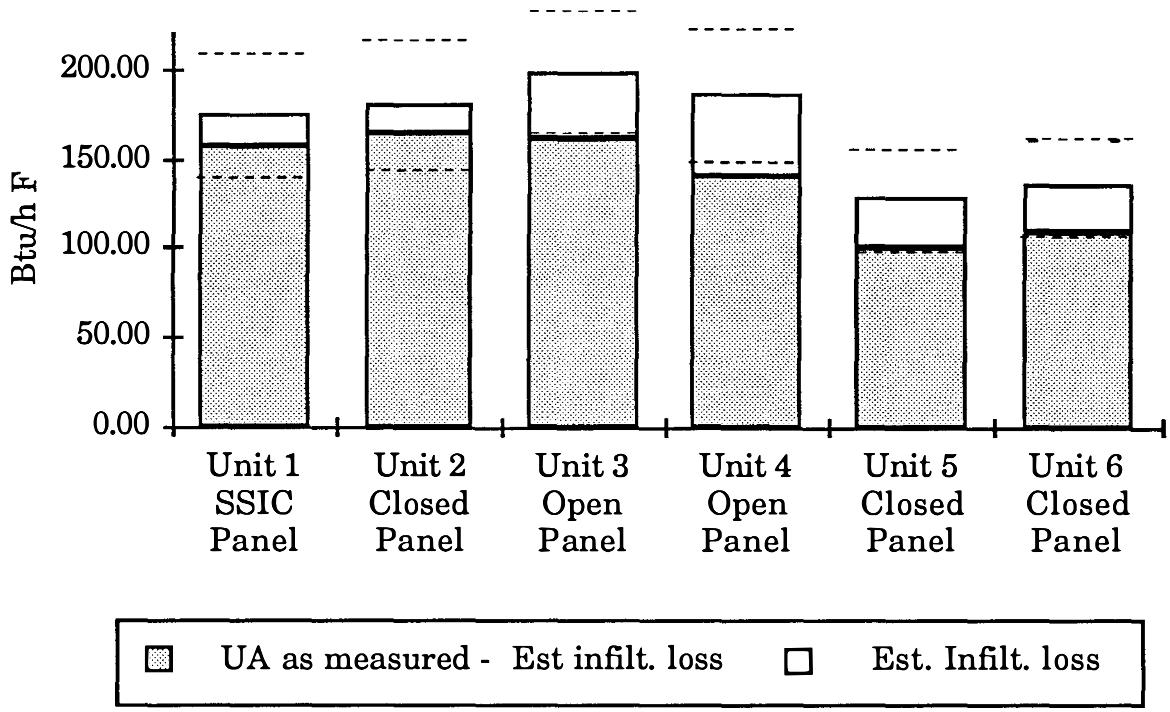


Figure 4-7
LBL Natural Infiltration from Fan Pressurization Results



Notes: dashes represent the margin of error

Figure 4-8
(UA as Measured) Including Infiltration Estimation

Many factors account for the difference in UA performance, including building design, orientation, geometry and construction method. In order to provide a better comparison of the actual building conductance, estimated infiltration losses using fan pressurization test data were calculated, Figure 4-7. The estimated losses due to infiltration are reflected in the unshaded portions of the "UA as measured values" of Figure 4-8. These estimated infiltration losses were subtracted from the measured UA values. In addition, the theoretical UA values, Figure 4-6, were calculated from data in ASHRAE 93 Fundamentals. Theoretical UA values were used to normalize the "UA as measured values" less the estimated infiltration losses.

Because each coheating test was performed on six different nights with different wind conditions and temperature conditions, error was estimated to be within 20%. The range of ΔT indoor to outdoor was from 20.3 ^{0}F to 51.3 ^{0}F and wind varied from 1.4 mph to 7.6 mph. Temperature data was measured from on site; whereas wind data was from the Solar Monitoring Lab located approximately .5

miles away at the University of Oregon. The measurements of wind data are taken at an approximate height of 45 feet. The different wind and temperature conditions have a large effect on heat loss due to infiltration. In a report by the Florida Solar Energy Center (FSEC), "Side-by-Side Evaluation of a Stressed-Skin Insulated-Core Panel House and a Conventional Stud Frame House," a plot of 17 nights of energy consumption versus temperature indicated energy consumption, a reflection of heat loss due to conductive and infiltration losses, varied by as much as 15% under the same ΔT. Consequently, error associated with the coheating tests was estimated to be 20%.

The normalized UA values, Figure 4-9, account for design differences such as window and door area, surface area, different roof construction, and losses due to infiltration. Ideally, the normalized values should all equal 1; however, the testing conditions for the coheating test vary from the testing conditions ASHRAE values were determined under. In addition, the F value for calculating heat loss to the perimeter was based on a value of .400 (Wattsun 5). The F value may vary for different soil types and soil temperature and moisture conditions.

The normalized results in Figure 4-9 reflect the relative performance of each unit as seen in the initial "as measured results." Unit 1 SSIC panel, Unit 2 closed panel unit, Unit 3 open pane,l and Unit 4 open panel all have as measured performance greater than theoretical UA values, suggesting problems with the thermal envelope. Infrared scanning of Units 1 and 2 revealed significant problems related to the placement of insulation around the transition from a vaulted roof to a flat roof over the bathroom. Thermographic imaging also revealed deficiencies in insulation in both the wall panels and roof areas of Units 3 and 4. Unit 3 also had the most significant instances of poorly installed insulation of all the units.

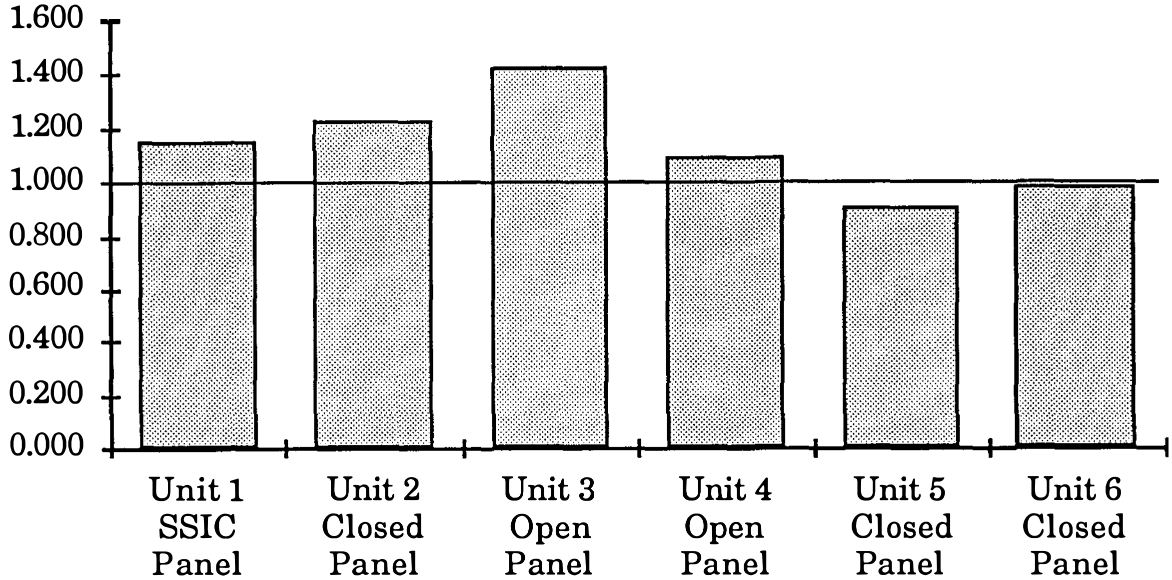


Figure 4-9
(UA as Measured) - (Infiltration) Normalized by Theoretical UA Values

Theoretical Thermal Transmittance (UA)

Pie charts reflecting theoretical UA values and the distribution of heat loss to building component are presented in Figures 4-10, 4-11, 4-12, 4-13, and 4-14. These figures reflect design differences between units due to different percentages of window area, door area, roof area, foundation slab perimeter.

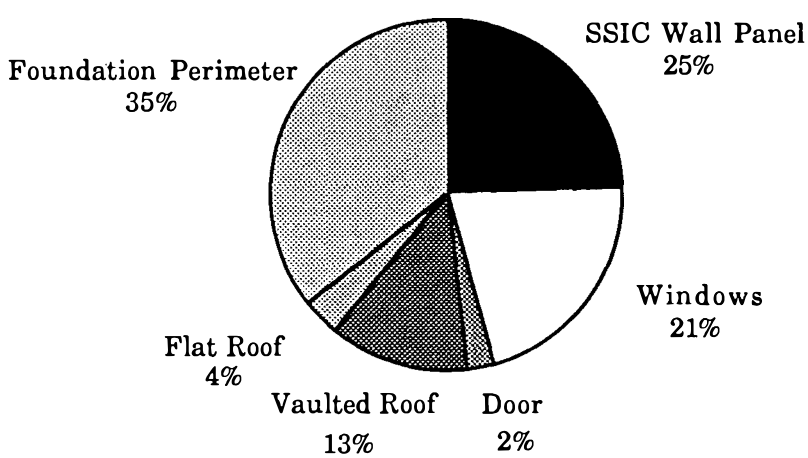


Figure 4-10

Theoretical Distribution of Heat Loss for 1 Story SSIC Unit-1.

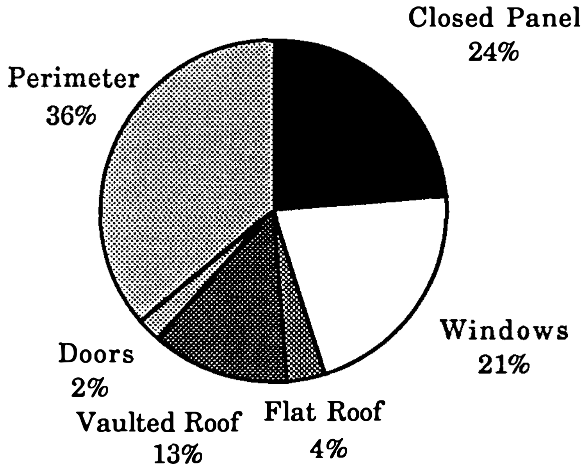


Figure 4-11

Theoretical Distribution of Heat Loss for 1 Story closed panel Unit-2.

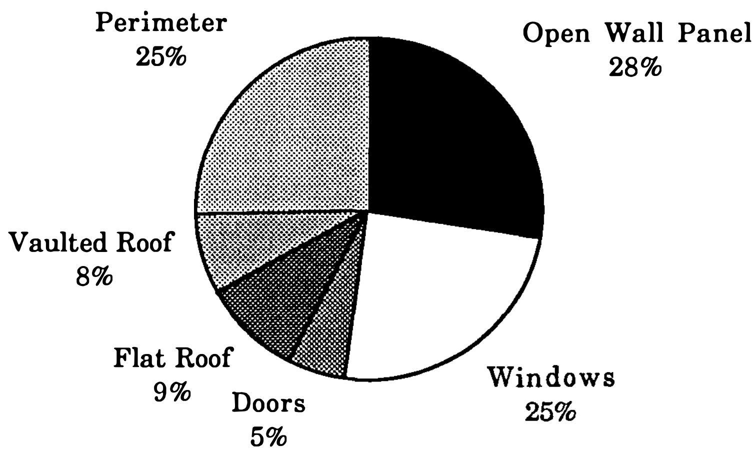


Figure 4-12

Theoretical Distribution of Heat Loss for 1 1/2 Story Open Panel Unit-3.

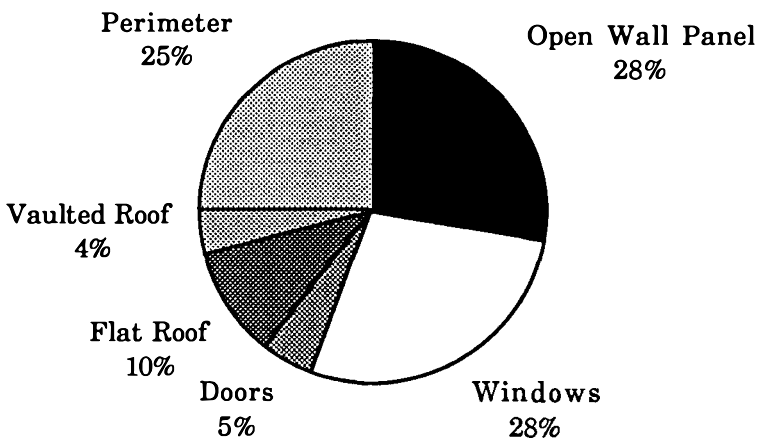


Figure 4-13

Theoretical Distribution of Heat Loss for 1 1/2 Story Open Panel Unit-4.

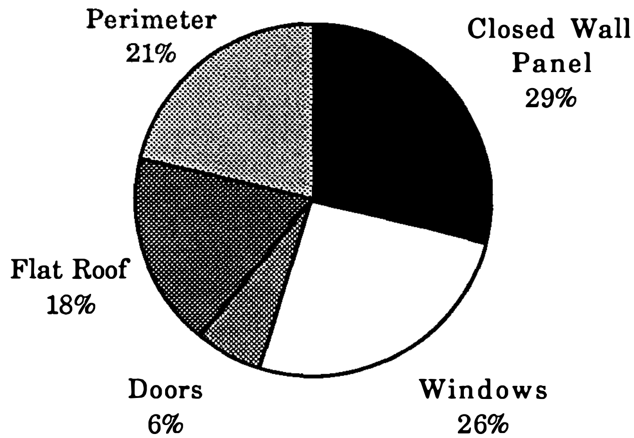


Figure 4-14
Theoretical Distribution of Heat Loss for 2 Story Closed Panel Units-5 and-6.

4.3 SHORT-TERM MONITORING

The results of energy consumption testing presented in Figure 4-15, indicate that the 2 story units had the lowest energy consumption per ΔT(Tin-Tout) followed by the 1 story closed panel, west 1 1/2 story open panel, 1 story SSIC panel and east 1 1/2 story open panel unit, respectively. The average ΔT of indoor to outdoor temperature varied from 36.9 ^{0}F (20.5$^{0)}$ to 42.12 ^{0}F (23.4^0). The short-term monitoring energy consumption results differ slightly from the coheating results. The difference in performance may be attributed to different orientations, which affect collection of solar irradiance and infiltration caused by wind. In addition, the short-term monitoring results are affected by varying levels of mass within the units. In addition, coheating data is taken at night when the effect of solar irradiance is zero and thermal conditions are most stable.

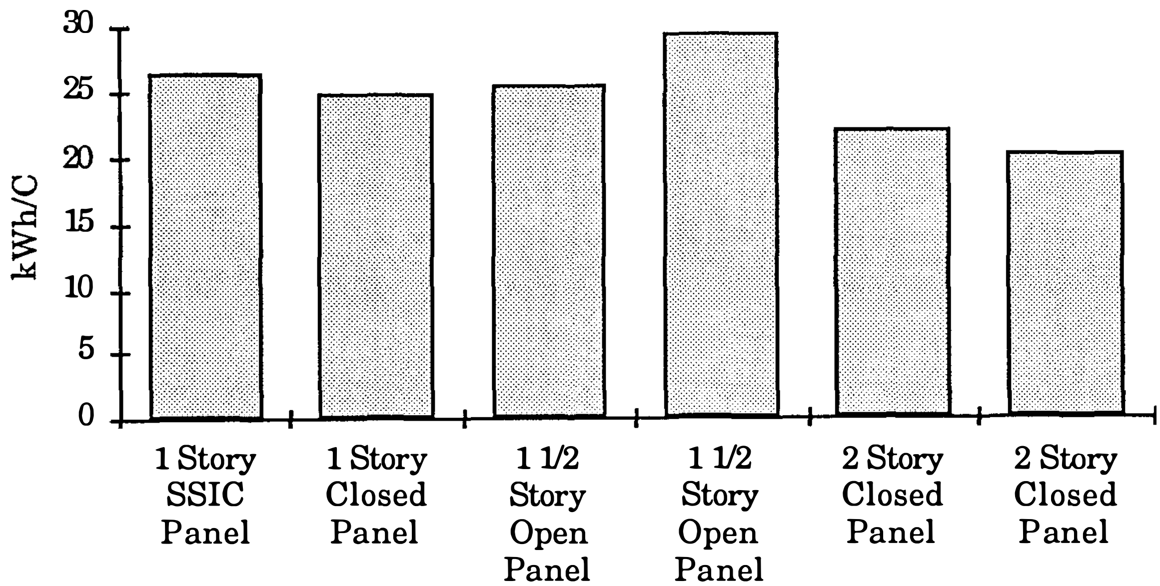


Figure 4-15
Short-Term Energy Consumption

Data presented in Appendix A.4 explain the performance of the units with respect to energy consumption, relative humidity, temperature, and south wall temperature.

4.4 SUMMARY OF RESULTS

Results of the infiltration tests indicate that the open panel units were the least airtight. ACH_{50} results, Figure 4-1, indicate that the 1 1/2 story open panel units were the least airtight followed by the 2 story closed panel units, the 1 story SSIC panel unit, and the 1 story closed panel unit, respectively. A plot of ELA, Figure 4-2, and SLA, Figure 4-3, also indicated that the 1 1/2 story open panel units were the least airtight. When the ELA's were adjusted to account for leakage due to windows and doors and leakage through the ceiling, Figure 4-4, the 1 1/2 story open panel units were again the least airtight. Furthermore, the ELA minus estimated ELA of windows, doors and ceiling joints and penetrations was divided by joint length of panel-to-panel joints, panel-to-slab joints and panel-to-ceiling joints to account for difference in size and configuration of the units, as shown in Figure 4-5. The open panel units are again the least airtight. Figures 4-4 and Figure 4-5 suggest that the high ELA for the open panel units is linked to the panel type.

Smoke leakage testing using titanium tetrachloride smoke under pressurized conditions of 20 pascals identified areas of leakage in the University Housing units. Common leakage areas in all units include the bathroom and kitchen vents, the tops and bottoms of sliding windows, the BPA vents on windows, and leakage into the attic space. Junction boxes and other punctures of the envelope for plumbing and electrical systems were also common areas of leakage. Units 1 and 6 exhibited leakage between the slab and wall joints. Leakage was also detected at the concrete masonry unit, party wall in Units 1 and 2 and Units 5 and 6; however, leakage was probably between units rather than to the exterior.

The results obtained by the thermographic imaging showed that Units 3 and 4 had the most significant number of problems with insulation in the walls and ceiling. Units 3 and 4 are open panel construction, which means that all of the insulation was installed on site. Both Units 1 and 2 had significant areas of missing or improperly installed insulation at the transition of vaulted insulation to flat roof insulation over the bathroom. This transition occurred within the overall roof envelope, so workers may have been more careless in installing this insulation. For the most part, the missing or improperly installed insulation corresponds to installation at the site, whether it was Units 1, 2, 3 or 4.

Other common problems detected by the thermographic imaging include conductive and infiltration losses along panel-to-slab joints, and infiltration through the BPA window vents, passive vents and electrical outlets. Thermal bridging due to studs was often detected; however, the thermally broken splines of the SSIC panel house were detectable only at the corner joints.

Coheating tests indicated the 2 story closed panel units had the lowest overall thermal transmittance (UA), followed by the 1 story SSIC unit, the 1 story closed panel unit, and the 1 1/2 story open panel units respectively, Figure 4-8. When the coheating results were adjusted to account for heat loss due to infiltration and normalized by theoretical UA to account for differences in design, the 1 story SSIC unit, 1 story closed panel unit, and the 1 1/2 story open panel units did not perform as well as predicted by theoretical UA values. The significant problems associated with insulation detected in the infrared scans may have contributed to the difference between as-measured to predicted UA values.

The results of short-term monitoring energy consumption indicate the 2 story closed panel units consume the least amount of energy as can be expected from coheating results. After the 2 story units, the 1 story closed panel unit consumed the least amount of energy followed by the 1 1/2 story west unit, 1 story SSIC unit and the 1 1/2 story east unit. The performance of Unit 3 is better than would be anticipated from coheating results. However, the short-term monitoring also measures effects of orientation to wind and irradiance.

5.0 REFERENCES

ASHRAE Handbook, Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. Atlanta, 1993.

Minneapolis Blower Door Operation Manual. Energy Conservatory, May 1994.

Rudd, Armin and Chandra Subrato, *Side- by-Side Evaluation of a Stressed-Skin Insulated-Core Panel House and a Conventional Stud-Frame House,* Florida Solar Energy Center. Cape Canaveral Florida, January 14, 1994.

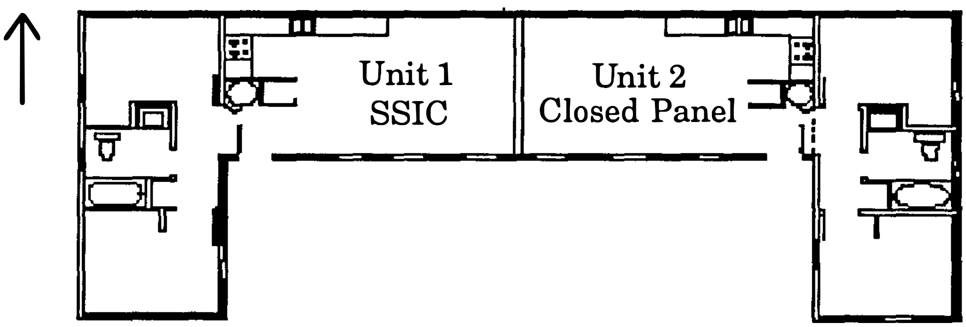
Wattsun 5 Reference Manual. Washington State Energy Office. Olympia WA. 1991.

6.0 ACKNOWLEDGEMENTS

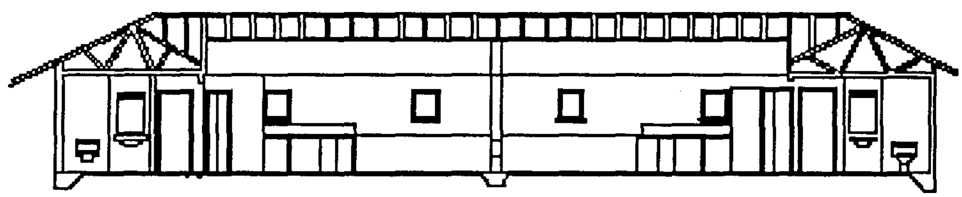
This project was funded by the U.S. Department of Energy contract #DE-FC51-94R020277. The University Housing units were designed by Don Corner and Will Sturges of the Center for Housing Innovation, University of Oregon. George Lei played an important role in the instrumentation and data collection for the University Housing project and conducted preliminary analysis of blower door and coheating data. Armin Rudd and David Beal of the Florida Solar Energy Center provided assistance in installing monitoring equipment, developing testing protocol and training Energy Studies in Buildings Laboratory staff in testing methods.

7.0 APPENDICES

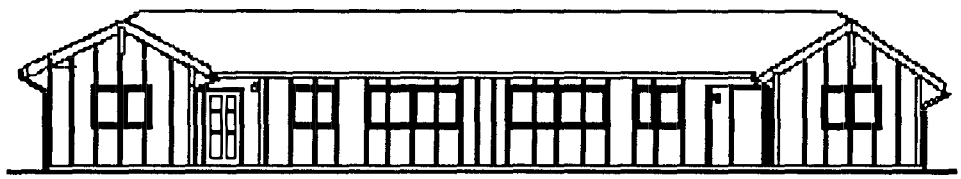
7.1 PLANS, SECTIONS, ELEVATIONS



Floor Plan



East-West Section of 1 Story Duplex



South Elevation of 1 Story Duplex

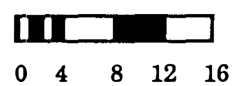
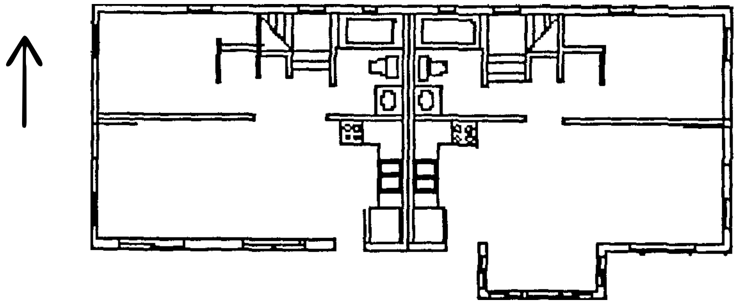
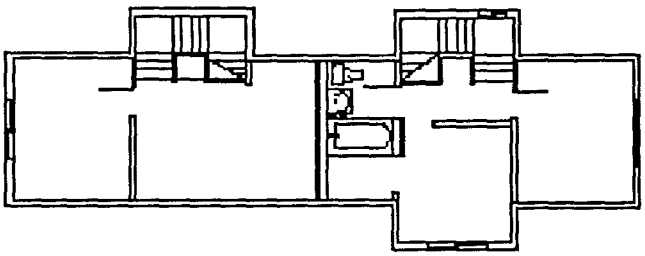


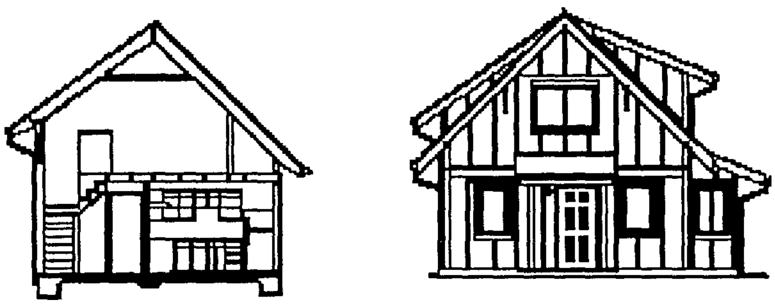
Figure 7.1-1
1 Story SSIC and Closed Panel Duplex



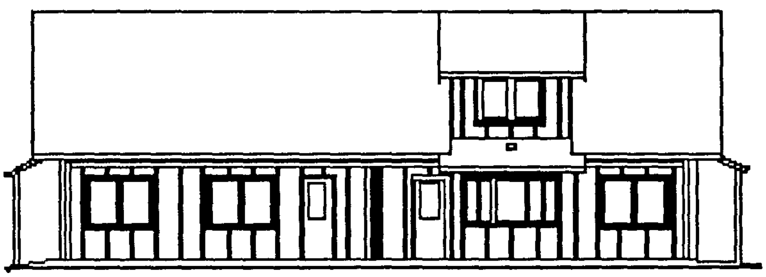
Ground Floor Plan



Second Floor Plan

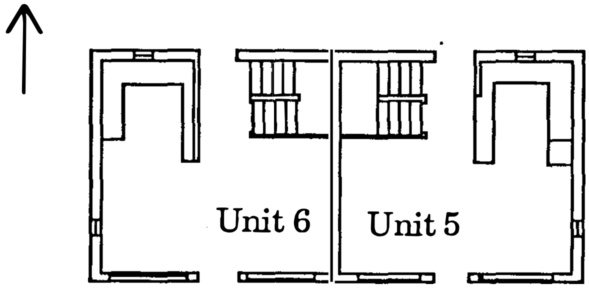


North-South Section and East Elevation

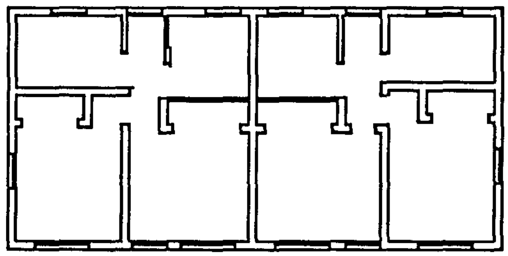


South Elevation

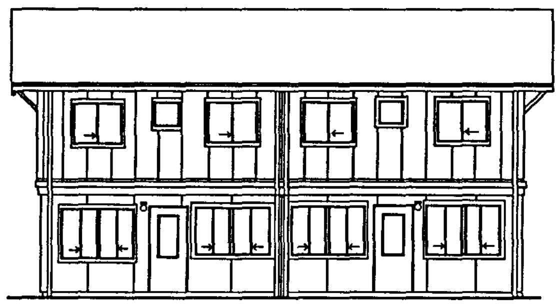
Figure 7.1-2
1 1/2 Story Duplex Plans, Sections and Elevations



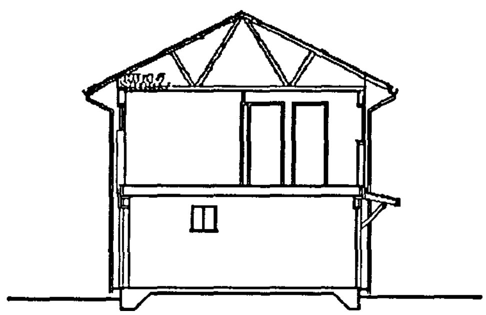
Ground Floor Plan



Second Floor Plan



South Elevation



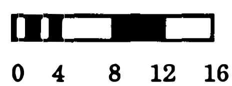


Figure 7.1-3
2 Story Closed Panel Duplex

7.2 INSTRUMENTATION

DATA LOGGER 1

No.	SENSOR TYPE	LOCATION	CHANNEL No.	OUTPUT LOC
1	Thermocouple	Unit-1, South Wall	Multiplexer 1.1	1
2	Thermocouple	Unit-1, Living rm.	Multiplexer 1.2	2
3	Thermocouple (MRT)	Unit-1, Living rm.	Multiplexer 2.1	3
4	Humidity Senor	Unit-1, Living rm.	Multiplexer 2.2	4
5	Meter Sensor (Main)	Unit-1, Meter	SDM 1	5
6	Meter Sensor (Heat)	Unit-1, Meter	SDM 2	6
7	Meter Sens (H water)	Unit-1, Meter	SDM 3	7
8	Meter Sensor (Main)	Unit-2, Meter	SDM 4	8
9	Meter Sensor (Heat)	Unit-2, Meter	SDM 5	9
10	Meter Sens (H water)	Unit-2, Meter	SDM 6	10
11	Thermocouple	Unit-2, Living rm.	Multiplexer 3.1	11
12	Thermocouple (MRT)	Unit-2, Living rm.	Multiplexer 3.2	12
13	Humidity Senor	Unit-2, Living rm.	Multiplexer 4.1	13
14	Thermocouple	Unit-2,South Wall	Multiplexer 4.2	14
15	Thermocouple	Unit-3,South Wall	Multiplexer 5.1	15
16	Thermocouple	Unit-3, Living rm.	Multiplexer 5.2	16
17	Thermocouple(MRT)	Unit-3, Living rm.	Multiplexer 6.1	17
18	Humidity Senor	Unit-3, Living rm.	Multiplexer 6.2	18
19	Thermocouple	Unit-3, Second Floor	Multiplexer 7.1	19
20	Meter Sensor (Main)	Unit-3, Meter	SDM 7	20
21	Meter Sensor (Heat)	Unit-3, Meter	SDM8	21
22	Meter Sens (H water)	Unit-3, Meter	CR10 Pulse 2	22
47	Wind Direction	Weather Station	CR10 Ch 2	26
48	Wind Speed	Weather Station	CR10 Pulse 1	27
49	Pyranometer (H Rad)	Weather Station	Multiplexer 7.2	28
50	Pyranometer (V Rad)	Weather Station	Multiplexer 8.1	29
51	Humidity sensor	Exterior wall Unit-1	Multiplexer 8.2	30
52	Thermocouple	Weather Station	Multiplexer 8.2	31
53	Mean Radiant Temp	Weather Station	Multiplexer 8.2	32
	Thermistor	Inside Data logger	CR 10 Ex 1	25

Table 7.2-1
Instrumentation Schedule

DATA LOGGER 2

No.	SENSOR TYPE	LOCATION	CHANNEL No.	OUTPUT LOC
23	Thermocouple	Unit-4, South Wall	Multiplexer 1.1	1
24	Thermocouple	Unit-4, Living rm.	Multiplexer 1.2	2
25	Thermocouple (MRT)	Unit-4, Living rm.	Multiplexer 2.1	3
26	Humidity Senor	Unit-4, Living rm.	Multiplexer 2.2	4
27	Thermocouple	Unit-4, Second Floor	Multiplexer 3.1	5
28	Meter Sensor (Main)	Unit-4, Meter	SDM 1	6
29	Meter Sensor (Heat)	Unit-4, Meter	SDM 2	7
30	Meter Sens (H water)	Unit-4, Meter	SDM 3	8
31	Thermocouple	Unit-5,South Wall	Multiplexer 3.2	9
32	Thermocouple	Unit-5, Living rm.	Multiplexer 4.1	10
33	Thermocouple (MRT)	Unit-5, Living rm.	Multiplexer 4.2	11
34	Humidity Senor	Unit-5, Living rm.	Multiplexer 5.1	12
35	Thermocouple	Unit-5, Second Floor	Multiplexer 5.2	13
36	Meter Sensor (Main)	Unit-5, Meter	SDM 4	14
37	Meter Sensor (Heat)	Unit-5, Meter	SDM 5	15
38	Meter Sens (H water)	Unit-5, Meter	SDM 6	16
39	Thermocouple	Unit-6,South Wall	Multiplexer 5.1	17
40	Thermocouple	Unit-6, Living rm.	Multiplexer 5.2	18
41	Thermocouple(MRT)	Unit-6, Living rm.	Multiplexer 6.1	19
42	Humidity Senor	Unit-6, Living rm.	Multiplexer 6.2	20
43	Thermocouple	Unit-6, Second Floor	Multiplexer 7.1	21
44	Meter Sensor (Main)	Unit-6, Meter	SDM 7	22
45	Meter Sensor (Heat)	Unit-6, Meter	SDM8	23
46	Meter Sens (H water)	Unit-6, Meter	CR10 Pulse 2	24
47	Thermistor	Inside Data logger	CR 10 Ex 1	25

Table 7.2-1
Instrumentation Schedule (continued)

7.3 INFRARED SCANS

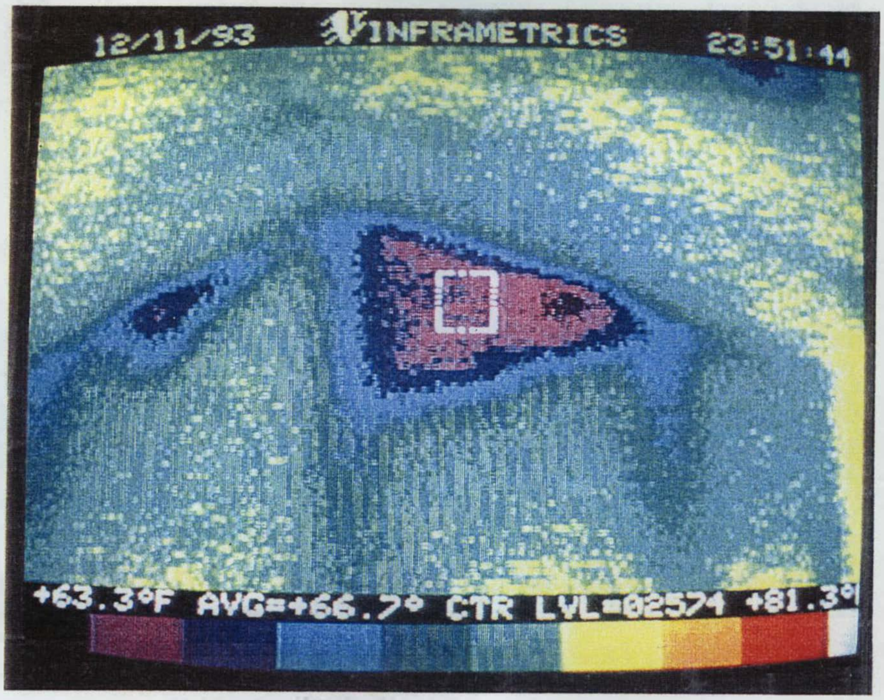


Figure 7.3-1, Missing or improperly installed insulation at the transition from a vaulted roof to a flat roof, Unit 1, 1 story SSIC Unit

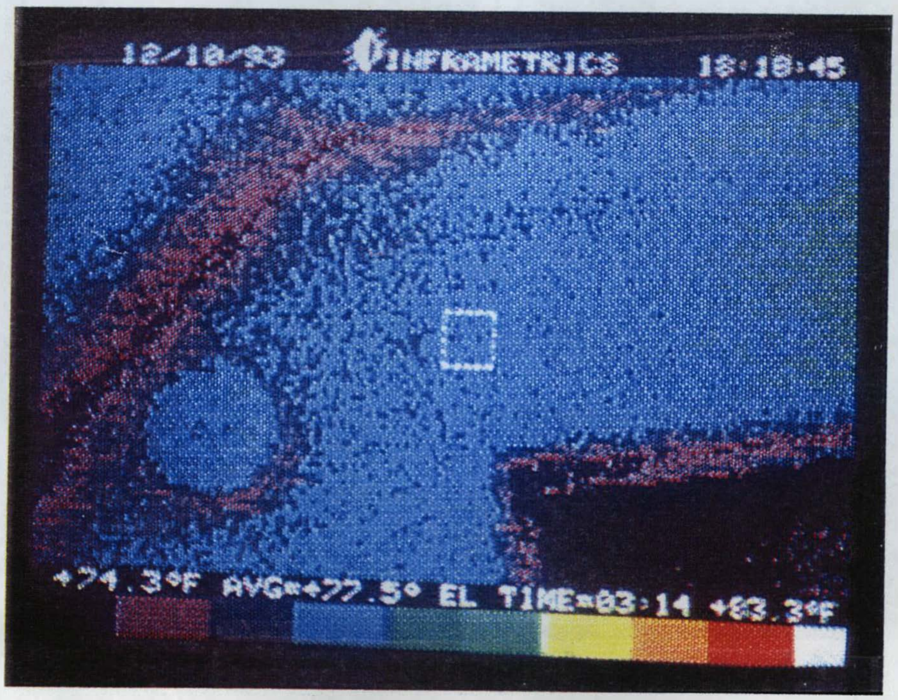


Figure 7.3-2, Heat loss at joint of wall to roof, around fresh air vent, and around window Unit 4, 1 1/2 Story Open Panel Unit

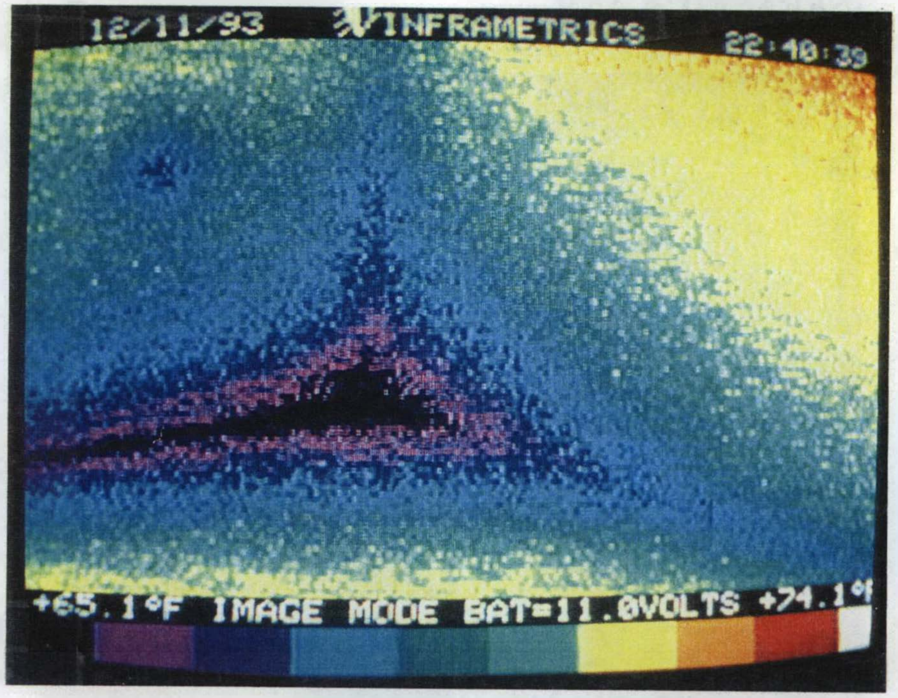


Figure 7.3-3
Heat loss at intersection of panels and wall slab at building corner typical of all Units, heat loss through electrical outlet also visible in upper left corner

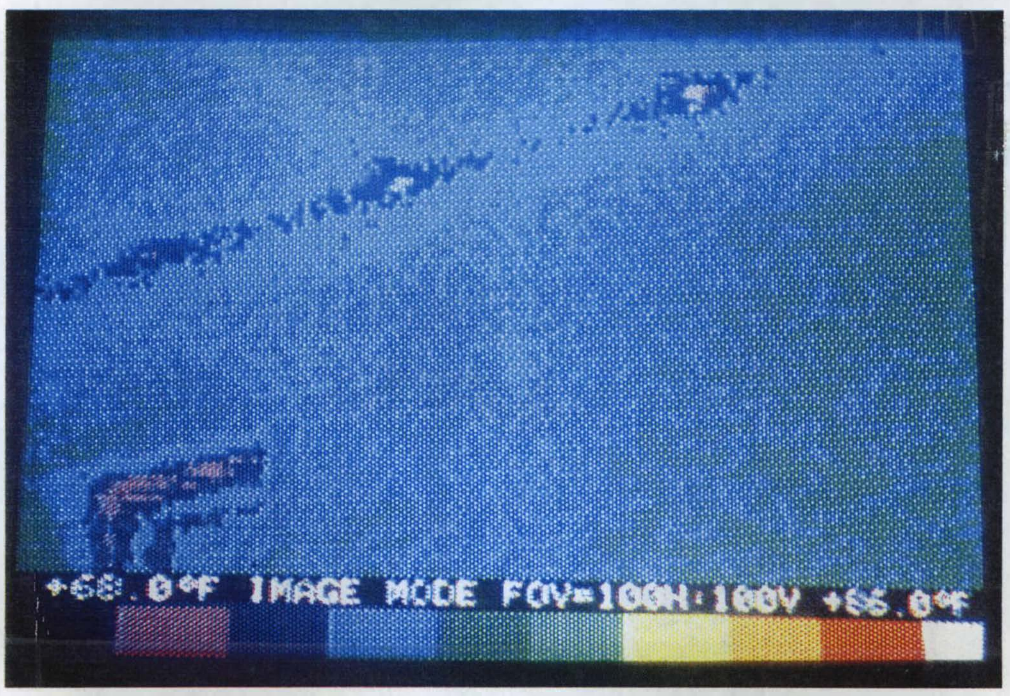
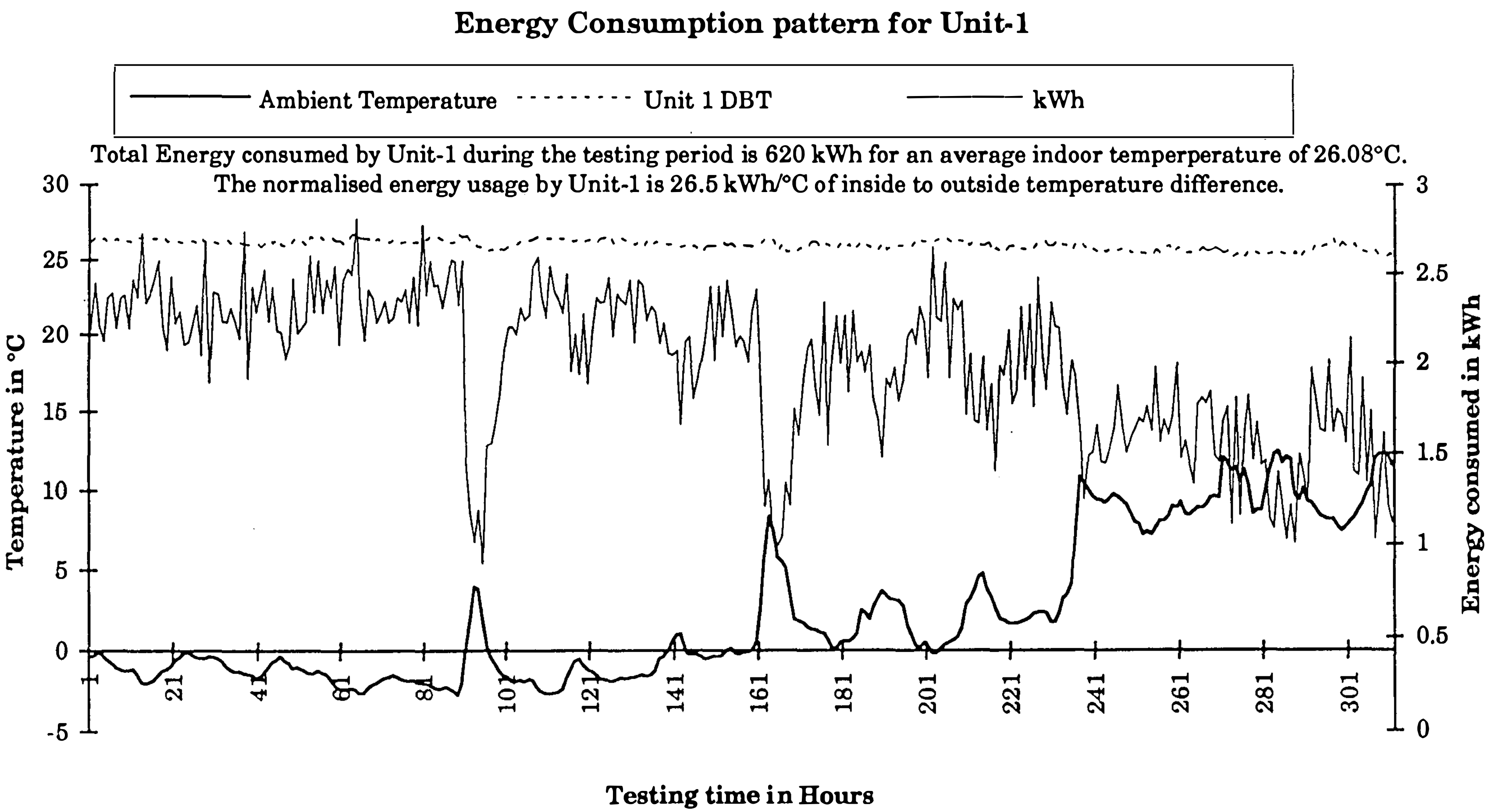
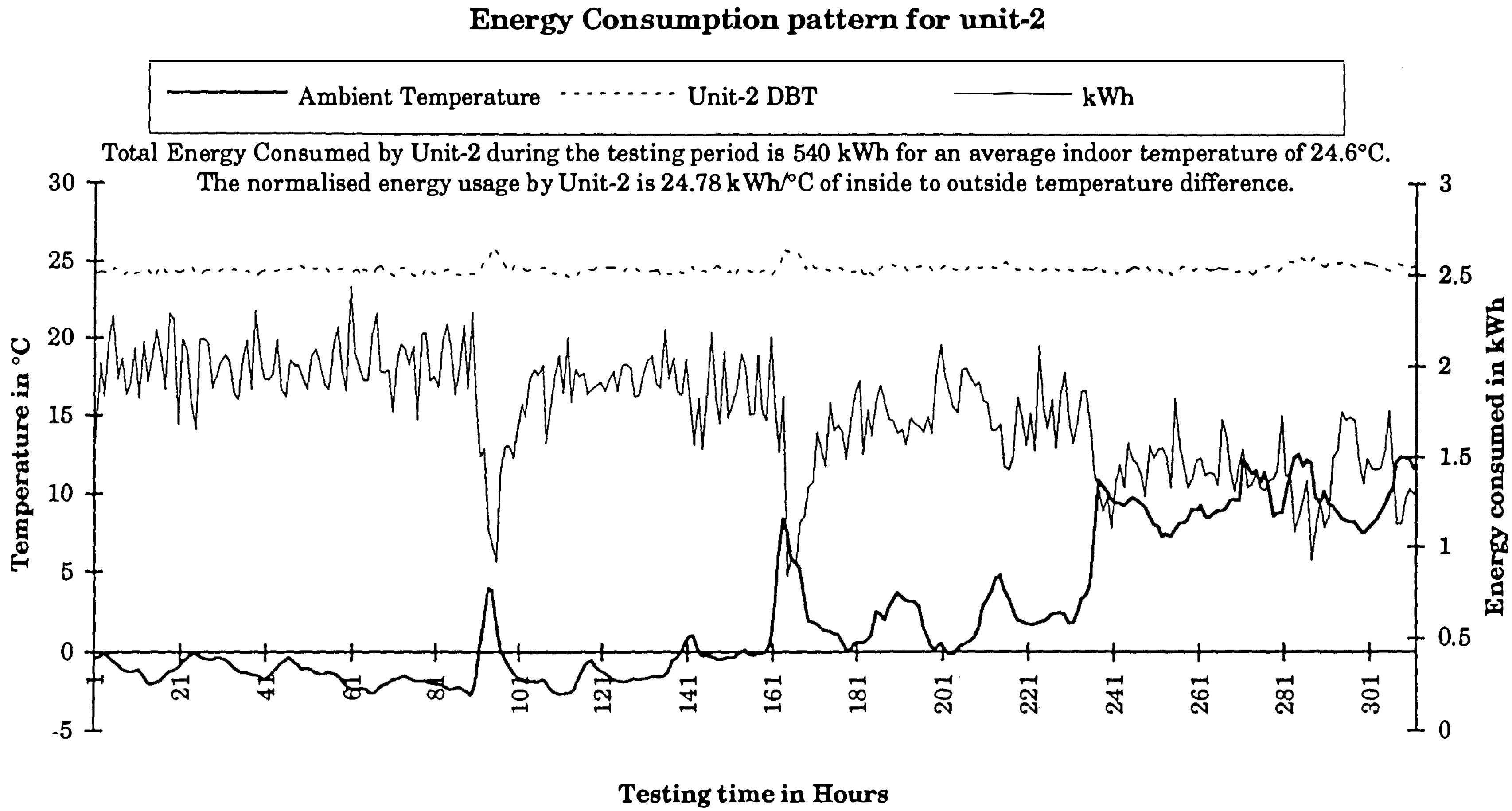


Figure 7.3-4
Heat loss at joint of wall and vaulted ceiling and at window. Heat loss at wall framing and roof truss framing more pronounced.

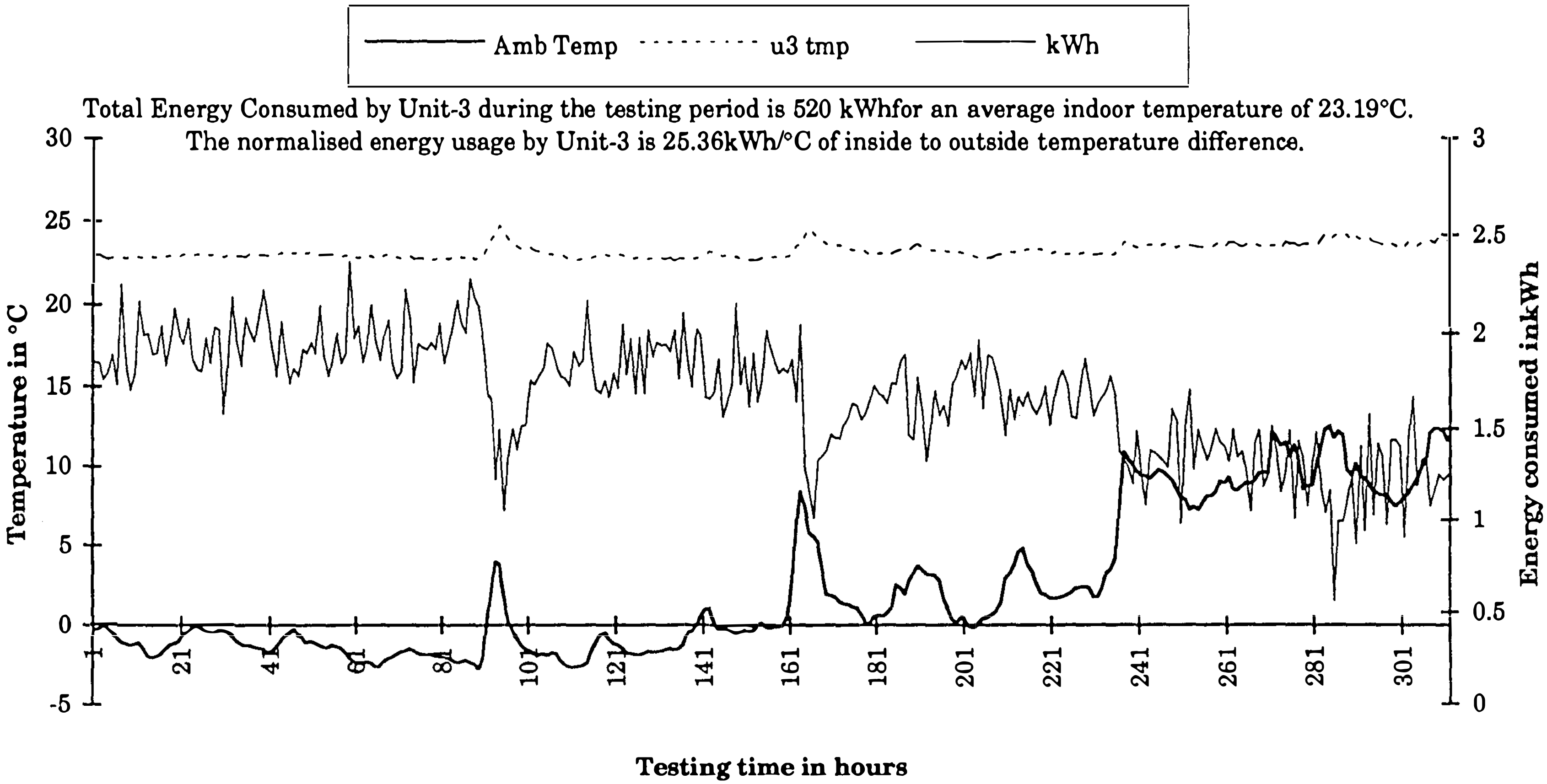
7.4 SHORT-TERM MONITORING


Energy Consumption pattern for Unit-1
Ambient Temperature
Unit 1 DBT
kWh
Total Energy consumed by Unit-1 during the testing period is 620 kWh for an average indoor temperperature of 26.08°C.
The normalised energy usage by Unit-1 is 26.5 kWh/°C of inside to outside temperature difference.
Temperature in °C
Energy consumed in kWh
Testing time in Hours

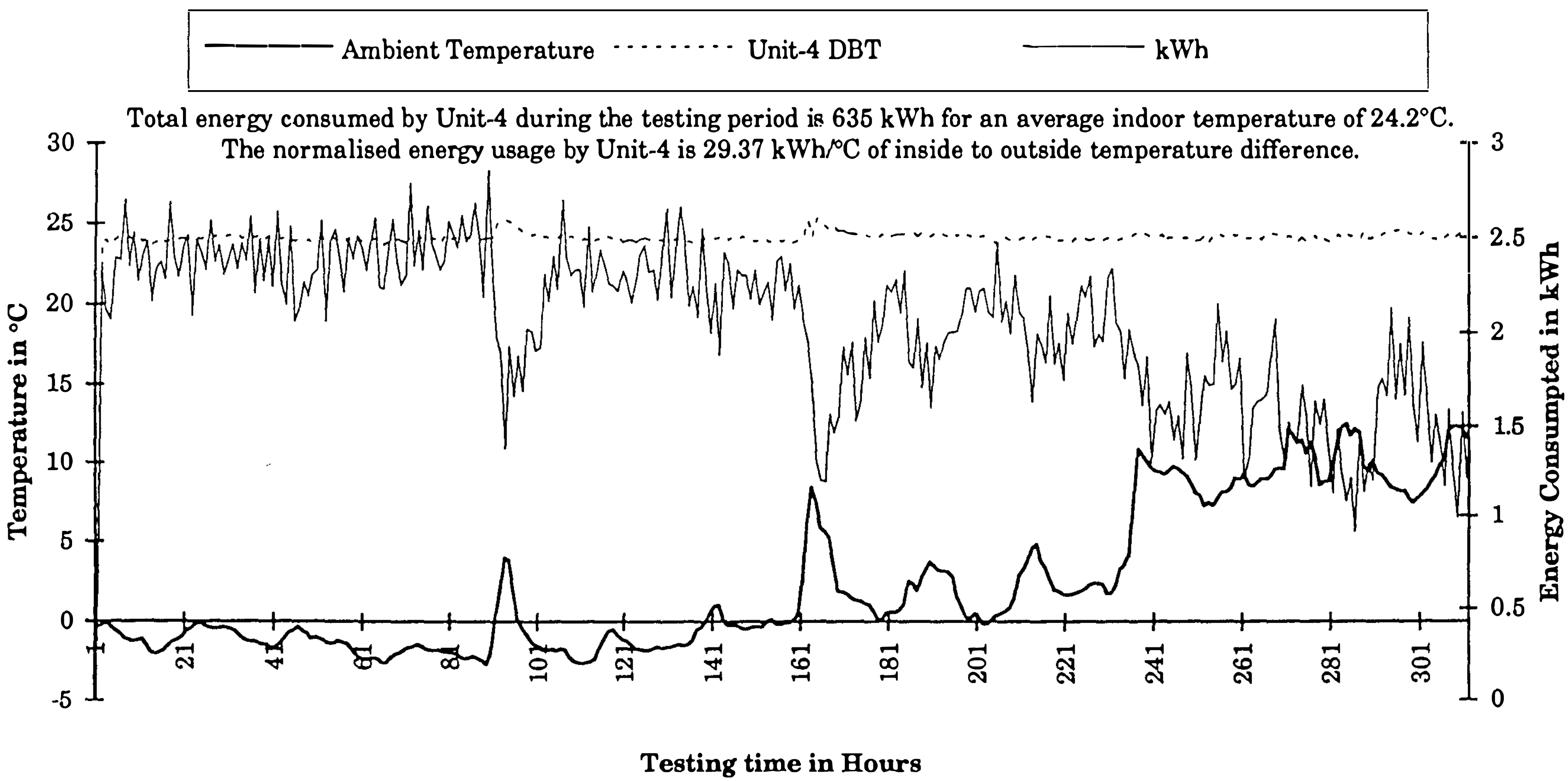


Energy Consumption pattern for unit-2
Ambient Temperature
Unit-2 DBT
kWh
Total Energy Consumed by Unit-2 during the testing period is 540 kWh for an average indoor temperature of 24.6°C.
The normalised energy usage by Unit-2 is 24.78 kWh/°C of inside to outside temperature difference.
Temperature in °C
Energy consumed in kWh
30
25
20
15
10
5
0
-5
3
2.5
2
1.5
1
0.5
0
1
21
41
61
81
101
121
141
161
181
201
221
241
261
281
301
Testing time in Hours

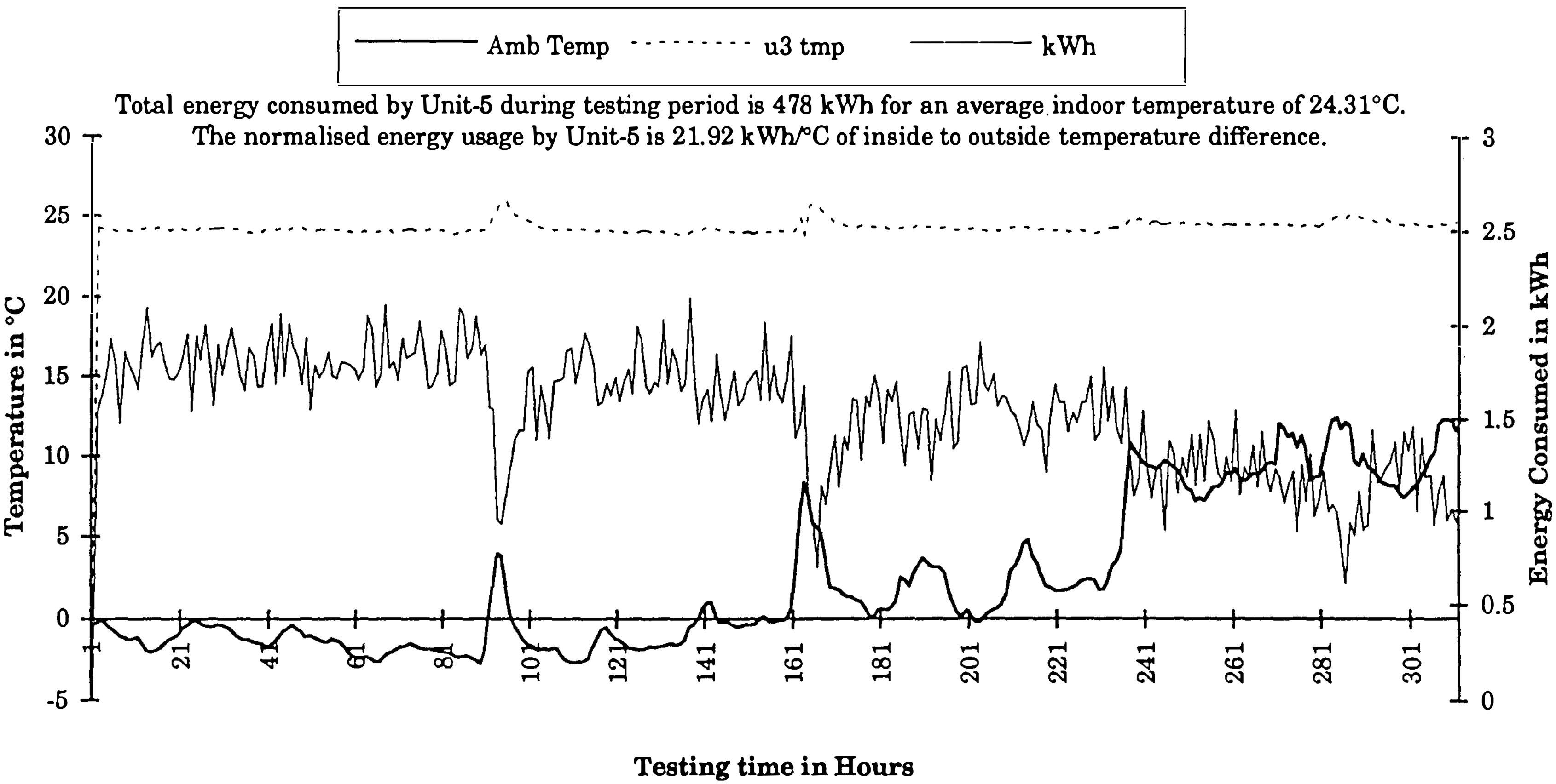
Energy Consumption Pattern for Unit-3



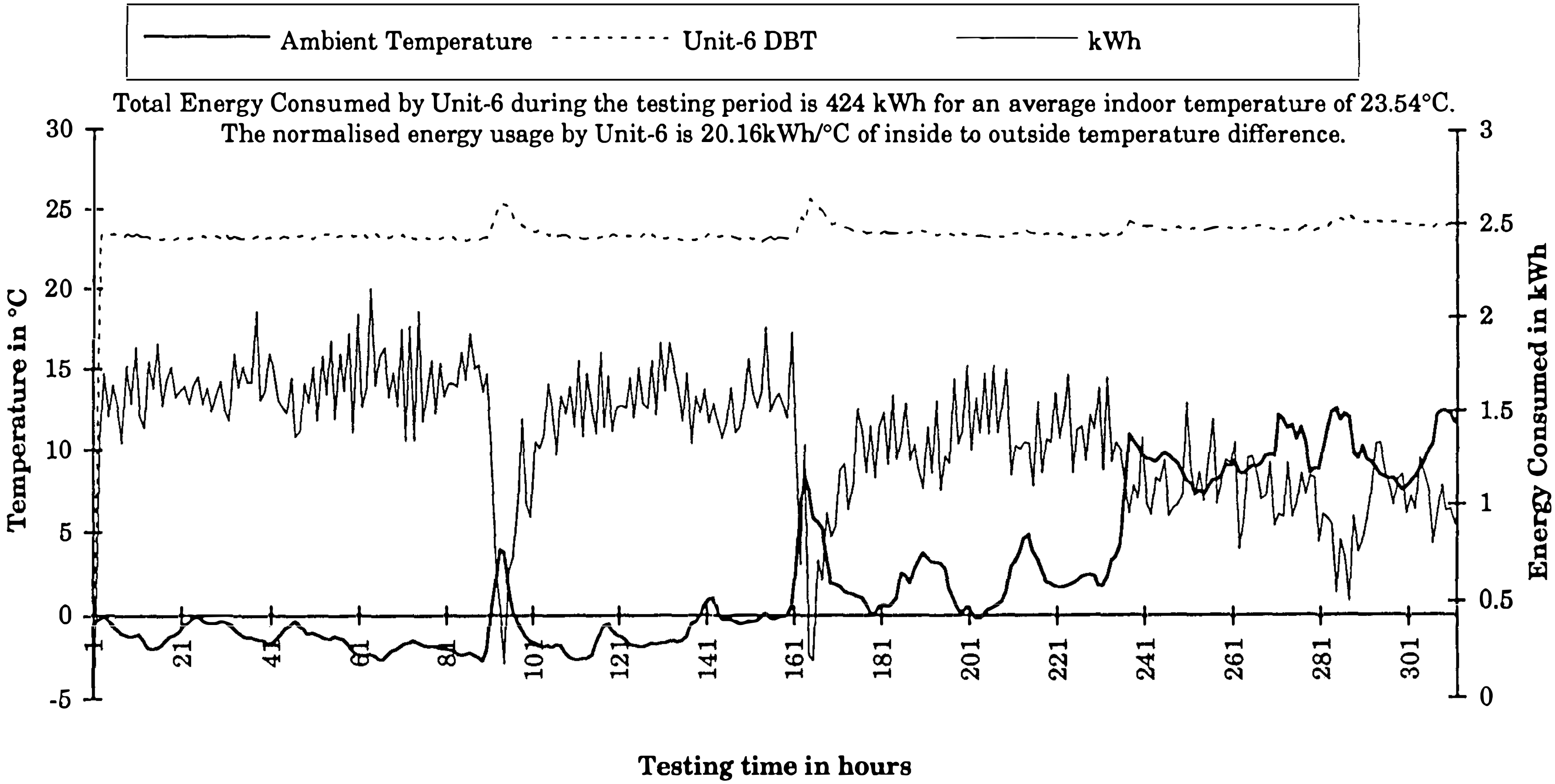
Energy Consumption pattern for Unit-4

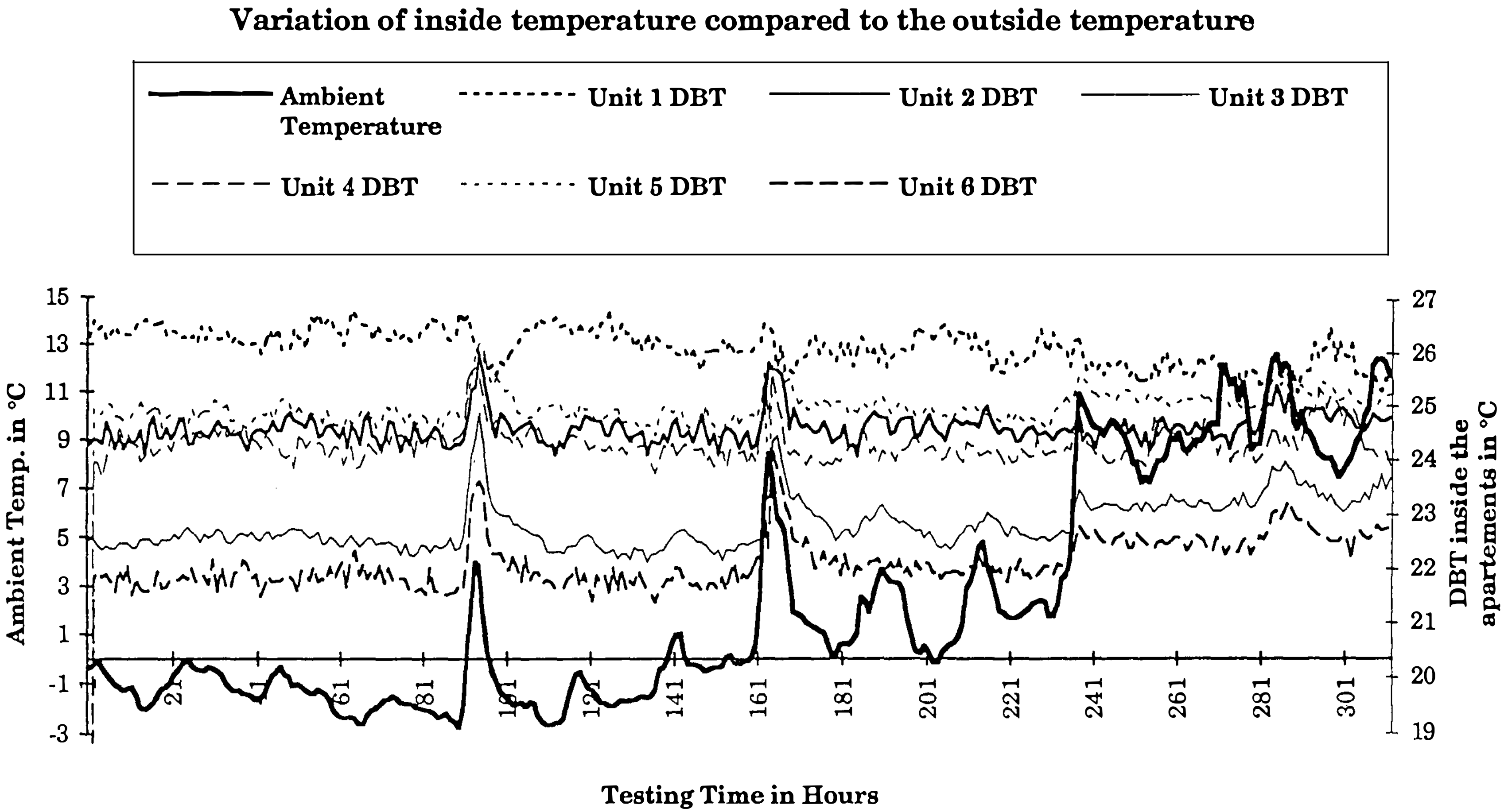


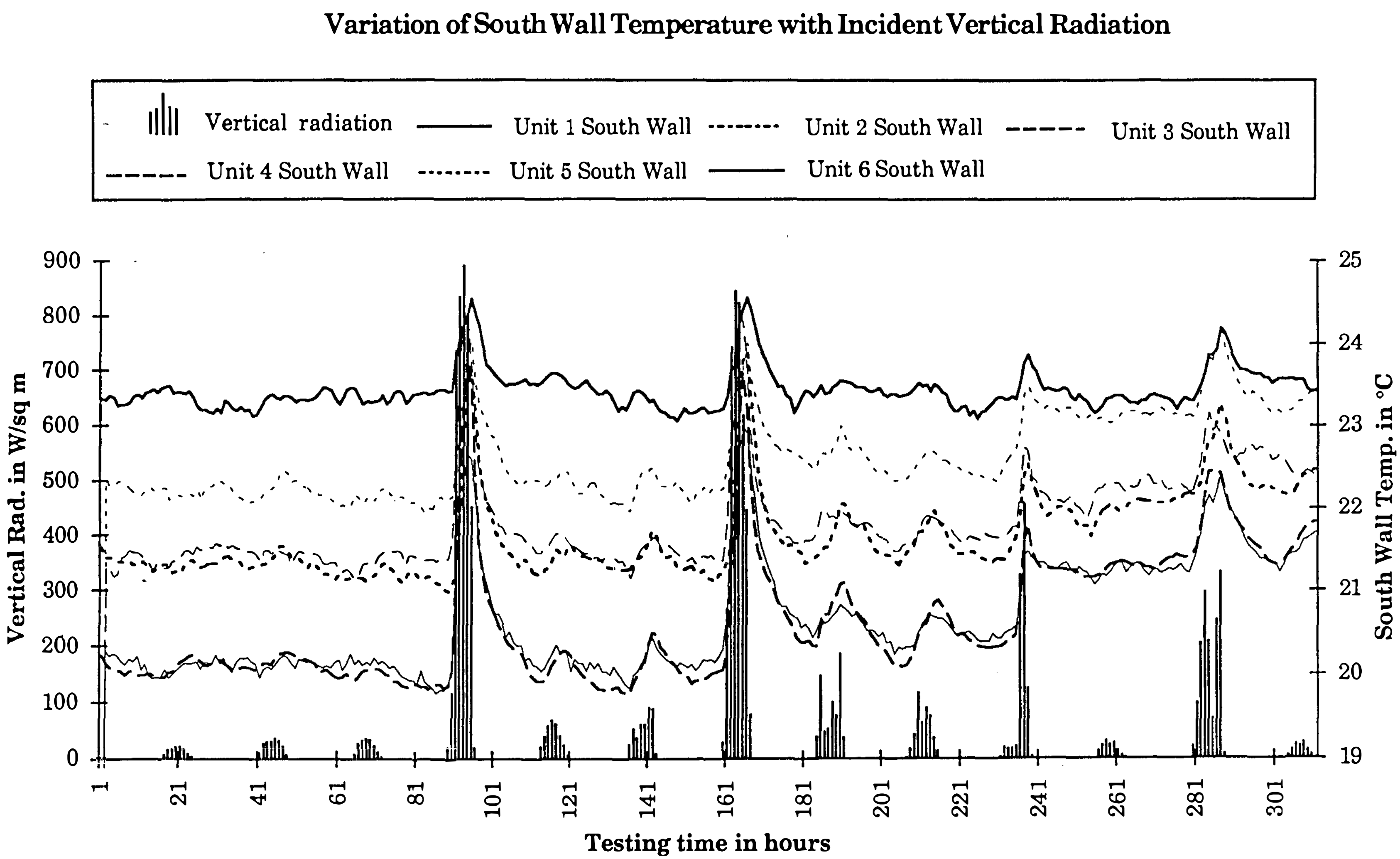
Energy Consumption pattern for Unit-5



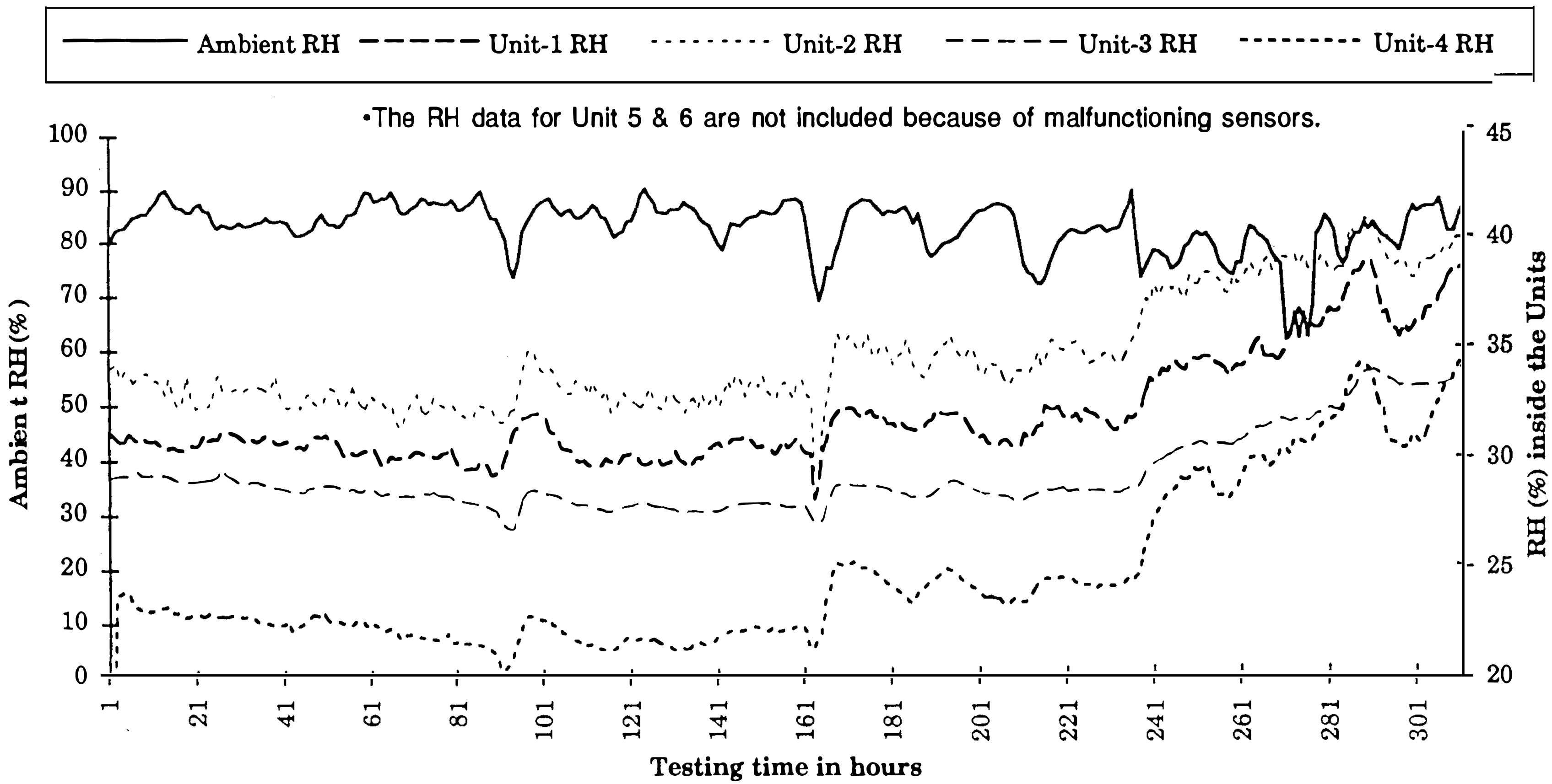
Energy Consumption Patttern for Unit-6




Variation of inside temperature compared to the outside temperature
Ambient Temperature
Unit 1 DBT
Unit 2 DBT
Unit 3 DBT
Unit 4 DBT
Unit 5 DBT
Unit 6 DBT
Ambient Temp. in °C
DBT inside the apartements in °C
Testing Time in Hours
15
13
11
9
7
5
3
1
-1
-3
27
26
25
24
23
22
21
20
19
21
61
81
141
161
181
201
221
241
261
281
301


Variation of South Wall Temperature with Incident Vertical Radiation
Vertical radiation
Unit 1 South Wall
Unit 2 South Wall
Unit 3 South Wall
Unit 4 South Wall
Unit 5 South Wall
Unit 6 South Wall
Vertical Rad. in W/sq m
South Wall Temp. in °C
Testing time in hours
0
100
200
300
400
500
600
700
800
900
19
20
21
22
23
24
25
1
21
41
61
81
101
121
141
161
181
201
221
241
261
281
301

Variation of Relative Humudity (%)



7.5 BLOWER DOOR DATA

BLOWER DOOR TEST RESULTS: AIR LEAKAGE THROUGH BUILDING ENVELOPE

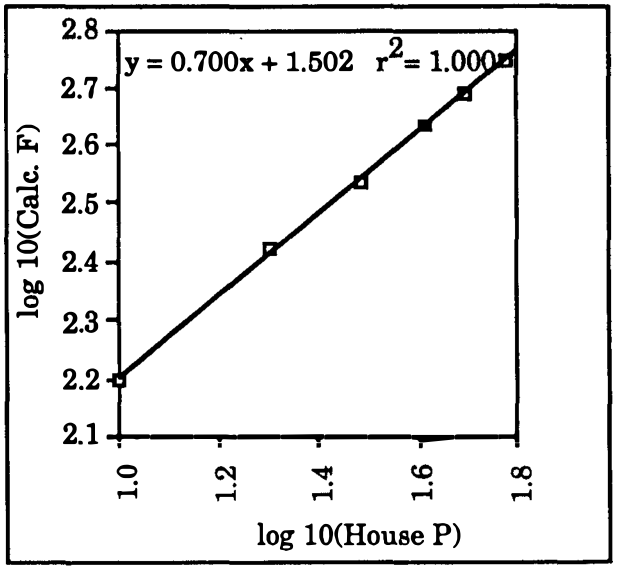
Passive Vent:	Taped	BPA Vents:	Closed		
Home:	U of O, Unit 1	Address:	Eugene, OR	C=	21
Date:	22 Nov 93			H=	1
House Floor Area:	674 sq. ft	Indoor Air Temp (F):	72	S=	1
House Volume:	6086 cu.ft.	Outdoor Air Temp (F):	44	L=	1.4
House Surface Area:	2392 sq.ft.	Air density factor:	0.97	N=	29.4

Special Note: No Forced Air

Rings	House Pressure	Log House Pressure	Fan Pressure	Calc Flow	Log Flow
O, A, B	(Pa)	log 10	(Pa)	(cfm)	log 10
B	10.00	1.00	-7.90	158.55	2.20
B	20.10	1.30	-21.40	262.64	2.42
B	30.60	1.49	-36.60	344.68	2.54
B	40.80	1.61	-56.90	431.00	2.63
B	50.20	1.70	-73.50	490.66	2.69
B	60.30	1.78	-94.90	558.46	2.75

Regression Output

X Coefficient	0.7
Constant:	1.5
r:	1.0
r squared:	1.0



CFM4 =	83.84	cfm - from curve fit
CFM10 =	159.22	cfm - from curve fit
ELA =	23.77	sq. in @ 4 Pa
EqLA =	46.80	sq. in @ 10 Pa
CFM50 =	491.22	cfm - from curve fit
ACH50 =	4.84	air changes per hour at 50 Pascal
ACH50/20 =	0.24	estimate of natural ACH by Persily
ACH50/N =	0.16	estimate of natural ACH by Sherman
SLA =	2.45	dimensionless specific leakage area

BLOWER DOOR TEST RESULTS: AIR LEAKAGE THROUGH BUILDING ENVELOPE

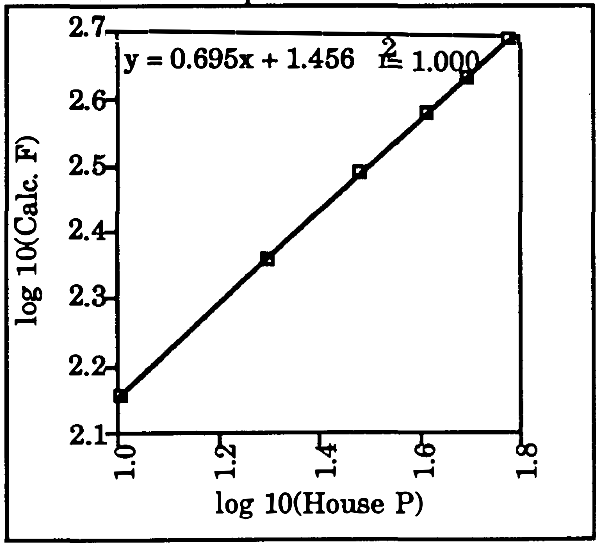
Passive Vent: Taped
Home: U of O, Unit 2
Date: 20 Nov 93
House Floor Area: 674 sq. ft
House Volume: 6086 cu.ft.
House Surface Area: 2392 sq.ft.
Special Note: No Forced Air

BPA Vents: Closed
Address: Eugene, OR
Indoor Air Temp (F): 76
Outdoor Air Temp (F): 40
Air density factor: 0.97

C= 21
H= 1
S= 1
L= 1.4
N= 29.4

Rings O, A, B	House Pressure (Pa)	Log House Pressure log 10	Fan Pressure (Pa)	Calc Flow (cfm)	Log Flow log 10
B	10.20	1.01	-6.60	143.71	2.16
B	20.00	1.30	-16.50	228.58	2.36
B	30.10	1.48	-29.50	306.79	2.49
B	40.80	1.61	-45.10	380.38	2.58
B	49.80	1.70	-56.60	426.75	2.63
B	60.30	1.78	-75.50	493.80	2.69

Regression Output
X Coefficient: 0.7
Constant: 1.46
r: 1.0
r squared: 1.0



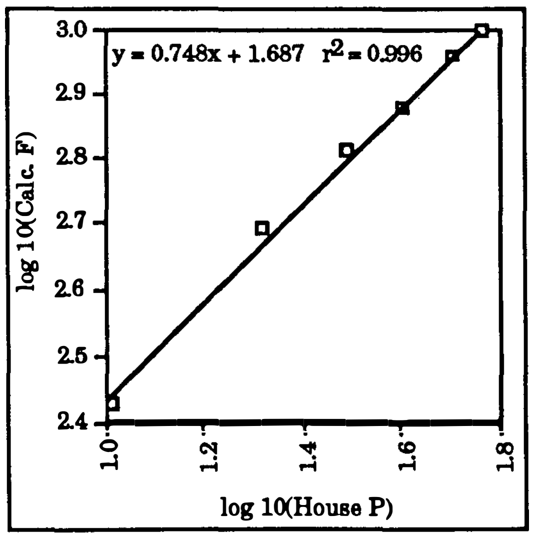
CFM4 = 74.89 cfm - from curve fit
CFM10 = 141.58 cfm - from curve fit
ELA = 21.23 sq. in @ 4 Pa
EqLA = 41.61 sq. in @ 10 Pa
CFM = 433.30 cfm - from curve fit
ACH50 = 4.27 air changes per hour at 50 Pascal
ACH50/20 = 0.21 estimate of natural ACH by Persily
ACH50/N 0.15 estimate of natural ACH by Sherman
SLA = 2.19 dimensionless specific leakage area

BLOWER DOOR TEST RESULTS: AIR LEAKAGE THROUGH BUILDING ENVELOPE

Passive Vent:	Taped		BPA Vents:	Closed		
Home:	U of O, Unit 3		Address:	Eugene, OR		
Date:	15 Nov 93					
House Floor Area:	800	sq. ft	Indoor Air Temp (F):	71.4	C=	21
House Volume:	5981	cu.ft.	Outdoor Air Temp (F):	57.1	H=	0.9
House Surface Area:	1965	sq.ft.	Air density factor:	0.99	S=	1
Special Note: No Forced Air					L=	1.4
					N=	26.46

Rings O, A, B	House Pressure (Pa)	Log House Pressure log 10	Fan Pressure (Pa)	Calc Flow (cfm)	Log Flow log 10
B	10.30	1.01	-21.60	267.41	2.43
B	20.60	1.31	-70.40	486.48	2.69
B	30.60	1.49	-121.20	640.57	2.81
B	39.90	1.60	-169.00	758.05	2.88
B	50.80	1.71	-242.00	909.23	2.96
B	58.30	1.77	-291.00	998.24	3.00

Regression Output	
X Coefficient:	0.748
Constant:	1.687
r:	0.998
r squared:	0.996



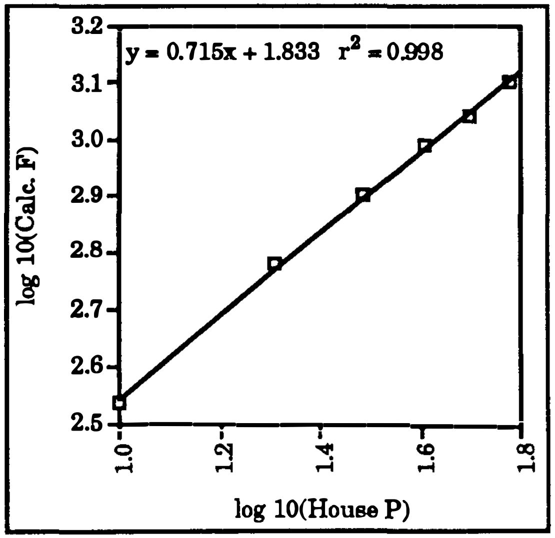
CFM4 =	137.20	cfm - from curve fit
CFM10 =	272.27	cfm - from curve fit
ELA =	38.90	sq. in @ 4 Pa
EqLA =	80.02	sq. in @ 10 Pa
CFM =	907.46	cfm - from curve fit
ACH50 =	9.10	air changes per hour at 50 Pascal
ACH50/20 =	0.46	estimate of natural ACH by Persily
ACH50/N	0.34	estimate of natural ACH by Sherman
SLA =	3.38	dimensionless specific leakage area

BLOWER DOOR TEST RESULTS: AIR LEAKAGE THROUGH BUILDING ENVELOPE

Passive Vent:	Taped	BPA Vents:	Closed		
Home:	U of O, Unit 4	Address:	Eugene, OR		
Date:	19 Nov 93				
House Floor Area:	868 sq. ft	Indoor Air Temp (F):	63	C=	21
House Volume:	6424 cu.ft.	Outdoor Air Temp (F):	37	H=	0.9
House Surface Area:	2182 sq.ft.	Air density factor:	0.9748	S=	1
Special Note: No Forced Air				L=	1.4
				N=	26.46

Rings O, A, B	House Pressure (Pa)	Log House Pressure log 10	Fan Pressure (Pa)	Calc Flow (cfm)	Log Flow log 10
A	10.00	1.000	-4.00	349.83	2.54
A	20.50	1.312	-12.00	602.48	2.78
A	30.30	1.481	-20.50	785.27	2.90
A	40.30	1.605	-31.80	975.81	2.99
A	50.10	1.700	-41.00	1106.54	3.04
A	60.10	1.779	-54.20	1270.42	3.10

Regression Output	
X Coefficient:	0.715
Constant:	1.833
r:	0.999
r squared:	0.998



CFM4 =	183.43	cfm - from curve fit
CFM10 =	353.18	cfm - from curve fit
ELA =	52.00	sq. in @ 4 Pa
EqLA =	103.80	sq. in @ 10 Pa
CFM =	1116.26	cfm - from curve fit
ACH50 =	10.43	air changes per hour at 50 Pascal
ACH50/20 =	0.52	estimate of natural ACH by Persily
ACH50/N	0.39	estimate of natural ACH by Sherman
SLA =	4.16	dimensionless specific leakage area

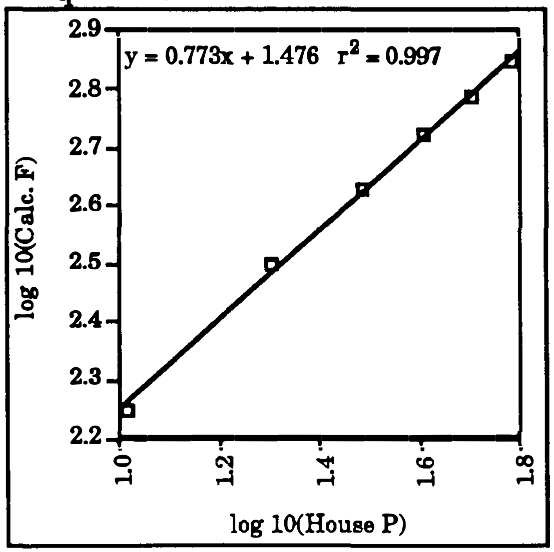
BLOWER DOOR TEST RESULTS: AIR LEAKAGE THROUGH BUILDING ENVELOPE

Passive Vent:	Taped	BPA Vents:	Closed		
Home:	U of O, Unit 5	Address:	Eugene, OR		
Date: 19 Nov 93					
House Floor Area:	713 sq. ft	Indoor Air Temp (F):	68	C=	21
House Volume:	5552 cu.ft.	Outdoor Air Temp (F):	37	H=	0.8
House Surface Area:	1721 sq.ft.	Air density factor:	0.9702	S=	1
				L=	1.4
Special Note: No Forced Air				N=	23.52

Rings O, A, B	House Pressure (Pa)	Log House Pressure (log 10)	Fan Pressure (Pa)	Calc Flow (cfm)	Log Flow (log 10)
B	10.30	1.01	-9.80	176.29	2.25
B	20.00	1.30	-31.00	315.89	2.50
B	30.50	1.48	-56.00	426.21	2.63
B	40.50	1.61	-85.00	526.52	2.72
B	50.30	1.70	-114.80	613.10	2.79
B	60.50	1.78	-150.00	702.03	2.85

Regression Output

X Coefficient:	0.773
Constant:	1.476
r:	0.999
r squared:	0.997



CFM4 =	87.38	cfm - from curve fit
CFM10 =	177.42	cfm - from curve fit
ELA =	24.77	sq. in @ 4 Pa
EqLA =	52.14	sq. in @ 10 Pa
CFM =	615.61	cfm - from curve fit
ACH50 =	6.65	air changes per hour at 50 Pascal
ACH50/20 =	0.33	estimate of natural ACH by Persily
ACH50/N	0.28	estimate of natural ACH by Sherman
SLA =	2.41	dimensionless specific leakage area

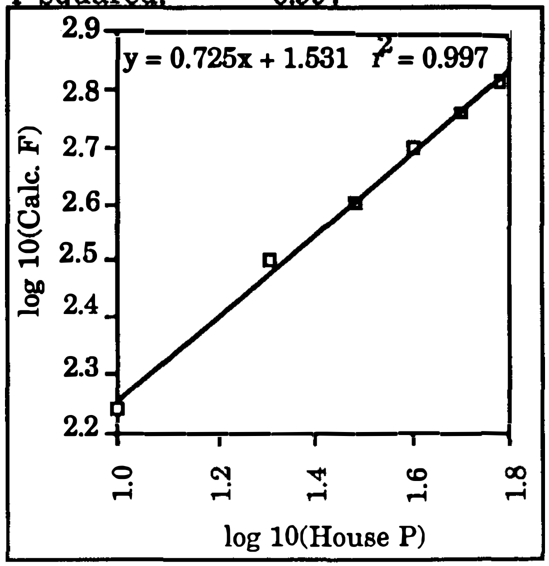
BLOWER DOOR TEST RESULTS: AIR LEAKAGE THROUGH BUILDING ENVELOPE

Passive Vent:	Taped		BPA Vents:	Closed			
Home:	U of O, Unit 6		Address:	Eugene, OR			
Date:	20 Nov 93						
House Floor Area:	713	sq. ft	Indoor Air Temp (F):	70		C=	21
House Volume:	5552	cu.ft.	Outdoor Air Temp (F):	40		H=	0.8
House Surface Area:	1721	sq.ft.	Air density factor:	0.9713		S=	1
Special Note: No Forced Air						L=	1.4
						N=	23.52

Rings O, A, B	House Pressure (Pa)	Log House Pressure log 10	Fan Pressure (Pa)	Calc Flow (cfm)	Log Flow log 10
B	10.00	1.00	-9.60	174.64	2.24
B	20.30	1.31	-30.90	315.70	2.50
B	30.10	1.48	-50.10	403.26	2.61
B	40.20	1.60	-75.50	496.36	2.70
B	49.80	1.70	-99.70	571.42	2.76
B	60.20	1.78	-128.90	650.82	2.81

Regression Output

X Coefficient:	0.725
Constant:	1.531
r:	0.998
r squared:	0.997



CFM4 =	92.79	cfm - from curve fit
CFM10 =	180.30	cfm - from curve fit
ELA =	26.31	sq. in @ 4 Pa
EqLA =	52.99	sq. in @ 10 Pa
CFM =	579.10	cfm - from curve fit
ACH50 =	6.26	air changes per hour at 50 Pascal
ACH50/20 =	0.31	estimate of natural ACH by Persily
ACH50/N	0.27	estimate of natural ACH by Sherman
SLA =	2.56	dimensionless specific leakage area

7.6 COHEATING DATA

Coheating Test: Unit 1, 1 story SSIC										
Passive Vents: Taped										
Nov. 24, 1993										
Time	Tair1(F)	Tair2(F)	Tair3(F)	Tair4(F)	Tair5(F)	Avg Tair(F)	Tamb(F)	ΔT	w-hr	UA(W/F)
306	74.9	75.2	75.0	76.3	75.0	75.3	22.0	53.3	424.8	79.70
312	74.9	75.1	75.0	75.9	75.1	75.2	22.1	53.1	403.2	75.98
318	75.0	75.1	75.0	76.9	75.6	75.5	21.7	53.9	331.2	61.49
324	75.2	75.1	75.0	77.3	75.5	75.6	21.2	54.4	208.8	38.38
330	75.1	75.2	75.0	76.2	75.0	75.3	21.1	54.2	165.6	30.54
336	75.0	75.7	75.0	76.2	74.8	75.3	20.9	54.5	208.8	38.35
342	75.0	76.3	75.0	76.4	74.9	75.5	20.7	54.8	223.2	40.70
348	75.0	76.8	75.0	76.1	74.8	75.5	20.6	55.0	237.6	43.22
354	75.0	77.1	75.0	76.2	74.8	75.6	20.6	55.0	439.2	79.84
400	74.9	76.7	75.0	76.5	75.2	75.7	20.4	55.3	388.8	70.36
406	74.9	76.0	75.0	76.8	75.2	75.6	20.3	55.3	381.6	69.01
412	75.2	75.7	75.0	77.6	75.6	75.8	20.1	55.8	201.6	36.15
418	75.2	75.2	75.0	76.4	75.1	75.4	19.7	55.6	172.8	31.06
424	75.1	75.1	75.0	76.2	74.9	75.3	19.4	55.9	158.4	28.36
430	75.1	75.1	75.0	76.2	74.9	75.3	19.6	55.7	187.2	33.61
436	75.0	75.1	75.0	76.1	74.8	75.2	19.6	55.6	237.6	42.74
442	74.9	75.2	75.0	76.2	74.7	75.2	19.7	55.5	460.8	83.03
448	74.9	75.7	75.1	76.5	75.2	75.5	20.1	55.4	489.6	88.38
454	74.9	76.3	75.2	77.1	75.3	75.8	20.2	55.6	432	77.70
500	75.0	76.9	75.3	77.7	75.7	76.1	20.0	56.1	345.6	61.57
506	75.1	77.2	75.3	76.8	75.4	76.0	19.8	56.1	187.2	33.36
512	75.2	76.8	75.1	76.3	74.9	75.7	19.7	56.0	151.2	27.02
518	75.1	76.0	75.1	76.2	74.9	75.5	19.6	55.8	122.4	21.92
524	75.0	75.3	75.0	76.2	74.7	75.2	19.7	55.5	172.8	31.11
530	74.9	75.1	75.0	76.0	74.7	75.1	19.8	55.4	295.2	53.32
						Avg. Tair	Avg. Tamb	Avg ΔT	Sum W-hr.	Avg. UA
						75.5	20.3	55.1	7027.2	51.08

Coheating Test: Unit 2, 1 story Closed Panel										
Passive Vents: Taped										
Nov. 28, 1993										
Time	Tair1(F)	Tair2(F)	Tair3(F)	Tair4(F)	Tair5(F)	Avg T	Tamb(F)	ΔT(F)	w-hr	UA(W/F)
306	75.0	75.2	75.0	75.3	75.0	75.1	35.4	39.7	223.2	56.2
312	75.0	75.3	75.0	75.3	75.0	75.12	35.1	40.0	208.8	52.2
318	75.0	75.2	75.1	75.4	75.0	75.14	35.1	40.0	194.4	48.6
324	75.0	75.2	75.1	75.3	75.1	75.14	35.2	40.0	201.6	50.4
330	75.0	75.2	75.0	75.3	75.1	75.12	35.2	40.0	230.4	57.7
336	75.0	75.3	75.0	75.4	75.1	75.16	35.2	39.9	201.6	50.5
342	75.0	75.2	75.1	75.3	75.1	75.14	35.3	39.8	201.6	50.6
348	75.0	75.2	75.0	75.3	75.0	75.1	35.5	39.6	223.2	56.4
354	75.0	75.2	75.0	75.4	75.0	75.12	35.5	39.6	208.8	52.7
400	75.0	75.2	75.1	75.4	75.0	75.14	35.6	39.6	187.2	47.3
406	75.0	75.2	75.0	75.3	75.1	75.12	35.7	39.4	208.8	52.9
412	75.0	75.2	75.1	75.3	75.0	75.12	35.7	39.5	223.2	56.6
418	75.0	75.2	75.1	75.5	75.0	75.16	35.6	39.6	223.2	56.4
424	75.0	75.3	75.0	75.4	75.0	75.14	35.7	39.4	201.6	51.2
430	75.0	75.3	75.1	75.3	75.0	75.14	35.7	39.5	194.4	49.3
436	75.0	75.2	75.0	75.3	75.0	75.1	35.6	39.5	223.2	56.5
442	75.0	75.3	75.1	75.4	75.0	75.16	35.5	39.6	201.6	50.9
448	75.0	75.2	75.0	75.4	75.1	75.14	35.6	39.5	208.8	52.8
454	75.1	75.2	75.0	75.3	75.0	75.12	35.6	39.5	201.6	51.0
500	75.0	75.2	75.1	75.3	75.1	75.14	35.6	39.5	223.2	56.5
506	75.0	75.2	75.1	75.4	75.0	75.14	35.7	39.5	216	54.7
512	75.0	75.2	75.1	75.4	75.0	75.14	35.6	39.6	194.4	49.1
518	75.1	75.3	75.0	75.4	75.1	75.18	35.5	39.7	187.2	47.1
524	75.0	75.3	75.0	75.3	75.0	75.12	35.4	39.8	230.4	58.0
530	75.0	75.3	75.1	75.4	75.0	75.2	35.5	39.7	216.0	54.5
						Avg. Tair	Avg. Tamb	Avg. ΔT	Sum W-hr	Avg. UA
						75.1	**35.5**	**39.7**	**5234.4**	**52.8**

Coheating Test: Unit 3, 1 1/2 story Open Panel										
Passive Vents: Taped										
Dec. 1, 1993										
Time	**Tair1(F)**	**Tair2(F)**	**Tair3(F)**	**Tair4(F)**	**Tair5(F)**	**T Avg**	**Tamb(F)**	**ΔT**	**w-hr**	**UA** (W/F)
306	75.3	75.1	75.2	75.3	75.1	75.2	51.73	23.47	122.40	52.15
312	75.2	75.1	75.2	75.3	75.2	75.2	51.64	23.56	144.00	61.12
318	75.3	75.1	75.1	75.3	75.1	75.2	51.66	23.52	158.40	67.35
324	75.1	75.2	75.2	75.3	75.2	75.2	51.58	23.62	144.00	60.97
330	75.3	75.2	75.3	75.3	75.3	75.3	51.45	23.83	108.00	45.32
336	75.2	75.1	75.2	75.3	75.2	75.2	51.34	23.86	151.20	63.37
342	75.4	75.1	75.1	75.2	75.1	75.2	51.4	23.78	151.20	63.58
348	75.4	75.2	75.3	75.3	75.1	75.3	51.31	23.95	136.80	57.12
354	75.3	75.2	75.3	75.3	75.2	75.3	51.21	24.05	129.60	53.89
400	75.2	75.2	75.3	75.3	75.1	75.2	51.3	23.92	151.20	63.21
406	75.4	75.4	75.3	75.3	75.1	75.3	51.34	23.96	129.60	54.09
412	75.3	75.1	75.3	75.4	75.2	75.3	50.89	24.37	144.00	59.09
418	75.3	75.2	75.3	75.2	75.2	75.2	50.89	24.35	144.00	59.14
424	75.1	75.2	75.2	75.3	75.2	75.2	50.61	24.59	144.00	58.56
430	75.4	75.2	75.2	75.2	75.1	75.2	50.88	24.34	136.80	56.20
436	75.3	75.2	75.3	75.2	75.2	75.2	51.16	24.08	165.60	68.77
442	75.5	75.4	75.3	75.4	75.2	75.4	51.2	24.16	122.40	50.66
448	75.4	75.3	75.2	75.2	75.2	75.3	51.05	24.21	129.60	53.53
454	75.3	75.2	75.2	75.3	75.1	75.2	51.36	23.86	144.00	60.35
500	75.2	75.1	75.2	75.2	75.2	75.2	51.32	23.86	129.60	54.32
506	75.3	75.1	75.3	75.2	75.2	75.2	51.23	23.99	122.40	51.02
512	75.2	75.1	75.2	75.3	75.1	75.2	51.18	24	151.20	63.00
518	75.4	75.2	75.2	75.3	75.1	75.2	50.98	24.26	136.80	56.39
524	75.4	75.2	75.2	75.2	75.2	75.2	51.34	23.9	136.80	57.24
530	75.2	75.3	75.3	75.2	75.2	75.2	51.31	23.93	144.00	60.18
						Avg. Tair	Avg. Tamb	Avg ΔT	Avg. W-hr.	Avg. UA
						75.23	**51.25**	**23.98**	**3477.60**	**58.02**

Coheating Test: Unit 4, 1 1/2 Story Open Panel Unit										
Passive Vents: Taped										
Time	Tair1(F)	Tair2(F)	Tair3(F)	Tair4(F)	Tair5(F)	Avg Tair	Tamb(F)	ΔT	w-hr	UA(W/F)
252	75.2	75.2	75.1	75.2	75.1	75.2	49.4	25.8	136.8	53.11
258	75.2	75.1	75.1	75.3	75.1	75.2	49.4	25.8	144.0	55.81
304	75.1	75.2	75.1	75.2	75.1	75.1	49.4	25.8	136.8	53.11
310	75.2	75.2	75.1	75.3	75.1	75.2	49.4	25.8	151.2	58.58
316	75.3	75.3	75.1	75.3	75.1	75.2	49.6	25.6	144.0	56.21
322	75.3	75.3	75.2	75.3	75.1	75.2	49.4	25.9	144.0	55.64
328	75.3	75.3	75.2	75.2	75.1	75.2	49.2	26.0	165.6	63.59
334	75.1	75.3	75.1	75.3	75.2	75.2	49.1	26.1	144.0	55.24
340	75.2	75.3	75.1	75.4	75.2	75.2	49.1	26.1	151.2	57.86
346	75.3	75.5	75.1	75.2	75.2	75.3	49.2	26.0	129.6	49.77
352	75.4	75.3	75.2	75.3	75.1	75.3	49.0	26.2	151.2	57.64
358	75.3	75.4	75.1	75.3	75.2	75.3	48.9	26.4	151.2	57.38
404	75.2	75.3	75.1	75.4	75.1	75.2	49.0	26.3	151.2	57.60
410	75.2	75.4	75.1	75.3	75.1	75.2	48.9	26.4	151.2	57.38
416	75.3	75.4	75.1	75.4	75.1	75.3	48.7	26.5	158.4	59.73
422	75.3	75.4	75.2	75.4	75.2	75.3	48.7	26.6	122.4	46.02
428	75.3	75.4	75.1	75.2	75.1	75.2	48.5	26.7	165.6	61.95
434	75.1	75.4	75.1	75.3	75.2	75.2	48.6	26.6	144.0	54.09
440	75.4	75.2	75.1	75.3	75.1	75.2	48.5	26.7	144.0	53.95
446	75.3	75.4	75.1	75.2	75.1	75.2	47.5	27.7	136.8	49.39
452	75.4	75.4	75.1	75.4	75.1	75.3	46.2	29.1	158.4	54.38
458	75.2	75.4	75.1	75.4	75.2	75.3	45.9	29.4	129.6	44.11
504	75.1	75.3	75.1	75.3	75.1	75.2	45.4	29.8	158.4	53.15
510	75.2	75.3	75.1	75.4	75.2	75.2	45.3	29.9	158.4	52.96
516	75.3	75.3	75.1	75.3	75.1	75.2	45.0	30.3	129.6	42.83
						Avg. Tair	Avg. Tamb	Avg. ΔT	Sum W-hr.	Avg. UA
						75.22	48.29	26.94	3657.6	54.46

Coheating Test: 2 Story Closed Panel										
Passive Vents: Taped										
5-Dec-93										
Time	Tair1(F)	Tair2(F)	Tair3(F)	Tair4(F)	Tair5(F)	T Avg	Tamb(F)	ΔT	w-hr	UA
306	75.3	75.1	75.3	75.4	75.1	75.2	36.8	38.5	136.80	35.56
312	75.3	75.2	75.2	75.4	75.0	75.2	36.4	38.8	158.40	40.84
318	75.3	75.4	75.3	75.4	75.0	75.3	35.6	39.7	151.20	38.12
324	75.3	75.3	75.2	75.3	75.0	75.2	35.7	39.5	144.00	36.47
330	75.2	75.3	75.2	75.3	75.0	75.2	35.7	39.5	151.20	38.27
336	75.4	75.3	75.2	75.4	75.0	75.3	35.7	39.5	144.00	36.42
342	75.3	75.3	75.2	75.4	75.0	75.2	35.5	39.7	158.40	39.86
348	75.2	75.1	75.3	75.3	75.0	75.2	35.1	40.1	129.60	32.30
354	75.2	75.1	75.2	75.3	75.0	75.2	34.6	40.6	151.20	37.25
400	75.2	75.1	75.2	75.4	75.0	75.2	34.4	40.8	158.40	38.84
406	75.3	75.2	75.2	75.3	75.0	75.2	34.6	40.6	129.60	31.92
412	75.3	75.1	75.2	75.3	75.1	75.2	34.2	41.1	309.60	75.42
418	75.3	75.3	75.2	75.3	75.0	75.2	34.2	41.1	122.40	29.82
424	75.2	75.2	75.2	75.4	75.1	75.2	34.4	40.9	201.60	49.34
430	75.4	75.1	75.2	75.3	75.1	75.2	34.2	41.0	165.60	40.40
436	75.2	75.4	75.2	75.5	75.1	75.3	34.4	40.9	180.00	43.98
442	75.2	75.4	75.3	75.3	75.1	75.3	34.2	41.1	115.20	28.04
448	75.2	75.1	75.3	75.4	75.1	75.2	34.5	40.8	108.00	26.50
454	75.2	75.1	75.2	75.4	75.0	75.2	34.4	40.8	136.80	33.56
500	75.2	75.2	75.2	75.5	75.0	75.2	34.6	40.6	144.00	35.47
506	75.2	75.2	75.3	75.4	75.0	75.2	34.7	40.5	136.80	33.79
512	75.2	75.1	75.2	75.5	75.0	75.2	35.0	40.2	144.00	35.86
518	75.3	75.2	75.2	75.4	75.1	75.2	35.3	39.9	144.00	36.05
524	75.3	75.3	75.2	75.3	75.1	75.2	35.4	39.9	151.20	37.94
530	75.3	75.1	75.3	75.5	75.0	75.24	35.73	39.51	144.00	36.45
						Avg. Tair	Avg. Tamb	Avg. ΔT	Sum W-hr.	Avg. UA
						75.2	35.01	40.2116	3816.00	**37.94**

Coheating Test: Unit 6, 2 Story Closed Panel										
Passive Vents: Taped										
Dec. 11, 1993										
Time	**Tair1(F**	**Tair2(F**	**Tair3(F**	**Tair4(F**	**Tair5(F**	**Tamb(F)**	**T Avg**	**ΔT**	**w-hr**	**UA**
306	75.5	75.2	75.2	75.2	75.3	44.8	75.3	30.5	136.80	44.93
312	75.3	75.4	75.2	75.4	75.5	44.9	75.4	30.5	79.20	25.98
318	75.3	75.4	75.2	75.3	75.4	44.9	75.3	30.4	158.40	52.09
324	75.4	75.4	75.2	75.4	75.4	44.9	75.4	30.5	100.80	33.05
330	75.4	75.4	75.2	75.3	75.5	44.9	75.4	30.5	136.80	44.85
336	75.4	75.5	75.2	75.3	75.5	44.9	75.4	30.5	108.00	35.42
342	75.4	75.3	75.2	75.4	75.5	44.9	75.4	30.5	108.00	35.43
348	75.5	75.3	75.2	75.3	75.3	44.9	75.3	30.4	129.60	42.59
354	75.4	75.2	75.2	75.5	75.5	44.9	75.4	30.4	108.00	35.50
400	75.3	75.2	75.2	75.2	75.4	45.0	75.3	30.3	136.80	45.18
406	75.3	75.3	75.2	75.4	75.5	45.0	75.3	30.3	86.40	28.51
412	75.5	75.4	75.2	75.3	75.3	45.2	75.3	30.2	144.00	47.76
418	75.5	75.4	75.2	75.5	75.4	45.1	75.4	30.3	93.60	30.90
424	75.4	75.3	75.2	75.3	75.4	45.1	75.3	30.2	144.00	47.63
430	75.3	75.3	75.2	75.3	75.4	45.0	75.3	30.3	122.40	40.45
436	75.4	75.3	75.2	75.4	75.5	45.1	75.4	30.2	108.00	35.70
442	75.2	75.2	75.2	75.3	75.3	45.2	75.2	30.1	129.60	43.10
448	75.3	75.3	75.1	75.4	75.5	45.4	75.3	30.0	108.00	36.05
454	75.4	75.3	75.2	75.2	75.4	45.4	75.3	29.9	136.80	45.75
500	75.5	75.2	75.2	75.3	75.4	45.4	75.3	29.9	100.80	33.71
506	75.3	75.3	75.2	75.3	75.4	45.5	75.3	29.8	115.20	38.66
512	75.3	75.3	75.2	75.2	75.3	45.6	75.3	29.7	144.00	48.52
518	75.4	75.3	75.2	75.4	75.5	45.7	75.4	29.7	100.80	33.99
524	75.5	75.4	75.2	75.3	75.3	45.7	75.3	29.6	122.40	41.35
530	75.4	75.3	75.1	75.4	75.5	45.9	75.3	29.4	108.00	36.68
						Avg. Tair	Avg. Tamb	Avg ΔT	Sum W-hr.	Avg. UA
						45.2	75.3	30.2	2966.4	39.35

7.7 THEORETICAL UA CALCULATIONS

UA DATA, ASHRAE 93 • University Housing				
UNIT 1				
Component	Material	R value	U value	Source
SSIC Panel		(F ft^2 h/Btu)	(Btu/F ft^2 h)	
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	EPS Foam Core	23.00		Constr. Doc
	.5" OSB (35 lb/ft^3)	0.62		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	26.65	0.038	
SSIC Panel at Spline				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	2x3 DG Stud, (1.03 F ft^2 h/ Btu in)	1.55		ASHRAE 93
	1.25" EPS Foam	4.81		ASHRAE 93
	2x3 DG Stud, (1.03 F ft^2 h/ Btu in)	1.55		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	11.55	0.09	
Window				
	window	2.94		Constr. Doc., includes air layers
	TOTAL	2.94	0.340	
Window Headers				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	2" Polyiso 1.5 lb/ft^3 (R5.9/in.)	11.81		ASHRAE 93
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	17.17	0.058	

Unit 1 Continued				
Door				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	Door	5.26		Constr. Doc.
	indoor air	0.68		ASHRAE 93
	TOTAL	6.19	0.162	
Vaulted Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	asphalt shingles	0.44		ASHRAE 93
	30 lb felt	0.06		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	R38 Batts	38.00		Constr. Doc.
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	40.54	0.025	
Vaulted Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	asphalt shingles	0.44		ASHRAE 93
	30 lb felt	0.06		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	2 x 6, DG fir, R1.03/in.	6.18		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	8.72	0.115	
Flat Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	R49 Batts	49.00		Constr. Doc
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		ASHRAE 93
	TOTAL	50.42	0.020	

Unit 1 Continued				
Flat Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	2 x 4, DG fir, R1.03/in.	6.18		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		ASHRAE 93
	TOTAL	7.6	0.132	
Perimeter			F2 (Btu/h F ft perim)	
	Perimeter		0.40	q=F2*PΔt
				F2 from Wattsun
UNIT 1		AREA (perimeter found.)	U Value	UA Value
	SSIC Wall Panel	772.44	0.038	28.98
	Wall Splines	51.67	0.087	4.47
	Windows	80.52	0.340	27.39
	Window Headers	22.67	0.058	1.32
	Doors	20.00	0.162	3.23
	Flat Roof	165.69	0.020	3.29
	Flat Roof at truss	12.38	0.132	1.63
	Vaulted Roof	535.43	0.025	13.21
	Vaulted Roof at Truss	36.83	0.115	4.22
	Foundation Perimeter	120.50	0.400	48.20
	Total			135.94

UNIT 2				
Component	Material	R value	U value	Source
Closed Panel		(F ft^2 h/Btu)	(Btu/F ft^2 h)	
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		ASHRAE 93
	Insulation	21.00		Constr. Doc
	5/8" gypboard	0.45		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	28.15	0.036	
Closed Panel at Stud				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		Constr. Doc
	2X6 DG Stud, (1.5x5.5" nominal)	5.67		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	12.93	0.08	
Window				
	window	2.94		Constr. Doc.
	TOTAL	2.94	0.340	
Window Headers				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	2" Polyiso 1.5 lb/ft^3 (R5.9/in.)	11.81		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		Constr. Doc.
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	22.17	0.045	

Unit 2 Continued				
Door				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	Door	5.26		constr. Doc
	indoor air	0.68		ASHRAE 93
	TOTAL	6.19	0.162	
Vaulted Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	asphalt shingles	0.44		ASHRAE 93
	30 lb felt	0.06		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	R38 Batts	38		constr. Doc
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	40.54	0.025	
Vaulted Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	asphalt shingles	0.44		ASHRAE 93
	30 lb felt	0.06		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	2 x 6, DG fir, R1.03/in.	6.18		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	8.72	0.115	
Flat Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	R49 Batts	49		Constr. Doc.
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		
	TOTAL	50.42	0.020	

Unit 2 Contnued				
Flat Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	2 x 6, DG fir, R1.03/in.	6.18		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		
	TOTAL	7.6	0.132	
Perimeter			F2 (Btu/h F ft perim)	
	Perimeter		0.40	q=F2*PΔt
				F2 from Wattsun
UNIT 2		**AREA** (perimeter found.)	U Value	UA Value
	Closed Panel	758.11	0.036	26.93
	Studs	66.00	0.077	5.10
	Windows	80.52	0.340	27.39
	Window Headers	22.67	0.045	1.02
	Doors	20.00	0.162	3.23
	Flat Roof	165.69	0.020	3.29
	Flat Roof at truss	12.38	0.132	1.63
	Vaulted Roof	535.43	0.025	13.21
	Vaulted Roof at Truss	36.83	0.115	4.22
	Perimeter	120.50	0.400	48.20
	Total			134.22

UNIT 3				
Component	Material	R value	U value	Source
Open Panel		(F ft^2 h/Btu)	(Btu/F ft^2 h)	
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		ASHRAE 93
	Insulation	21.00		Constr. Doc
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	28.26	0.035	
Open Panel at Stud				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	2X6 DG Stud, (1.03 F ft^2 h/ Btu in)	5.67		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		Constr. Doc
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	13.54	0.07	
Window				
	window	2.94		Constr. Doc, includes air layer
	TOTAL	2.94	0.340	
Window Headers				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	2" Polyiso 1.5 lb/ft^3 (R5.9/in.)	11.81		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		ASHRAE 93
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	22.17	0.045	

Unit 3 continued				
Door				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	Door	5.26		Constr. Doc.
	indoor air	0.68		ASHRAE 93
	TOTAL	6.19	0.162	
Vaulted Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	asphalt shingles	0.44		ASHRAE 93
	30 lb felt	0.06		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	R38 Batts	38.00		Constr. Doc.
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	40.54	0.025	
Vaulted Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	2 x 4, DG fir, R1.03/in.	3.61		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	5.04	0.199	
Flat Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	R49 Batts	49.00		Constr. Doc.
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		ASHRAE 93
	TOTAL	50.42	0.020	

Unit 3 continued				
Flat Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	2 x 4, DG fir, R1.03/in.	3.61		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		ASHRAE 93
	TOTAL	5.03	0.199	
Perimeter			F2 (Btu/h F ft perim)	
	Perimeter		0.40	q=F2*PΔt
				F2 from Wattsun
UNIT 3		AREA (perimeter found.)	U Value	UA Value
	Open Wall Panel	733.78	0.035	25.97
	Wall studs	75.15	0.074	5.55
	Windows	78.30	0.340	26.63
	Window Headers	21.67	0.045	0.98
	Doors	36.70	0.162	5.93
	Flat Roof	288.05	0.020	5.71
	Flat Roof at truss	24.75	0.199	4.93
	Vaulted Roof	207.58	0.025	5.12
	Vaulted Roof at Truss	16.82	0.199	3.34
	Perimeter	71.33	0.400	28.53
	Total			112.69

UNIT 4				
Component	Material	R value	U value	Source
Open Panel		(F ft^2 h/Btu)	(Btu/F ft^2 h)	
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	Insulation	21.00		Constr. Doc
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	28.87	0.035	
Open Panel at Spline				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	2X6 DG Stud, (1.03 F ft^2 h/ Btu in)	5.67		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	13.54	0.07	
Window				
	window	2.94		Constr. Doc, includes air layer
	TOTAL	2.94	0.340	
Window Headers				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	2" Polyiso 1.5 lb/ft^3 (R5.9/in.)	11.81		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		ASHRAE 93
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	22.17	0.045	

Unit 4 continued				
Door				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	Door	5.26		Constr. Doc.
	indoor air	0.68		ASHRAE 93
	TOTAL	6.19	0.162	
Vaulted Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	asphalt shingles	0.44		ASHRAE 93
	30 lb felt	0.06		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	R38 Batts	38.00		Constr. Doc.
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	40.54	0.025	
Vaulted Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	asphalt shingles	0.44		ASHRAE 93
	30 lb felt	0.06		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	2 x 4, DG fir, R1.03/in.	3.61		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	6.15	0.163	
Flat Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	R49 Batts	49.00		Constr. Doc.
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		ASHRAE 93
	TOTAL	50.42	0.020	

Unit 4 continued				
Flat Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	2 x 4, DG fir, R1.03/in.	3.61		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		ASHRAE 93
	TOTAL	5.03	0.199	
Perimeter			F2 (Btu/h F ft perim)	
	Perimeter		0.40	q=F2*PΔt
				F2 from Wattsun
UNIT 4		AREA (perimeter found.)	U Value	UA Value
	Open Wall Panel	846.75	0.035	29.33
	Wall studs	93.15	0.074	6.88
	Windows	101.30	0.340	34.46
	Window Headers	33.00	0.045	1.49
	Doors	36.70	0.162	5.93
	Flat Roof	374.50	0.020	7.43
	Flat Roof at truss	29.50	0.199	5.87
	Vaulted Roof	126.25	0.025	3.11
	Vaulted Roof at Truss	16.25	0.163	2.64
	Perimeter	79.33	0.400	31.73
	Total			128.87

UNIT 5 and 6				
Component	Material	R value	U value	Source
Closed Panel		(F ft^2 h/Btu)	(Btu/F ft^2 h)	
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	Insulation	21.00		Constr. Doc
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	28.87	0.035	
Closed Panel at Spline				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	2X6 DG Stud, (1.03 F ft^2 h/ Btu in)	5.67		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	13.54	0.07	
Window				
	window	2.94		Constr. Doc., includes air layers
	TOTAL	2.94	0.340	
Window Headers				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	5/8" DG plywood	0.77		ASHRAE 93
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	2" Polyiso 1.5 lb/ft^3 (R5.9/in.)	11.81		ASHRAE 93
	5/8 inch polyisocyanurate	5.00		ASHRAE 93
	1.5" DG (1.03 1/k)	1.55		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.68		ASHRAE 93
	TOTAL	22.17	0.045	

Unit 5 and 6 continued				
Door				
	outdoor air (7.5 mph)	0.25		ASHRAE 93
	Door	5.26		Constr. Doc.
	indoor air	0.68		ASHRAE 93
	TOTAL	6.19	0.162	
Vaulted Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	asphalt shingles	0.44		ASHRAE 93
	30 lb felt	0.06		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	R38 Batts	38.00		Constr. Doc.
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	40.54	0.025	
Vaulted Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	asphalt shingles	0.44		ASHRAE 93
	30 lb felt	0.06		ASHRAE 93
	7/16" OSB (35 lb/ft^3)	0.61		ASHRAE 93
	2 x 4, DG fir, R1.03/in.	3.61		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air (sloping 45)	0.62		ASHRAE 93
	TOTAL	6.15	0.163	
Flat Roof	outdoor air (7.5 mph)	0.25		ASHRAE 93
	R49 Batts	49.00		Constr. Doc.
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		ASHRAE 93
	TOTAL	50.42	0.020	

Unit 5 and 6 continued				
Flat Roof at Truss	outdoor air (7.5 mph)	0.25		ASHRAE 93
	2 x 4, DG fir, R1.03/in.	3.61		ASHRAE 93
	5/8" gypboard	0.56		ASHRAE 93
	indoor air	0.61		ASHRAE 93
	TOTAL	5.03	0.199	
Perimeter			F2 (Btu/h F ft perim)	
	Perimeter		0.40	q=F2*PΔt
				F2 from Wattsun
UNIT 5 and 6		AREA (perimeter found.)	U Value	UA Value
	Closed Wall Panel	786.10	0.035	27.23
	Wall studs	75.15	0.074	5.55
	Windows	81.50	0.340	27.72
	Window Headers	28.53	0.045	1.29
	Doors	40.00	0.162	6.46
	Flat Roof	323.00	0.020	6.41
	Flat Roof at truss	69.50	0.199	13.83
	Perimeter	59.00	0.400	23.60
	Total			112.09