FLORIDA SOLAR ENERGY CENTER®

Field Data Delivery - *Final Report* Thermal Performance Field Monitoring of Various Conservation Construction Techniques

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I. Introduction

An instrumentation and data collection proposal was first made on May 3, 1983 to Brookhaven National Laboratory to study an energy conserving design townhouse in Cocoa, Florida. The approval for funding came on October 16, 1984. The townhouses were designed with energy conservation advice from the Florida Solar Energy Center. During the construction process instrumentation and wiring were placed in the walls and roof of two units (Units A and B) for the data acquisition system. In May 1984 the Rangewood Villas townhouses were completed and by July, 1984 calibration of probes was completed and data collection was begun.

The object of the project during 1984 and 1985 was to obtain an accurate and comprehensive set of data about the thermal and humidity performance of an energy conserving townhouse in a hot, humid climate. This data could then be used to validate building simulation models (e.g., TARP, BLAST, DOE-2), and make modifications to these models.

This data has been analyzed in this report to assess the ability of simplified building cooling load algorithms to predict the air conditioner energy use. Using the parameters of ambient temperature, sol-air envelope temperature, window solar gain, infiltration gains, slab conduction, and internally generated heat, it was found that monthly air conditioning energy use could be predicted generally within ± 10% for room temperatures ranging from 73.5°F to 81.5°F. This is presented in Section IV.

The latest phase of this project, carried out during June through October, 1986, collected moisture, temperature, and energy use data on nighttime ventilation and daytime air conditioning. The purpose was to assess the impact of nighttime introduced moisture upon the air conditioner's sensible heat ratio (or AC moisture removal) and energy use, and the accompanying humidity levels in the conditioned space. Additionally, it is hoped that this data can be used to modify and validate building load simulation models.

II. Description of Project Setup

A. Description of Townhouses

The Rangewood Villas townhouses are located in Cocoa, Florida at 28.4°N latitude and 80.6°W longitude on the east coast of the Florida peninsula about 10 miles inland from the ocean. They are located near undeveloped land covered by lush tropical vegetation. They were designed with a number of energy conserving design features. The exterior block walls have 3/4" sprayed cellulose insulation behind the sheetrock. The west wall has a vented-skin design with a radiant barrier. The roof structure above the cathedral ceilings has a vented space below a radiant barrier and above R-19 glass batt insulation. The attic portion is insulated with R-19 glass batts and a radiant barrier. There are 3 ft roof overhangs on the north and south, and no windows on the east and west.

There are four units in each building. During 1984 and 1985, units A and B were both monitored. In 1986, only unit A was monitored. Each unit has approximately 1200 ft^2 of conditioned floor area on two stories. The second floor is open to the living room below and has 355 ft^2 in a bedroom, bathroom, vanity room, and two closets (Figure 1). Ceilings are mostly cathedral

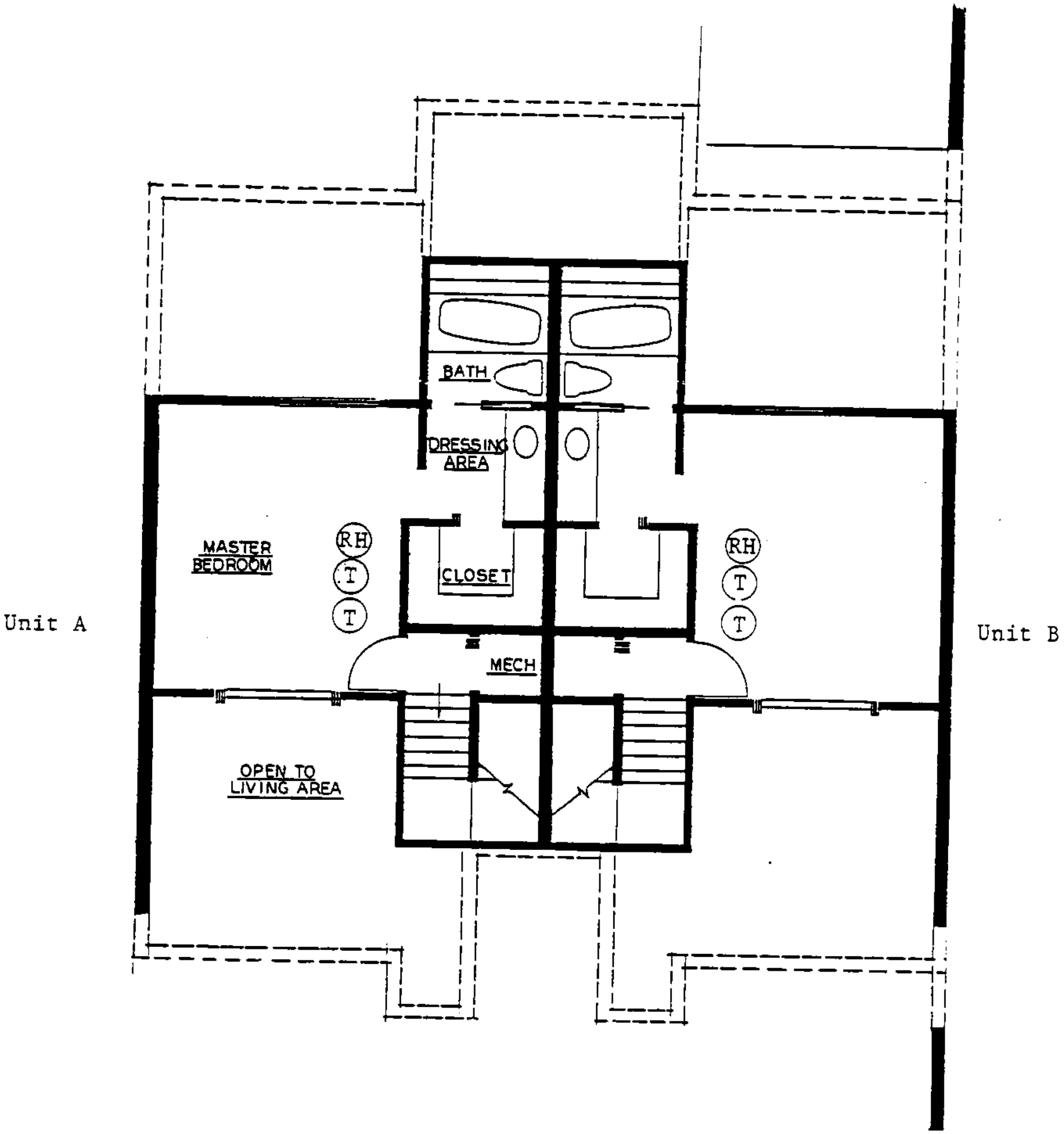


Figure 1. Second Floor Plan of Units A and B Showing the Location of Temperature Sensors (T) and Relative Humidity Probes (RH)

design, except for an area 7' x 30' from front to back of the building along the common wall of the adjacent unit. This forms an attic space where the AC air handler and second story ductwork are located.

The first floor has 820 ft^2 in a bathroom, vanity room, washer/dryer closet, bedroom, kitchen, and large combined living room/dining room area (Figure 2). The cathedral ceiling in the living room rises upward directly to the open air space of the upstairs bedroom. Because of the open air design there is considerable potential for thermal stratification of air. This does not often occur because the air conditioner keeps the air well mixed. During sunny winter days when neither the heating nor cooling is on, there is a significant thermal gradiant.

The exterior block walls are a cream color stucco (about 865 ft^2). Exterior frame walls have wood siding painted brown (about 236 ft^2). The roof is tan/brown fiberglass shingles. There is a concrete patio in front of the south and north patio doors. There is a wood trellis over the front patio which blocks about 10 percent of the solar radiation reaching 2/3 of the south block wall. Interior walls are frame construction with white painted sheet rock.

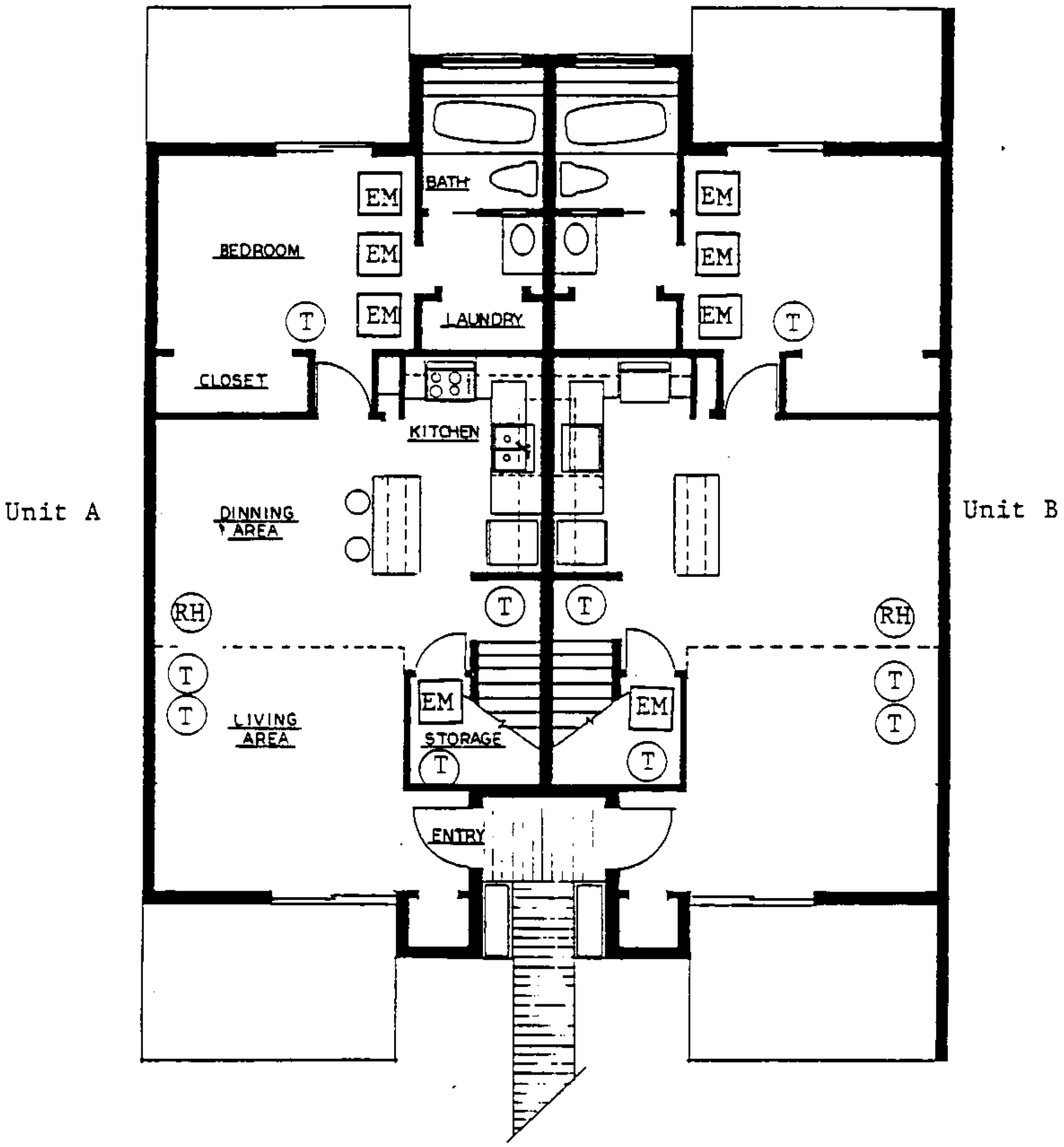


Figure 2. First Floor Plan of Units A and B
Showing the Location of Temperature Sensors T,
Relative Humidity Probes RH, and
Electric Meters EM

Unit A has not been occupied during this period. It has generally been partially furnished (two couches and one bed), though in 1986 the furnishings varied from none to a great deal. In terms of internal heat generation, Unit A has a 40-gallon hot water heater (heated by a designated heat pump) located in a closet under the stairway, a refrigerator, a Campbell CR7 datalogger, and three small wattage aspirator fans for two relative humidity probes and the datalogger. There are ceiling fans in the bedrooms, the living room, and the dining room which are generally off except during specific experiments. Lights are generally off.

The heat pump system is a York Model E2CPO18A068. It is rated at 18,000 Btu/hr cooling and has a model N2AH010A06A air handler rated at 1000 CFM at .4 inches. The coil is York Model G1AC024AA and the internal heater is Model 2HM0651306A. The compressor and condenser are located in the backyard on the north side of the building. The evaporator and air handler are located in the attic above the upstairs walk-in closet. In the original plans, however, it was designed to be located in a small upstairs closet which was used instead as a linen closet.

B. Building Monitoring Equipment

The Rangewood Villas townhouse units under study were completed in May 1984. During the construction process the wiring and instrumentation were installed. Wiring for sensors and probes was run throughout the walls so that the unit would be as normal in appearance as possible. Data was collected on Units A and B during 1984 and 1985. In 1986, only Unit A was monitored.

Figures 1 and 2 show the floor plans of Units A and B and the location of sensors throughout the structure. There are temperature and relative humidity sensors in zone 1 (downstairs), zone 2 (upstairs), and zone 3 (attic). In zone 1 there are two aspirated temperature probes on the west side of the living room (1 thermocouple and 1 thermistor) and a thermocouple in the downstairs bedroom and at the thermostat. An aspirated relative humidity probe is located in the living room. In zone 2 (upstairs) there are two temperature sensors in the bedroom (1 thermocouple and 1 thermistor) and a relative humidity probe. They are all aspirated. In zone 3 (attic) there are two temperature sensors (1 thermocouple and 1 thermistor) and a relative humidity probe, all of which are aspirated. The thermocouples are type-T copper-constantan and the RH probes are a

Campbell Scientific Model 207, containing a Phys-Chemical Research PCRC-11 RH sensor and a Fenwal Electronics UUT51J1 thermistor.

The heat pump is instrumented in the following manner. Thermocouples measure the dry-bulb temperature of the air entering and leaving the coil. Model DEW-10 Chilled Mirror Hygrometers by General Eastern measure the dewpoint temperatures entering and leaving the coil. The fan run time is measured by using a small AC to DC transformer that provides a DC voltage to the datalogger whenever the fan is energized. By software control, the datalogger only records the scans of heat pump inlet and outlet temperatures when the fan is on. In this way, the datalogger only averages heat pump "run" data for each 15-minute interval.

Condensate from the heat pump when in the cooling mode is measured by a tipping bucket Model 525, manufactured by Texas Electronics, Inc. As the bucket tips, a switch closure is counted by the datalogger which is converted to ml of condensate.

A thermocouple tree was installed through the cathedral ceiling of the south facing roof of Unit A. A total of 8 thermocouples measure the temperature at the following surfaces (Figure 3):

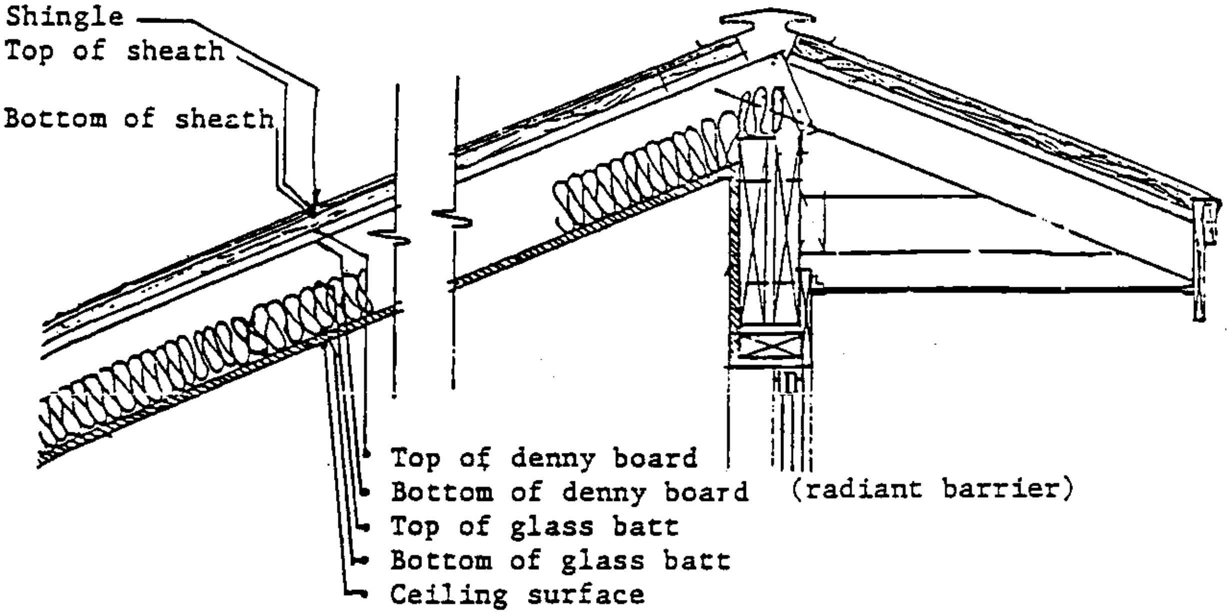


Figure 3. Thermocouple tree in roof.

1. asphalt shingle
2. top of plywood
3. bottom of plywood
4. top of denny board
5. bottom of denny board
6. top of glass batt
7. bottom of glass batt
8. ceiling surface

The roof is a "vent skin" design. The vented space is located between the denny board and the glass batt. A typical sunny spring day temperature profile through the roof section is shown in Figure 4.

A thermocouple is located at the top of the domestic hot water tank so that the heat transfer to the space can be computed.

Watt-hour meters were installed to measure energy use of specific zones and equipment within the townhouse. Three meters were located near the door to the bathroom at the circuit breaker board on the first floor to measure:

1. total house energy
2. heat pump energy
3. zone 2 (upstairs) energy

Another watt-hour meter was located near the water heater under the stairs to measure the energy use of the hot water heater heat pump. The energy use of zone 1 can be calculated by subtracting the other meters energy

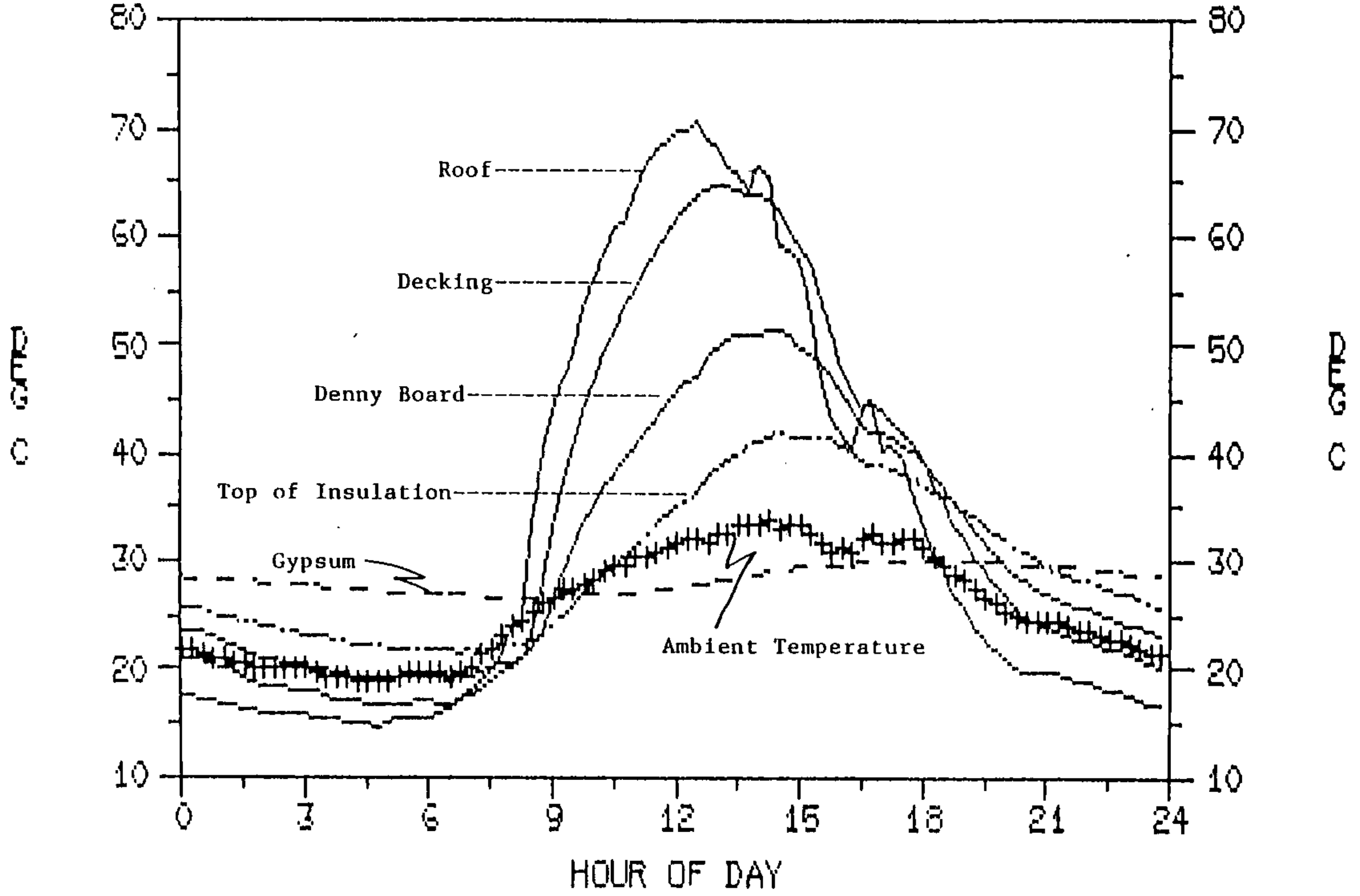


Figure 4. ROOF TEMPERATURE PROFILE 4-28-85

use from the total energy use.

Zone 1 = Total - Zone 2 - DHW - heat pump

At the beginning of 1986 the instrumentation in Unit B was removed and additional probes were added to Unit A. Several thermocouples were left in Unit B to monitor temperature in the space on the other side of the common wall. Monitoring of Unit A was increased for the 1986 project by adding General Eastern Model DEW-10 Chilled Mirror Hygrometers at the same location as the RH probes to measure dewpoint in Zone 1 (downstairs), Zone 2 (upstairs), and Zone 3 (attic). All the DEW-10s are aspirated by small blowers. An additional thermocouple was added at the return grill. In November 1986, six of the probes of the thermocouple tree were removed from the datalogger (temporarily) and in their place were put thermocouples to measure the building surface temperatures at the following locations:

North block wall
South block wall
West vent-skin block wall
South frame wall
West frame wall
North roof

These envelope surface temperatures have been used to assess the accuracy of the sol-air method.

C. Weather Station Equipment

A weather station was installed on the west end of the uppermost portion of the roof of Unit A, and on the ground at a height of 4 feet on the west side of the building. The following equipment was in use during 1984 and 1985. On the roof were located barometer, rain gauge, wind speed and direction, solar radiation, sky radiation, and net radiation instruments. The barometer is a Model 7115 unit by Weathertronics. The rain gauge is a Model 525 tipping bucket by Texas Electronics which produces a switch closure each time the bucket tips. Wind speed is measured by a Model 014 Wind Speed Sensor (cup anamometer) and wind direction is a Model 024 Wind Direction Sensor. They are mounted as a single unit and are manufactured by Met-One Inc. The Model 014 produces switch closures while rotating and the 024 produces a changing electrical resistance as it points to different directions. Solar radiation is measured on the horizontal and on the south roof tilt (22°) by two LI-COR LI-200S pyranometers and two Eppley Precision Spectral Pyranometers (PSP's).

The radiant temperature of the sky is measured by an Eppley Precision Infrared Radiometer. It measures the downward longwave radiation in the wavelength range of 3 to 100 μm and provides a hardware temperature compensation to factor out the upward radiation. A net total radiation measurement is made by a Swissteco Funk-type pyrradiometer suspended 12" above and in the same plane as the roof. This measurement is a balance of the downward shortwave and longwave radiation and the upward reflected shortwave and radiated longwave radiation.

On the ground two aspirated temperature sensors (1 thermocouple and 1 thermistor) and one aspirated Model 207 RH probe monitor the ambient air condition (at 4' elevation). Also, out five feet from the west edge of the house, thermocouples are located in the ground at 24", 12", and 6" depth to record ground temperatures. There is also a thermocouple to record the slab temperature at ground level.

In 1986 a General Eastern DEW-10 Chilled Mirror Hygrometer was installed outdoors with an aspirator. An additional unaspirated thermocouple was also installed to measure the ambient dry-bulb temperature.

D. Data Aquisition Equipment

A Campbell Scientific, Inc. CR-7 measurement and control system datalogger collects the data from the current 62 instrument channels. The CR-7 has been programmed to scan the 62 channels every 10 seconds. This data is stored in a temporary "intermediate" memory until a 15-minute sum or average is calculated. The 15-minute value is then recorded on an internal "final" memory. In our application, the final memory holds approximately 3.0 days worth of data before the oldest data (e.g., data 3.0 days old) begins to be written over. This internal memory storage has been helpful many times in recovering lost data. For example, if the transmission over the phone lines had errors, the data could be transmitted again up to 3.0 days later. Less than two days of data was lost during the period June 19, 1986 to November 8, 1986.

Since the Rangewood Villas townhouses are 13 miles from the Florida Solar Energy Center (FSEC), data has to be transmitted from the CR-7 datalogger to FSEC by phone lines. The transfer process occurs in the following way:

1) A Radio Shack TRS-80 Model III micro computer controls a Hayes Smartmodem which calls Rangewood Villas each night at midnight. A Campbell Scientific, Inc. DC103A Answer Modem answers from Rangewood Villas and downloads the data from the past 24 hours. The data consists of 96 fifteen minute records each with 62 data channels and datalogger number, date, and time for 65 channels

total. The transfer takes place over the phone lines to the TRS-80 Model III. The data is stored on 5 1/4 inch double sided, double density, 96 TPI floppy diskettes. Data transfer and storage is controlled by a BASIC program called "Cromdome". A program "Chanout" produces a printed hardcopy and another called "Costas" converts it to ASCII code in a format which FSEC's VAX computer can accept. All of this occurs automatically each night and is complete by 2:00 A.M. This program software was developed specifically for this project.

2) Each morning a program entitled "KERMIT" is manually run. It transfers the data to the mainframe VAX where it is stored in a raw file in ASCII code on the disk drive system. This raw file is then converted to an INTEGER*2 compressed data format (which saves 80% on storage space) and is added to a large data file which contains all the previous days and months of data. Backup copies of this file are made weekly on tape to protect against a major loss. The 5 1/4 inch floppy disks containing the raw data are also saved as a second backup. More detailed information on the data is presented in the data delivery section of this report.

III. Description of Building Performance

A. Infiltration Testing - Blower Door

Blower door tests were done on the townhouse. The resulting infiltration rates under various pressures are shown in Figure 5. Unit A has an infiltration rate of 9.6 air changes per hour (ACH) at .20 in. H_20 (or 50 Pa). This result was nearly identical when measured on both August 19 and November 5, 1985 with less than a 2 percent difference recorded.

After the "base case" test was completed, various infiltration sources were covered by masking tape and the house was retested. Infiltration sources were taped up in the following order:

- AC vents
- wall plates
- windows
- plumbing penetrations, dryer vent, and kitchen exhaust

The results of the tightening of the house were significant, as can be seen in Figure 5 and 6. After all the tightening was done the infiltration rate dropped from 9.6 ACH to 6.2 ACH, a 35.5 percent

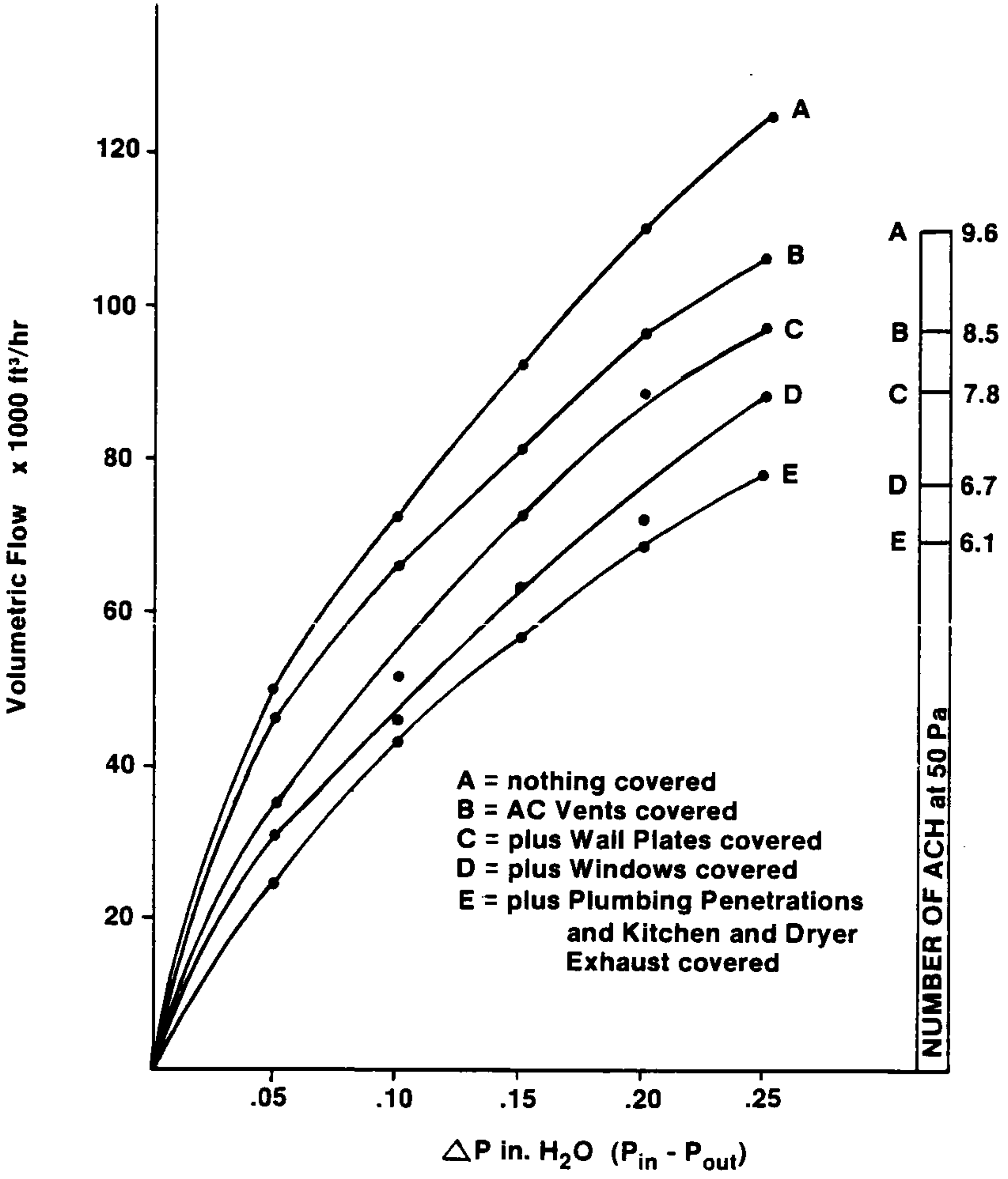


Figure 5. Blower Door Tests at Rangewood Villas (Covering Sources of Infiltration)

reduction. On the average, the AC ducts accounted for 13.6 percent of the leakage, the electrical wall plates accounted for 5.2 percent, the windows accounted for 8.9 percent, and the plumbing penetrations, kitchen exhaust, and dryer vent accounted for 7.8 percent (Figure 6). The remaining 64.5 percent of the leakage was unaccounted for, and came from other sources such as the sillplate and inaccessible penetrations in the wall.

B. Sulfur Hexafluoride Tracer Gas Infiltration Tests

A series of Sulfur Hexafluoride tracer gas infiltration tests were carried out under varying wind and temperature conditions. From these tests it was found that the building infiltration ratio could be characterized as a function of wind speed and air conditioner fan run time (Figure 7). The following equations can be used to estimate infiltration:

AC Blower Off

$$ACH = .095 - .0050\ WS + .0027\ WS^2$$

AC Blower On

$$ACH = .506 - .0198\ WS + .0041\ WS^2$$

where WS is wind speed in MPH.

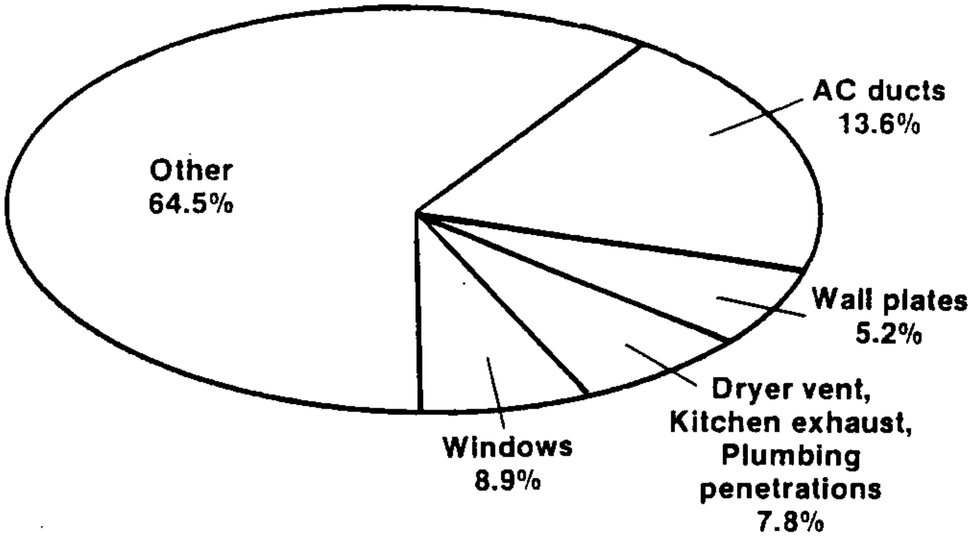


Figure 6. Sources of Infiltration at Rangewood Villas Unit A

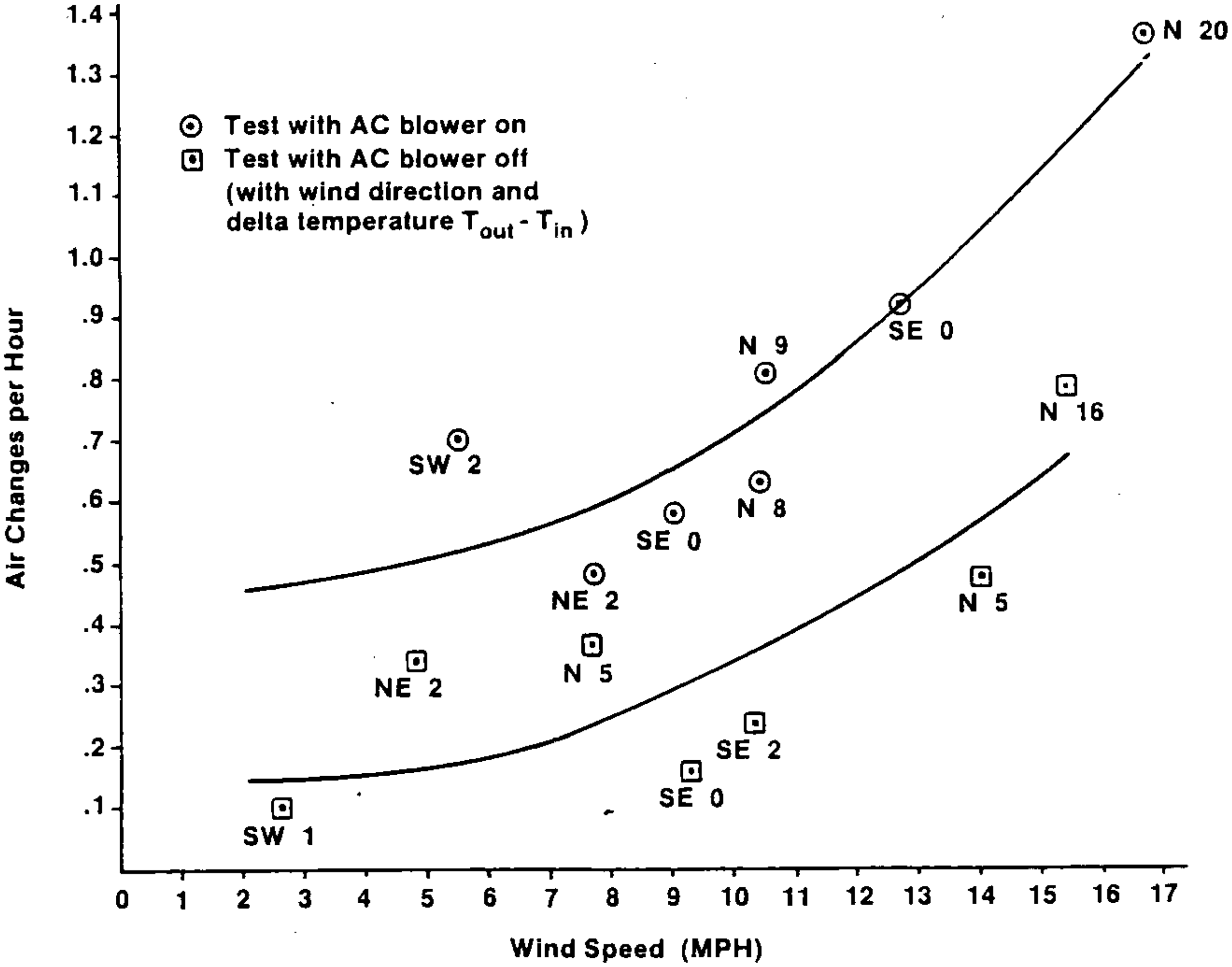


Figure 7. SF_6 Measured Infiltration vs. Wind Speed at Rangewood Villas

C. Night Ventilation/Daytime Air Conditioning Building Performance

During the summer of 1986 (June - October) a series of tests were performed on Rangewood Villas with nighttime ventilation and daytime air conditioning. Test periods ran for 7 to 10 days at 78°F (25.6 C) and 7 to 10 days at 80°F (26.7 C) thermostat set point and were repeated for four levels (Phases) of interior furnishings. Phase I had no furniture and the carpet was covered by taped sheets of polyethylene. Phase II had no furniture but the carpet was exposed. Phase III had exposed carpet and a moderated level of furniture, papers, magazines, blankets, towels, etc. Phase IV included many additional furnishings to yield a heavily furnished house. A complete itemization of the furnishings during Phase III and Phase IV is included in Appendix A. At the end of each phase, a five day drying out period (at 80°F) occured during which the AC was on all day. In this five day period, the interior humidity ratio was brought down to approximately the long term equilibrium level. A table of the test schedules is included in Appendix B.

D. AC Moisture Removal Results

Moisture removed by the air conditioner during the daytime hours (8 A.M. to 9 P.M.) differed greatly between Phase I (carpet covered) and the other three phases (carpet uncovered, moderately furnished, and heavily furnished). At the 78°F (25.6°C) set point, moisture removed jumped from 6.8 liters/day in Phase I to an average of 26.2 liter/day for Phases II through IV. This nearly four fold increase in moisture removal appears to be caused by moisture absorption into the carpet (and other furnishings) during the nighttime ventilation period and desorption during the air conditioning period. As can be seen in Table 1, uncovering the carpet provides large moisture absorbing capacity, and adding furnishings does not have a major additional impact. Lower outdoor dewpoints during Phase IV (which has the greatest amount of moisture absorbing furnishings) has the affect of reducing the moisture removed below Phases II and III.

A day-by-day comparison of moisture removal in Phases I and II is shown in Figure 8. Phase II moisture removal is nearly four times as great across the the range of 4 to 11 cooling degree days (base 74°F). The slight downward slope of the best fit lines may be caused by higher evaporator coil temperatures produced

Table 1. Ambient Conditions, Energy Use, and Air Conditioner Moisture Removal for Four Furnishing Levels at Rangewod Villas in 1986

Phase	Ambient Dry-bulb (C)	Cooling Degree Days	Ambient Dew point (C)	AC Energy Use (kWh/Day)	Condensate Moisture (1/day)
I	26.8	6.2	23.5	14.4	6.8
II	27.4	7.3	24.0	17.9	25.9
III	27.4	7.3	24.3	17.4	29.0
IV	27.0	6.6	22.5	16.4	23.8

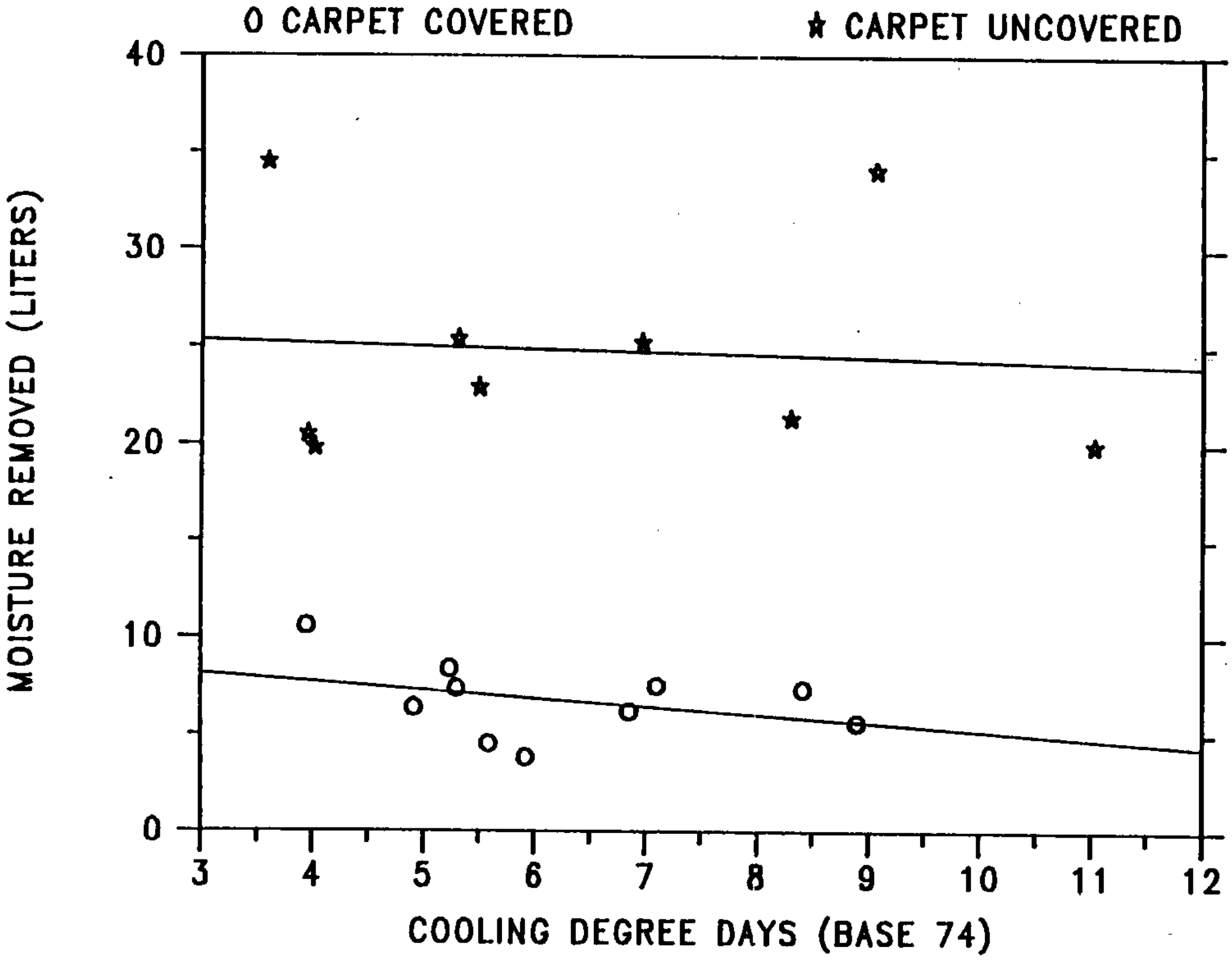


Figure 8. A/C MOISTURE REMOVAL FOR RANGEWOOD VILLA WITH AND WITHOUT CARPET

by higher outdoor dry-bulb temperatures.

In conjunction with greater moisture removal, there is increased air conditioner energy use for the same number of cooling degree days (CDD). In Figure 9 it can be seen that Phase II energy use is about 25 percent greater (about 3.5 kWH) than Phase I at 7 CDD. However, this increase in AC energy use is not as great as might be expected considering the energy required to condense the additional 19.1 liters of water (25.9 - 6.8 = 19.1). At 1050 Btu/lb heat of phase change of water and an air conditioner coefficient of performance of (COP) 2.40 (measured COP), this would equal 5.4 kWh of electricity use. Actual increase in AC energy use is 3.5 kWH, or about 65 percent as much.

E. Discussion of Results

A thermodynamic evaluation of the envelope and enclosed space does not provide an explanation of the additional energy use recorded at Rangewood. The prevailing theory provides the following description of heat/moisture interation. The moisture vapor that enters the building during nighttime ventilation gives off heat to the space as it condenses into the furnishings (19.1 liters of water produces 44,200 Btu/night heat). This heat of phase change was repeatedly measured at Rangewood and can be observed in

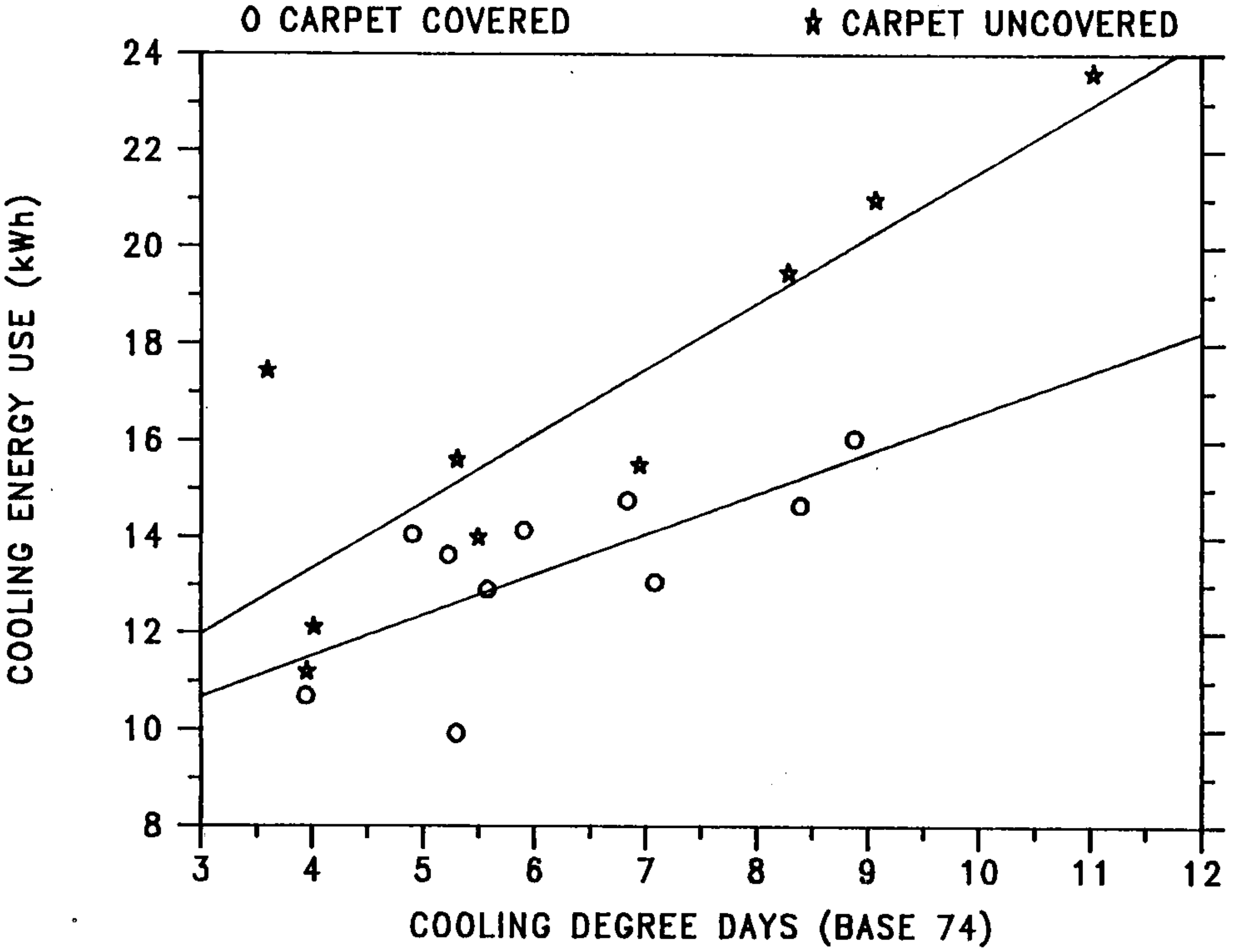


Figure 9. COOLING REQUIREMENTS FOR RANGEWOOD VILLA WITH AND WITHOUT CARPET

Figure 10, with the room temperatures averaging about 2.5°F (1.4°C) warmer during nights when the carpet and furnishings are available to absorb moisture. Some of this heat of condensation is ventilated during the night. With an approximate ventilation rate of 2.5 ACH, an average interior temperature of 80.1°F, and an average ambient temperature of 74°F, there would be 31,900 Btu of ventilative cooling. In the morning when the windows are closed and the air conditioner is turned on, the moisture in the furnishings evaporates providing 44,200 Btu cooling. On net balance, it appears that the cooling load should actually be 11,000 Btu/day <u>less</u> than when the carpet is uncovered. This is because the estimated 31,900 Btu night ventilative cooling when the carpet is uncovered is 11,000 Btu higher than the estimated 20,900 Btu ventilative cooling produced when the carpet is covered and the average interior room temperature is 78.0°F. In actual fact, the cooling load is about 26,000 Btu/day higher when the carpet is uncovered.

This added load at 78°F (see Figure 11) may not be a space defined thermodynamic effect, but one of interaction between the space and the conditioning equipment. The carpeted space should show a thermodynamic gain because the nighttime ventilative cooling removes some additional load. However, the carpeted space daytime load on the AC is shifted from

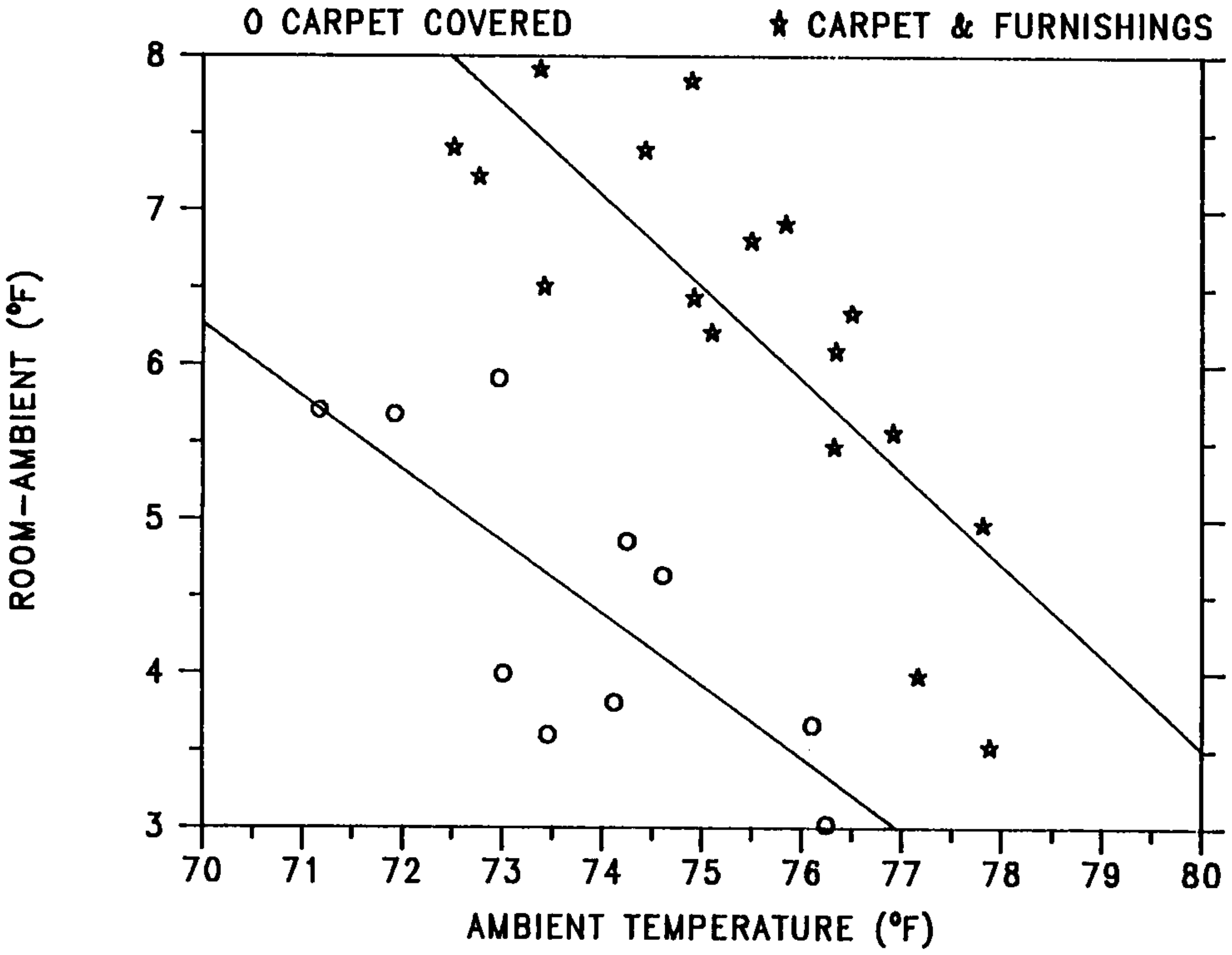
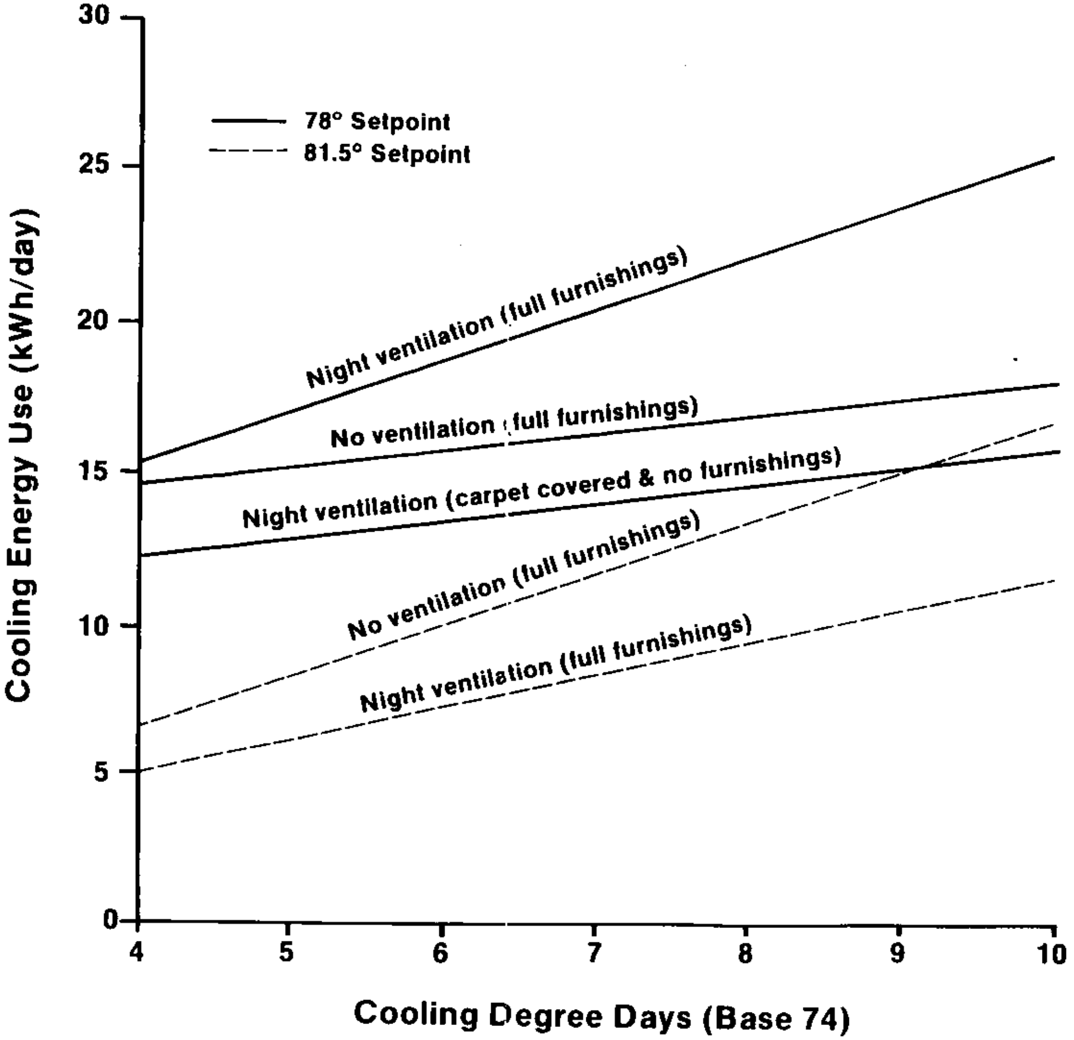


Figure 10. EFFECTS OF MOISTURE ADSORPTION ON ROOM TEMPERATURE DURING VENT

Figure 11. **Cooling energy use at Rangewood Villas for two setpoints (78 & 81.5°F) for night ventilation and no ventilation during 1985 and 1986**



predominately sensible to heavily latent. The additional energy use recorded at 78^{o}F setpoint may be the result of the AC equipment's inability to handle this latent load efficiently.

In addition to the interaction of moisture loads on the AC performance, the ventilation rate would logically also have a bearing on the energy use effect of night ventilation. Moist summer nights in the Southeast are typically characterized by low wind speeds, and the Rangewood experiments used only natural ventilation. The higher the ventilation rate, the more heat of sorption that is removed during the vent period. Therefore, it may be economical to run some form of forced ventilation strategy, such as a whole house fan, to improve the performance of night ventilation.

Further research will be required to understand the interaction of equipment response, ventilation rate and thermostat setting on energy savings that may be associated with the transfer of moisture into and out of structures and furnishings. Such understanding will certainly lead to better housing designs and conceivably lead to advanced housing designs and equipment that take advantage of these processes to provide comfortable spaces at minimal energy use (perhaps off peak) within this hot-humid environment.

IV. Presentation of Simplified Algorithms Predicting Cooling Energy Use

A. Sensible Cooling Loads

Data collected at Rangewood Villas during 1984 and 1985 has been used to develop and verify ASHRAE algorithms useable in microcomputer programs which calculate building cooling loads. Much of the information presented here has been incorporated into a simplified monthly calculation program which is partially complete at this time. Five separate time periods, each with a different thermostat set point are evaluated. Table 2 provides a breakdown of the measured and predicted sensible cooling load for each of these periods. There is an average of 6 percent error in predicting the actual sensible load. The actual sensible load is measured by thermocouples in front of and after the air handler. At the different thermostat set points, from 73.5 F to 81.3 F, there is considerable variation in what portion of the externally generated (non-internal) cooling load derives from which source. The envelope portion of the load generally declines as the set point temperature is raised. The common wall load, the infiltration sensible load, and the slab conduction load also decline in proportion as room temperature rises. The window solar load becomes an

Table 2. Measured and Calculated Sensible Cooling Load at Rangewood Villas for Five Thermostat Set Points

Date	Room Temp.	Ambient Temp.	Weighted Envelope Temp.	COP		HP Energy kWH/day	HP Sens. Load kBtu/day	Internal Load kBtu/day	Envelope Load kBtu/day	Common Wall Load kBtu/day	Window Solar Gain kBtu/day	Infiltration Sens. Load kBtu/day	Slab Gain kBtu/day	Calculated load kBtu/day	Percent of Actual Load
				Sensible	Total										
6/18-7/22/85	73.5	80.2	82.9	1.656	2.400	25.24	142.6	21.4	65.2 (52.4)	4.3 (3.5)	27.9 (22.4)	12.9 (10.4)	14.1 (11.3)	145.8	102.2
8/29-9/20/84	74.8	79.7	82.3	1.759	2.385	23.72	142.4	33.9	52.3 (49.4)	3.7 (3.5)	30.7 (29.0)	10.5 (9.9)	8.6 (8.1)	139.7	98.1
7/26-9/09/85	77.8	81.7	84.5	1.615	2.359	16.70	92.0	19.4	46.8 (55.6)	- .1 (-.1)	28.6 (34.0)	6.1 (7.2)	2.8 (3.3)	103.6	112.6
8/04-8/19/84	78.8	81.4	84.3	1.736	2.363	20.90	123.8	32.9	38.2 (48.0)	-1.2 (-1.5)	35.8 (45.0)	5.9 (7.4)	0.9 (1.1)	112.3	90.7
9/11-9/28/85	81.3	79.1	81.6	1.620	2.518	7.96	44.0	30.1	2.1 (17.6)	-2.0 (-16.8)	25.8 (217.0)	- .2 (-1.7)	-13.8 (-116.0)	42.0	95.5
Average	77.2	80.4	83.1	1.677	2.405	18.90	109.01	27.5	40.9	+ .9	29.8	7.0	2.5	108.7	99.7

In parentheses is a percent breakdown of the non-internal load portion of the calculated sensible load.

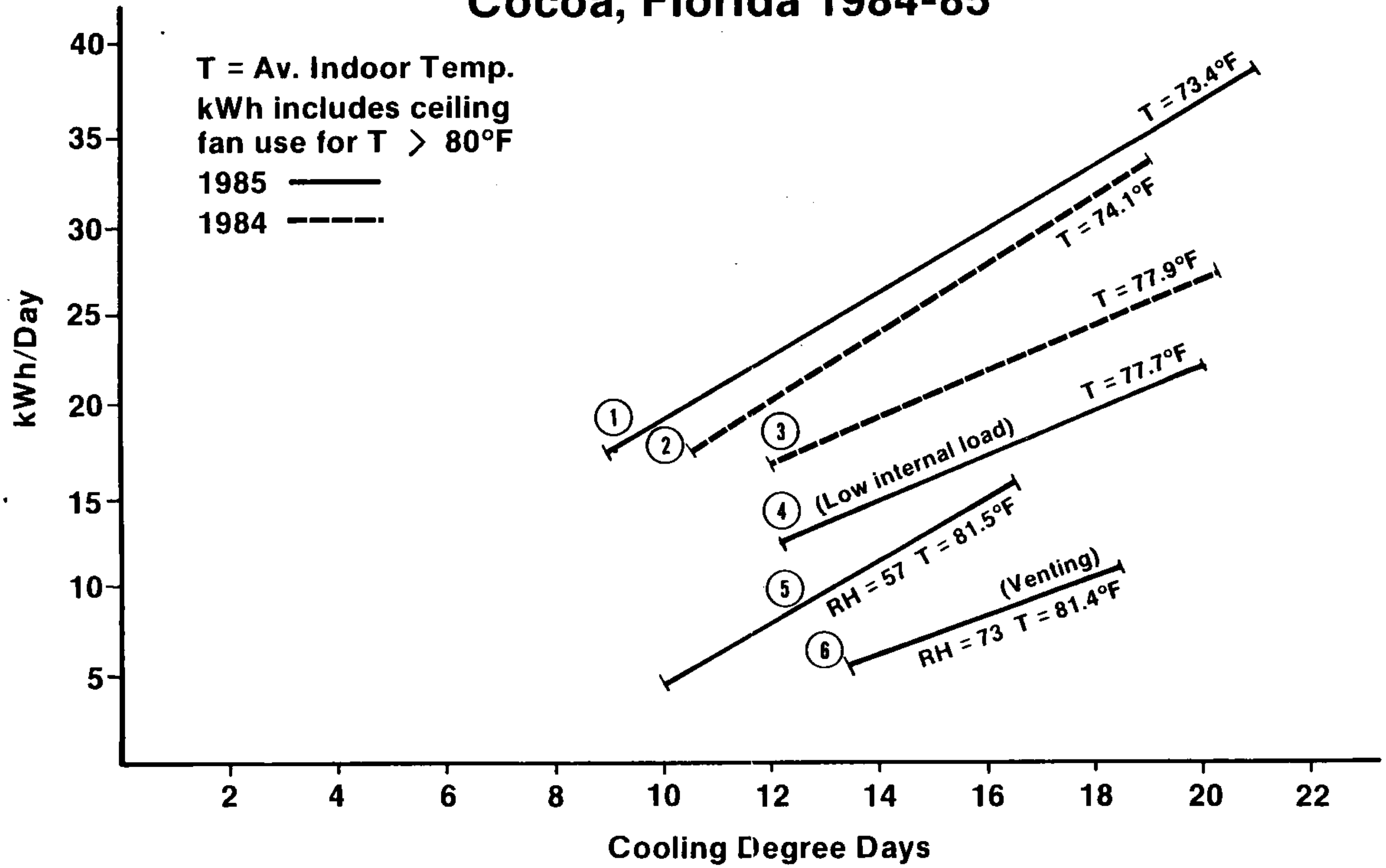
increasing proportion of the load at higher set points. The internally generated load also becomes an increasing portion of the load at higher set points. In this study, the internal load was much higher in the two 1984 periods than in the three 1985 periods because the domestic hot water tank was 150 F compared to 110 F. No hot water was used, but the tank heat loss was much greater. The higher internal load caused the air conditioner (heat pump) to operate at a higher sensible heat ratio (SHR) in 1984 (SHR=.737) compared to 1985 (SHR=.673).

The impact of thermostat set point can be seen by a plot of air conditioning energy use versus CDD (base 65 F) in Figure 12. The time periods coincide approximately with those of Table 2. These lines in Figure 12 are best fit lines to over 150 days of data. Some conclusions can be drawn from this data. At a 78°F set point, zero AC energy use occurs at about zero CDD using a base 65 F and this occurs with smaller than typical internally generated latent and sensible loads. AC energy use appears to decline by about 7 percent per degree F as the thermostat set point is increased over the range from 73.5 to 81.5 F. Rangewood Villas uses only 45 percent as much air conditioning energy at 81.5°F as at 73.4°F.

FSEC

Figure 12. **Measured A/C energy use vs cooling degree days**

Rangewood Villas
Cocoa, Florida 1984-85



During time period number six (see Table 3) Rangewood Villas was vented at night much like the 1986 tests. Compared to unvented periods at the same room temperature, total energy use declined by about 40 percent as a result of night venting. Relative humidity in the space, however, jumped from 57 to 73 percent.

A presentation of the methodology and algorithms used to predict the sensible cooling load follows. Prediction of the sensible cooling load includes calculations for:

1. conduction through the building envelope
2. solar radiation gain through windows
3. infiltration sensible load
4. conduction through slab

A.1 Conduction Through Building Envelope

Conduction through the building envelope follows the following procedure. Thermal resistance (R value) for each element is determined using ASHRAE methods for wall sections, roof sections, doors and windows. The envelope's daily average surface temperatures are calculated using the ASHRAE sol-air method.

FSEC

Table 3. Rangewood Villas Statistics

		Outdoor		Sun	Indoor		Int.
Dates	Days	Dry Bulb	RH	(Btu/ ft^2Day)	Dry Bulb	RH	Load (kWh/Day)
1. 5/26-7/22/85	58	80.2	87.9	1847	73.4	58.8	7.60
2. 8/29-9/20/84	19	79.7	78.7	NA	74.1	60.6	11.20
3. 8/4-8/19/84	16	81.4	78.6	NA	77.9	59.0	10.48
4. 7/24-9/9/85	43	81.9	86.7	1630	77.7	58.5	6.48
5. 9/11-9/28/85	18	79.1	89.0	1433	81.5	57.0	9.84
6. 10/2-10/13/85	7	81.4	90.7	1525	81.4	73.3	9.76

First it is necessary to determine the solar radiation impinging upon each of the building's surfaces. If daily solar radiation is known for a horizontal surface, average monthly solar on each surface ($\bar{H}_T$) can be fairly accurately approximated by a method presented by Klein and Theilacker[1]:

$$\bar{H}_T = \bar{R} \cdot \bar{H}$$

where

$$\bar{R} = D + \frac{\bar{H}_d}{\bar{H}} \; \frac{(1+COS\ (\beta)}{2} + \rho \frac{(1-COS\ (\beta)}{2}$$

where D is the beam portion of the solar falling on an inclined surface. It is defined by a fairly lengthy series of equations which account for the time that the sun rises and sets upon surfaces of various orientations. $\bar{H}_d/\bar{H}$ is the monthly-average diffuse radiation fraction defined as a function of $\bar{K}_T$, the ratio of monthly-average daily total to extraterrestrial radiation ($\bar{H}/\bar{H}_O$) and is calculated by:

$$\bar{H}_d/\bar{H} = 1.390 - 4.027\ \bar{K}_T + 5.531\ \bar{K}_T\ 2 - 3.108\bar{K}_T{}^3$$

β is the tilt of the surface from horizontal.

To check the sol-air methodology at Rangewood Villas, six thermocouples were attached to the envelope surface at the following locations:

north block wall
south block wall
west vent-skin block wall
south frame wall
west frame wall
north roof

A thermocouple was already in place for the south tilted roof. Solar radiation is also measured in the plane of the south tilted roof.

Measurements were made of solar absorptivity of surfaces at Rangewood Villas and at the Florida Solar Energy Center. An Eppley Precision Spectral Pyranometer was used to measure solar radiation incident upon the surface and (after being turned around) to measure the solar radiation reflected off the surface. A small correction was made to account for shading by the pyranometer. Absorptivities range from .15 for very clean white paint to .90 for dark color fiberglass shingles and gray ceramic tile shingles. A list of measured solar absorptivities are presented in Table 4 (the values for asphalt and brick were obtained from other sources). These values can be used as approximations of solar absorptivity in the absense of

Table 4. Solar Absorptivity of Common Building Surface

Painted surfaces			
		white	.15 - .30
		medium	.35 - .50
		dark	.65 - .80
Roof surfaces			
	Asphalt		
		white	.70 - .75
		medium	.85
		dark	.90
	Tile		
		white	
		burnt orange	.85
		gray	.90
	Built up roof		
		white gravel	.40 - .55
		dark gravel	.70 - .85
	Wood shingles		
		new	.65 - .75
		old	.80 - .90
	Hypalon		.20 - .30
Other surfaces			
	Concrete		
		new	.50 - .65
		old	.60 - .75
	Asphalt		.85 - .95
	Brick		
		light	.35 - .50
		light red	.50 - .60
		red	.65 - .70
	Bare ground		.70 - .80
	Grass		.75 - .80

measured values in the calculation of sol-air temperatures. At Rangewood Villas, the cream stucco exterior (on block) measured .45 absorptivity, the brown wood (frame wall) measured .80 absorptivity, and the fiberglass shingles (tan/brown) measured .85 absorptivity. The concrete patios measured .65 absorptivity. The Sol-Air calculation equation from ASHRAE is:

$$t_{ea} = t_{oa} + \alpha/ho\ (I_{DT}/24) - (\epsilon \Delta R/ho)$$

where

t_{ea}	is the average daily radiation produced surface temperature
α	is the solar absorptivity of the surface
I_{DT}	is the total daily solar on a tilted surface (Btu/hr-ft^2)
ho	is the coefficient of heat transfer by longwave radiation and convection at the outer surface (Btu/hr-ft^2-F)
t_{oa}	is the average daily outdoor air temperature
ϵ	is the hemispherical emittance of the surface

ΔR is the differential IR radiation between surface and sky/surroundings assuming the surface is black body emitter.

ASHRAE 1985 Fundamentals Handbook (26.4) states that the last term of the equation (R/ho) can be approximated by -7°F for horizontal surfaces and 0°F for vertical surfaces. We found, however, that a view factor adjusted surface temperature depression more closely matched the measured temperatures on non-horizontal surfaced.

$$\mathrm{SKYCOOL} = 7 * \frac{\mathrm{(1+COS(B)}}{2} * \mathrm{SKYVIEW}$$

SKYVIEW is the proportion of the surface's view above the horizon which is unobscured by buildings, trees, etc. From the sol-air equation, predicted envelope surface temperatures are calculated and compared to measured surface temperatures. The results are shown in Table 5 for a 34 day period from November 6 to December 15, 1986. The predicted surface temperatures are generally within 1° F of the measured surface temperatures excepting the frame walls which overlook a hot south-tilted roof (about 10° F above ambient on a daily basis).

Table 5. Measured Vs Sol-Air Calculated Building Envelope Surface Temperatures

Surface	Tilt	Solar Absorptivity	Ambient Temp.	Measured Surface Temp.	Predicted Surface Temp.
South roof	22°	.85	72.8	82.1	83.7
South block	90°	.45	72.8	79.7	79.4
West block	90°	.45	72.8	74.5	74.4
North block	90°	.45	72.8	72.5	72.1
South frame	90°	.80	72.8	87.3*	85.9
West frame	90°	.80	72.8	80.0*	78.2
North roof	22°	.85	72.8	74.2	73.8

* These walls look out over a hot shingle roof, which can account for their elevated temperature.

Using the sol-air envelope surface temperatures, the daily envelope conductive cooling load is calculated for each wall surface, each roof surface, and each door. The window conductive load (apart from solar radiation load) used the ambient air temperature.

$$Q_{surf} = (T_{surf} - T_{room}) * U * AREA * 24 \text{ hrs}$$

The total envelope load is:

$$Q_{env,\ total} = Q_{surf1} + Q_{surf2} + Q_{surf3} + \ldots + Q_{surfN}$$

The common wall to the adjacent townhouse (Unit B) also produced heat gain or heat loss. Since Unit B was monitored, the temperature difference across the wall was known. When Unit A had a low room temperature (73.5F and 74.8F), there was heat gain to the space. At 78.8 F and 81.3 F room temperature, Unit A was cooled slightly by the adjacent unit.

A.2 Window Solar Gain

Solar radiation entering the building through windows is affected by the transmittance of the window assembly and shading of the window by structures, trees, etc. The following generalized values for transmittance are mostly from the ASHRAE Fundamentals Handbook. Window transmittance is a function of the number of glazings, window tinting or reflective film, window dressings, and external or internal screens. Each layer of glass reduces solar transmittance by about 15 percent. Tinted glass reduces transmittance by an additional 15 percent. Reflective glass reduces transmittance by about 45 percent. Low-E glass reduces transmittance by about 25 percent. Venetian or vertical blinds reduce transmittance 75 percent when white, 45 percent when medium color, and 25 percent when dark. Roller shades reduce transmittance 60 percent when a light transluscent color, 80 percent when white opaque, and 10 percent when a dark color. Curtains reduce transmittance 35 percent when white thin lace, 70 percent when white, 40 percent when medium color, and 10 percent when dark. External screens block 40 percent of the incident solar over that portion of the window which is covered (this was measured at FSEC). Internal screens can be considered to reduce transmittance 10 percent. The total window transmittance is the product of all the transmittances.

$$\begin{aligned} T_{window} = {} & T_{glaz} * T_{tint} \\ & * \ 1.0 * (1.0 - DC) + (T_{DRESS} * DC) \\ & * \ 1.0 * (1.0 - SC) + (T_{SCREEN} * SC) \end{aligned}$$

where DC is the portion of the window covered by window dressing and SC is the portion covered by screen.

For example, the transmittance of a window with two glazings, one tinted, with an external screen covering one half the window, and white vertical blinds covering 30 percent of the window area is:

$$\begin{aligned} T_{window} &= .70 * .85 * (1.0 * .70 + .25 * .30) \\ &\qquad * (.50 * 1.0 + .50 * .60) \\ &= .37 \end{aligned}$$

Shading of windows is complex to accurately assess in a microcomputer program. The proportion of the diffuse and beam solar radiation shaded by overhangs on surfaces of arbitrary azimuth can be calculated by methods such as that presented by Robert E. Jones Jr.[2] The sky diffuse shading does not vary greatly over the seasons and is not too difficult to calculate. Ground reflected diffuse can change significantly at various solar declinations as the proportion of the ground view which is shaded changes. This can be particularly important if a more reflective gound surface is located immediately in front of the window (e.g. patio slab, reflectivity = .35). Shading of beam solar radiation is very season dependent and requires quite complicated calculations. It can be accurately calculated for overhangs. Awnings can be difficult. Trees and adjacent structures can be very difficult to asses.

During the test periods at Rangewood Villas, June through September, no direct solar radiation entered the windows because they are on the north and south sides of the building and are shaded by overhangs. There are also no adjacent trees or structures to provide shade. Only shading of sky diffuse and changes in the proportions of the concrete patios shaded had to be determined, and these do not require extensive calculations. Calculated solar heat gain through the windows ranged from 25.8 to 35.8 KBtu/day for the five periods, on the average about 38 percent of the non-internal cooling load. Since this is quite a large portion of the sensible load, errors in calculating window solar heat gain can cause significant errors in total predicted sensible load.

A.3 Infiltration Sensible Load

The infiltration rate was characterized at Rangewood Villas as a function of wind speed and air conditioner blower run time. This is presented in Section III. Infiltration sensible load can be calculated from the infiltration rate and the temperature of the room air and ambient air. However, since there is considerable variation in the infiltration rate at different times of the day, using daily average values will produce significant error.

For example, during the period June 18 - July 22, 1985, the infiltration rate was .425 air changes per hour (ACH) during the hours 9 AM to 6PM when the ambient dry-bulb temperature averaged 87.3 F, while it was .270 ACH for the rest of day when ambient temperatures averaged 75.9 F. Infiltration rates are typically twice as high in the afternoon as in the middle of the night at Rangewood Villas. Consequently, to correctly assess the sensible infiltration load there must be a time of day analysis. For three lower thermostat settings (73.5F, 74.8F, 77.8F), a multiplier factor of 1.30 corrects the results obtained by using daily average values. At 78.8 F, the factor is 1.55. At 81.3 F a multiplier does not work. The actual sensible load is slightly negative (-234 Btu/day), while using daily averages produces a large negative sensible load (-2190 Btu/day), as can be seen in Table 6. Computer models using average monthly data will have to consider time of day infiltration cooling loads. In the case of Rangewood Villas, using daily average values rather than time of day analysis underestimates the infiltration sensible cooling load by 1400 to 3000 Btu/day for the five periods, with an average underestimation of 2200 Btu/day (about a 2% error in total sensible cooling load.)

Table 6. Time of Day Analysis of Infiltration Sensible Load for September 11-28, 1985

Time	Wind Speed MPH	Fan Run Fraction	T_{amb} $-T_{room}$	Air Changes Per Hour		Sensible Load
3	2.3	.09	-6.8	.13		-541
6	2.2	.06	-7.5	.12		-533
9	3.9	.07	-5.4	.14		-459
12	7.0	.18	1.2	.26		187
15	8.3	.30	5.7	.36		1199
18	6.9	.29	4.2	.30		756
21	3.5	.20	-3.3	.19		-373
24	2.6	.12	-5.3	.15		-470
	---	---	----	---		----
Average	4.6	.16	-2.2	.21	Total	-234

A.4 Conduction Through Slab

In most of the United States the ground is a source of cooling during the cooling season. In Cocoa, Florida the measured ground temperature at 2 feet depth is about $80^{o}F$ during the summer ($74^{o}F$ on an annual basis), and therefore may be a source of heating or cooling depending upon the thermostat setting. However, the ground temperature under a building will not be as warm during the summer as exposed ground surfaces. Kasuda et. al. presented a method in 1982 for Seasonal Heat Loss Calculation for Slab-On-Grade Floors which determines ground temperature beneath the slab and the appropriate slab R-values[3]. Measured ground temperatures are presented in Table 7. At Rangewood Villas this method predicted ground temperatures 1 foot underneath the slab that are $2.0^{o}F$ cooler than the measured soil temperatures 5' west of the west end of the building at one foot depth. Following is a brief overview of the Kasuda method.

Thermal conductance for the slab is first calculated.

	$hr \cdot ft^2 \cdot F/Btu$
Inside surface resistance	0.6
Carpet	1.0
Pad	1.4
4" Concrete	.3

	3.3

Table 7. Ground Temperatures (^{o}C), Room and Ambient Air Temperatures (^{o}C), Solar Radiation (MJ/M^2), and Heat Pump Energy Use (kWH/Day) at Rangewood Villas during 1985

Month	SLAB EDGE	GROUND @ 6"	GROUND @ 12"	GROUND @ 24"	AMBIENT TEMP.	ROOM DOWN	ROOM UP	SOLAR HORIZONTAL	ENERGY
January	17.42	16.89	17.49	17.99	13.28	21.68	22.81	13.03	14.95
February	19.16	17.99	18.17	18.33	17.24	22.81	23.74	14.70	7.68
March	22.27	21.24	21.21	21.19	20.51	24.04	24.59	18.79	1.05
April	23.02	22.16	22.12	22.09	21.60	24.86	25.26	19.41	0.00
May	25.86	24.80	24.62	24.50	24.79	26.38	26.73	23.76	7.11
June	26.40	26.44	26.23	26.05	26.97	23.05	23.06	20.40	29.78
July	26.42	26.68	26.49	26.33	27.04	23.76	23.75	20.30	24.18
August	27.17	27.32	27.16	27.03	27.58	25.30	25.63	17.51	17.69
September	26.83	26.74	26.74	26.62	26.71	26.69	26.84	16.91	11.61
October	26.46	26.29	26.28	26.25	26.33	27.18	27.41	15.47	6.69
November	23.84	23.49	23.76	23.89	22.80	25.12	25.50	12.24	4.03
December	19.50	19.29	19.87	20.31	15.08	21.55	22.20	11.08	7.68
Average	23.70	23.28	23.35	23.38	22.49	24.37	24.79	16.04	11.04

U_{floor} is equal to .30 (1/3.3). Next, the soil conductance is determined by k/Z, where k is the soils thermal conductance and Z is the soil's depth. U_{ground} is .5/1.0 or .5 Btu/hr·ft^2·F. Several temperatures are defined:

T_m	is the mean annual air temperature (71.8 F)
B	is the typical difference between the warmest and coldest month (21.5 F)
T_R	is the mean annual room temperature (75 F)
C	is one-half the difference between cooling season and heating season room temperature (78-72 F)/2 (3.0)

The slab dimensions are defined: 2a is the length, and 2b is the width.

The equation which predicts soil temperature under the slab is then solved.

$$\bar{T}_z = T_m + (T_R - T_m)\ \theta'_{1m} + B\theta'_{2m} + (C-B)\theta'_{3m}$$

Three terms must be defined; θ'_{1M}, θ'_{2m}, and θ'_{3m}.

θ'_{1m} is the annual average temperature rise function found in given figures, or can be approximated by the following relationship

$$\theta'_{1M} = e^{\frac{-Z\cdot 0.8}{Z}}\ \left[3.312 - 3.324\left(\frac{b}{a}\right) + 1.476\left(\frac{b}{a}\right)^2\right]$$

θ'_{2m} is the annual cycle of undisturbed earth temperature, which is calculated by the following equation:

$$\theta'_{2m}=e^{-Z\sqrt{\omega/2\alpha}}\sin\left(Wt-Z\sqrt{\omega/2\alpha}\right)$$

θ'_{3m} is the annual cyclic temperature effect upon the sub-slab temperature. It is more easily found in three lookup figures, but can be solved by a lengthy series of equations which will not be reiterated here.

The final calculated ground temperature one foot below the slab and the resulting heat gain or loss for the five periods are shown in Table 8. For the typical thermostat set point of 78°F, heat gain or heat loss during the cooling season can be considered negligible. However, at 73.5 F room temperature, slab heat gains (if we believe the calculations) represent over 11 percent of the non-internal load. At 81.3 F room temperature, the slab reduced the non-internally generated sensible cooling load quite significantly by 54 percent.

B. Prediction of Latent Cooling Load

Latent cooling load at Rangewood Villas is limited largely to infiltration moisture since there are no occupants in the townhouse. There is no significant

Table 8. Ground Temperatures (F) and Slab Heat Gain or Loss (kBtu/Day) at Rangewood Villas Based on Kasuda Method

	Date	Measured Ground Temp.	Calculated Ground Temp.	Adjusted Ground Temp.	Heat Gain
I.	85169-203 7/5 (73.51)	79.30	77.6	77.3	14.1
II.	84242-264 9/10 (74.80)	79.11	78.0	77.1	8.6
III.	85207-252 8/21 (77.85)	80.76	78.6	78.6	2.8
IV.	84217-232 8/13 (78.76	81.36	78.6	79.0	.9
V.	85254-271 9/20 (81.30)	79.70	77.6	77.6	-13.8

water use in the house except for the toilets. Calculations indicate that about .9 lb of water evaporate from the two toilets each day, or about 900 Btu/day latent load. This should not add to the total load because as the water evaporates it provides sensible cooling.

The internal and ambient dew point temperatures are known at Rangewood Villas because they are measured. Since the infiltration rate can be reasonably accurately approximated from the equations in Section III, the latent cooling load produced by infiltration can be calculated by the following equation.

$$Q_{latent}=(W_A-W_R)*ACH*Volume*Density$$

The calculated latent load agrees quite well with the measured condensate. If the .9 KBtu/day latent load from the toilets is added, the average calculated latent load for the five periods is 98 percent of the measured latent. This can be seen in Table 9. For the five periods the Sensible Heat Ratio (SHR) is .71 (29% is latent load).

However, for most buildings, the internal dew point is not known. Therefore the infiltration latent load cannot be determined. If the building infiltration rate

Table 9. Detailed Calculations of Latent Cooling at Rangewood Villas for Five Periods

	Date	Room Temp.	Ambient Temp.	Ambient Dew Point	Room Dew Point	Ambient Humidity Ratio	Room Humidity Ratio	Wind Speed MPH	Fan Run Fraction	Air Changes/ Hour	Air Spec. Volume ft^3/lb	Pounds Dry Air/Day	Calculated Latent Load kBtu/Day	Measured Latent Load kBtu/Day
I	6/18-7/22/85	73.5	80.2	74.1	58.1	.0183	.0104	3.8	.624	.300	13.65	6257	57.6	64.1
II	8/29-9/20/84	74.8	79.7	75.2	59.4	.0180	.0110	4.4	.494	.311	13.70	6237	50.6	50.6
III	7/26-9/08/85	77.8	81.7	75.7	67.5	.0194	.0116	2.8	.343	.233	13.79	4640	40.1	42.4
IV	8/04-8/19/84	78.8	81.4	75.6	62.6	.0193	.0122	3.8	.425	.274	13.83	5441	42.2	44.7
V	8/11-9/28/84	81.3	79.1	74.1	63.5	.0183	.0126	4.6	.165	.192	13.89	3796	27.0	24.4
Ave.		77.2	80.4	74.9	61.0	.0189	.0116	3.9	.380	.262	13.77	5274	43.5	45.2

and internally generated moisture are assumed, and air conditioner operating characteristics are known, then the infiltration latent load and the AC SHR can be determined iteratively.

Based on assumptions of generated moisture and infiltration rates, an iterative solution to the AC latent load can be made. Room and ambient dry-bulb temperatures and ambient dew point temperatures are known. Estimate the room wet-bulb temperature. Based on an estimated room wet-bulb temperature, calculate the infiltration latent load. Also at the estimated room wet-bulb temperature determine the latent cooling fraction from the AC machine data. See if this latent cooling matches the sum of infiltration and internal generated moisture. If it is too high or too low, lower or raise the (respective) estimated room wet-bulb and recalculate the latent load till it matches the infiltration and internally generated moisture. A more detailed explanation of this method for determining SHR, total moisture removed, room humidity conditions, and total energy use is presented in a paper by Khattar.[4]

V. Delivery of Rangewood Villas Data

A. Data File Format

The data collected at Rangewood Villas during the night ventilation/day air conditioning tests during the summer of 1986 has been processed from 15 minute to hourly data and placed in two separate files: WEATHER and BUILDING. A total of 62 channels of data was recorded by the datalogger, but only 47 are being included on the tapes because of sensor redundancy; 14 on the WEATHER file and 33 on the BUILDING file.

Data was collected continuously during the summer. During the 110 days from the beginning (6/19) to the end (10/13) of the summer ventilation test, only 1.54 days of data was lost. The two periods of lost data occurred on:

July 10, 12:30 EST - July 11, 09:00 EST (20.75 hours)
July 15, 16:30 EST - July 16, 07:45 EST (15.5 hours)

Three additional 15 minutes scans were lost.

The format of the WEATHER file is shown in Table 10. It follows the SOLMET data format. Data is provided for only portions of the format (other fields will be blank). The following data is included:

1. Solar time computed by equation of time and longitude correction.

2. Local standard time recorded by Campbell Scientific, Inc. CR7.

3. Global solar radiation on 22° south facing tilted surface of roof at Rangewood Villas (KJ/m^2 hr).

4. Global solar radiation on horizontal (KJ/m^2 hr).

5. Weather as rainfall in mm.

6. Barometric pressure measured at the Florida Solar Energy Center by a Weathermeasure Model 7105-A. This is the only data not measured on site.

7. Ambient dry-bulb temperature measured by 1) an aspirated thermocouple (°C) and 2) an unaspirated but radiation shielded thermocouple (°C).

8. Ambient dew point temperature measured by an aspirated General Eastern DEW-10 Chilled Mirror Hygrometer with external heating of ambient air

able 10. Weather Tape Format[1]

IDENTIFICATION								Solar Radiation Observation										
Tape Deck #	WBAN STN #	Solar Time				LST TIME	ETR kJ/m^2	Radiation Values KJ/m^2										SUN MIN
		YR	MD	DY	HRMN			DIRECT	DIFFUSE	NET	TILTED	HORIZ	ENG COR	STD YR COR	A	B		
xxxx	xxxxx	xx	xx	xx	xxxx	xxxx	xxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	xx	
001	002	003				004	101	102	103	104	105	106	107	108	109	110	111	

SURFACE METEOROLOGICAL OBSERVATION														OTHER MEASUREMENTS					
OBS LST	CEILING dam	Sky Cond.	DRY BULB TEMP ^oC	WEATHER Rain mm	PRESSURE kPa		TEMP ^oC		WIND		CLOUDS		SNOW COVER		FUNK kJ/m^2	GROUND TEMP ^oC			
					SEA LEVEL	STA-TION	DRY BULB	DEW POINT	DIR DEG	SPD m/s	TOTAL	OPAQUE				6"	12"	24"	SLAB
xx	xxxx	ixxxx	xxxx	xxxxxxxx	xxxxx	xxxxx	xxxx	xxxx	xxx	xxxx	xx	xx	x	xxxxx	xxxxx	xxxx	xxxx	xxxx	xxxx
201	202	203	204	205	206		207		208		209		210	301	302	303	304	305	306

TAPE FIELD NUMBER	TAPE POSITIONS	NUMBER OF DECIMAL PLACES	ELEMENT
001	001 - 004		Tape Deck Number
002	005 - 009		WBAN Station Number
* 003	010 - 019	(0)	Solar Time (Year, Month, Day, Hour, Minute
* 004	020 - 023	(0)	Local Standard Time (Hour and Minute)
* 101	024 - 027	(0)	Extraterrestrial Solar Radiation
102	028 - 032		Direct Solar Radiation
103	033 - 037		Diffuse Solar Radiation
104	038 - 042		Net Solar Radiation
* 105	043 - 047	(1)	Global Solar Radiation on a Tilted Surface
* 106	048 - 052	(1)	Global Solar Radiation on a Horiz. Surface - Observed Data
107	053 - 057		Global Solar Radiation on a Horiz. Surface - Engineering Corrected Data
108	058 - 062		Global Solar Radiation on a Horiz. Surface - Standard Year Corrected Data
109, 110	063 - 072		Additional Solar Radiation Measurements
111	073 - 074		Minutes of Sunshine
201	075 - 076		Time of Collateral Surface Observation (LST)
202	077 - 080		Ceiling Height (Dekameters)
203	081 - 085		Sky Condition
* 204	086 - 089	(2)	Temperature Dry-bulb (unaspirated)
* 205	090 - 097	(1)	Weather (Rain-mm)
* 206	098 - 107	(2)	Pressure (Kilopascals)
* 207	108 - 115	(2)	Temperature Dry-bulb and Dewpoint in Celsius (aspirated)
* 208	116 - 122	(2/0)	Wind Speed (m/s) and Wind Direction
* 209	123 - 126	(0)	Clouds (Tenths of Total and Opaque Sky Cover)
210	127		Snow Cover Indicator
* 301	128 - 132	(1)	Precision Infrared Radiometer
* 302	133 - 137	(1)	FUNK-type Pyrradiometer
* 303	138 - 141	(2)	Ground Thermocouple 6" (Degrees Celsius to Tenths)
* 304	142 - 145	(2)	Ground Thermocouple 12" (Degrees Celsius to Tenths)
* 305	146 - 149	(2)	Ground Thermocouple 24" (Degrees Celsius to Tenths)
* 306	150 - 153	(2)	Slab Thermocouple (Degrees Celsius to Tenths)

[1] FORMAT follows that of SOLMET data tapes.

* Asterisk indicates data included on this tape.

Table 10. Weather Tape Format (Continued).

stream to maintain operating RH well below 95 percent.

9. Wind direction measured by the Met-One Inc. Model 024 Wind Direction Sensor.

10. Wind speed measured by the Met-One Inc. Model 014 Wind Speed Sensor.

In addition, the Precision Infrared Radiometer, ground temperatures at 6", 12", and 24", and the building slab (west edge) temperature are included.

The instrumentation was generally considered reliable. The aspirated dry-bulb temperature was found to be reading significantly high during the period 6/19 - 7/15 (11:00 A.M. EST). This data has been replaced by the temperatures from the unaspirated dry-bulb sensor, corrected to account for radiation affects by correlation with the aspirated dry-bulb after it was adjusted by use of the following equation:

$$T_{db}, \text{corrected} = -8.47 + 1.75(T_{db,UA}) - 0.016(T_{db,UA})^2$$

where $T_{db,UA}$ is the unaspirated thermocouple. During the period 6/24-6/27 0700 hour EST, as a result of programming error, the nighttime (2000-0700 EST) dry-bulb temperatures were not recorded by the unaspirated thermocouple. During those hours, corrected aspiratd thermocouple temperatures are included. In addition, late in the summer it was discovered that the wind speed probe was reading lower values apparently because of higher friction. Therefore, the algorithms predicting infiltration as a function of wind speed will underpredict infiltration during 1986.

B. BUILDING FILE

This file contains 33 channels of data, 29 in Unit A and 4 in Unit B. The format of the BUILDING file is shown in Tables 11 and 12. In Unit B only four dry-bulb temperatures were recorded in 1986 (in previous years it had the same instrumentation as Unit A). Unit A has 5 room air temperature measurements: living room (zone 1), thermostat, downstairs bedroom, upstairs bedroom (zone 2), and attic (zone 3). There are RH and dew point probes in zones 1, 2 and 3. The heat pump is monitored with dry-bulb and dew point temperatures into and out of the air handler. Air conditioner condensate and blower run times are measured.

Four watt-hour meters measure total, heat pump, domestic hot water, and zone 2 (upstairs) electricity use. A series of 8 thermocouples measure temperatures

Table 11. Building Tape Format

UNIT A

IDENTIFICATION							ZONE TEMPERATURES					ZONE DEWPOINTS			RELATIVE HUMIDITY		
Tape Deck #	WBAN STN #	Solar Time YR	MO	DY	HRMN	LST TIME	LR Zone 1	BRU Zone 2	Attic Zone 3	BRD	TS	LR Zone 1	BRU Zone 2	Attic Zone 3	RH Zone 1	RH Zone 2	RH Zone 3
xxxx	xxxxx	xx	xx	xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
001	002	003				004	101	102	103	104	105	106	107	108	109	110	111

UNIT A

HEAT PUMP						DHW	POWER USE					
COIL TEMPERATURES DRY BULB IN	DRY BULB OUT	DEW POINT IN	DEW POINT OUT	RETURN GRILL DRY BULB	CON-DEN-SATE	FAN RUN TIME	TEMP	TOTAL	HEAT PUMP	DHW	ZONE 1	ZONE 2
xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxx	xxxx	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx
201	202	203	204	205	206	207	208	301	302	303	304	305

UNIT A								UNIT B			
THERMOCOUPLE TREE								ZONE TEMPERATURES			
SHIN-GLE	TOP SHEATH	BOT SHEATH	TOP DENNY BOARD	BOT DENNY BOARD	TOP GLASS BATT	BOT GLASS BATT	BOT GYP-SUM	LR ZONE 1	BRU ZONE 2	ATTIC ZONE 3	BRD
xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
401	402	403	404	405	406	407	408	501	502	503	504

Table 10. Weather Tape Format[1]

IDENTIFICATION							Solar Radiation Observation										
Tape Deck #	WBAN STN #	Solar Time				LST TIME	ETR kJ/m²	Radiation Values KJ/m²									SUN MIN
		YR	MD	DY	HRMN			DIRECT	DIFFUSE	NET	TILTED	HORIZ	ENG COR	STD YR COR	A	B	
xxxx	xxxxx	xx	xx	xx	xxxx	xxxx	xxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	ixxxx	xx
001	002	003				004	101	102	103	104	105	106	107	108	109	110	111

SURFACE METEOROLOGICAL OBSERVATION															OTHER MEASUREMENTS				
OBS LSTS	CEILING dam	Sky Cond.	DRY BULB TEMP °C	WEATHER Rain mm	PRESSURE kPa		TEMP °C		WIND		CLOUDS		SNOW COVER		FUNK kJ/m²	GROUND TEMP °C			
					SEA LEVEL	STATION	DRY BULB	DEW POINT	DIR DEG	SPD m/s	TOTAL	OPAQUE				6"	12"	24"	SLAB
xx	xxxx	ixxxx	xxxx	xxxxxxxx	xxxxx	xxxxx	xxxx	xxxx	xxx	xxxx	xx	xx	x	xxxxx	xxxxx	xxxx	xxxx	xxxx	xxxx
201	202	203	204	205	206		207		208		209		210	301	302	303	304	305	306

TAPE FIELD NUMBER	TAPE POSITIONS	NUMBER OF DECIMAL PLACES	ELEMENT
001	001 - 004		Tape Deck Number
002	005 - 009		WBAN Station Number
* 003	010 - 019	(0)	Solar Time (Year, Month, Day, Hour, Minute
* 004	020 - 023	(0)	Local Standard Time (Hour and Minute)
* 101	024 - 027	(0)	Extraterrestrial Solar Radiation
102	028 - 032		Direct Solar Radiation
103	033 - 037		Diffuse Solar Radiation
104	038 - 042		Net Solar Radiation
* 105	043 - 047	(1)	Global Solar Radiation on a Tilted Surface
* 106	048 - 052	(1)	Global Solar Radiation on a Horiz. Surface - Observed Data
107	053 - 057		Global Solar Radiation on a Horiz. Surface - Engineering Corrected Data
108	058 - 062		Global Solar Radiation on a Horiz. Surface - Standard Year Corrected Data
109, 110	063 - 072		Additional Solar Radiation Measurements
111	073 - 074		Minutes of Sunshine
201	075 - 076		Time of Collateral Surface Observation (LST)
202	077 - 080		Ceiling Height (Dekameters)
203	081 - 085		Sky Condition
* 204	086 - 089	(2)	Temperature Dry-bulb (unaspirated)
* 205	090 - 097	(1)	Weather (Rain-mm)
* 206	098 - 107	(2)	Pressure (Kilopascals)
* 207	108 - 115	(2)	Temperature Dry-bulb and Dewpoint in Celsius (aspirated)
* 208	116 - 122	(2/0)	Wind Speed (m/s) and Wind Direction
* 209	123 - 126	(0)	Clouds (Tenths of Total and Opaque Sky Cover)
210	127		Snow Cover Indicator
* 301	128 - 132	(1)	Precision Infrared Radiometer
* 302	133 - 137	(1)	FUNK-type Pyrradiometer
* 303	138 - 141	(2)	Ground Thermocouple 6" (Degrees Celsius to Tenths)
* 304	142 - 145	(2)	Ground Thermocouple 12" (Degrees Celsius to Tenths)
* 305	146 - 149	(2)	Ground Thermocouple 24" (Degrees Celsius to Tenths)
* 306	150 - 153	(2)	Slab Thermocouple (Degrees Celsius to Tenths)

[1] FORMAT follows that of SOLMET data tapes.
* Asterisk indicates data included on this tape.

Table 10. Weather Tape Format (Continued).

Table 11. Building Tape Format

UNIT A

IDENTIFICATION							ZONE TEMPERATURES					ZONE DEWPOINTS			RELATIVE HUMIDITY		
Tape Deck #	WBAN STN #	Solar Time YR	MO	DY	HRMN	LST TIME	LR Zone 1	BRU Zone 2	Attic Zone 3	BRD	TS	LR Zone 1	BRU Zone 2	Attic Zone 3	RH Zone 1	RH Zone 2	RH Zone 3
xxxx	xxxxx	xx	xx	xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
001	002	003				004	101	102	103	104	105	106	107	108	109	110	111

UNIT A

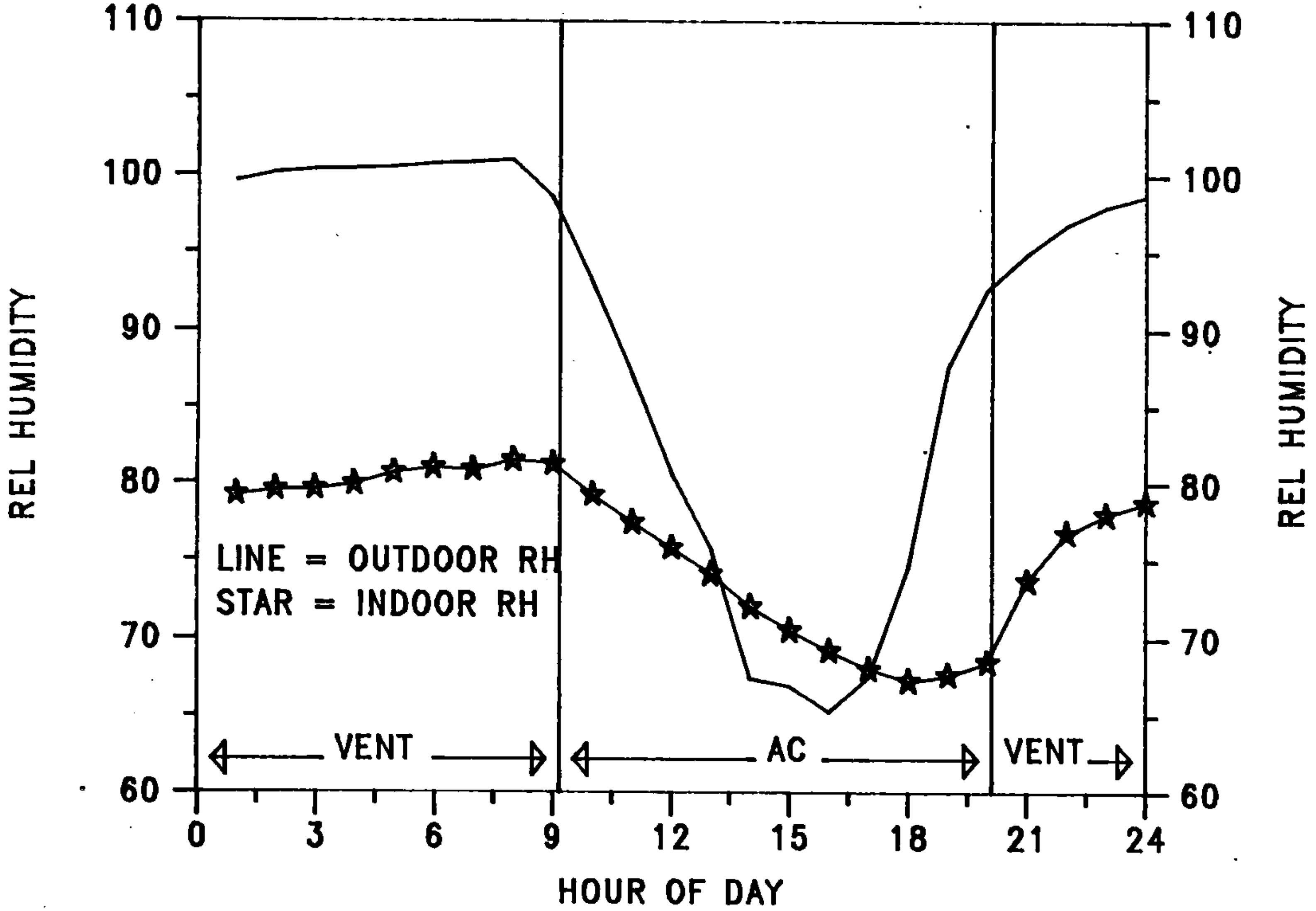
HEAT PUMP							DHW	POWER USE				
COIL TEMPERATURES DRY BULB IN	DRY BULB OUT	DEW POINT IN	DEW POINT OUT	RETURN GRILL DRY BULB	CON-DEN-SATE	FAN RUN TIME	TEMP	TOTAL	HEAT PUMP	DHW	ZONE 1	ZONE 2
xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxx	xxxx	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx
201	202	203	204	205	206	207	208	301	302	303	304	305

UNIT A

UNIT B

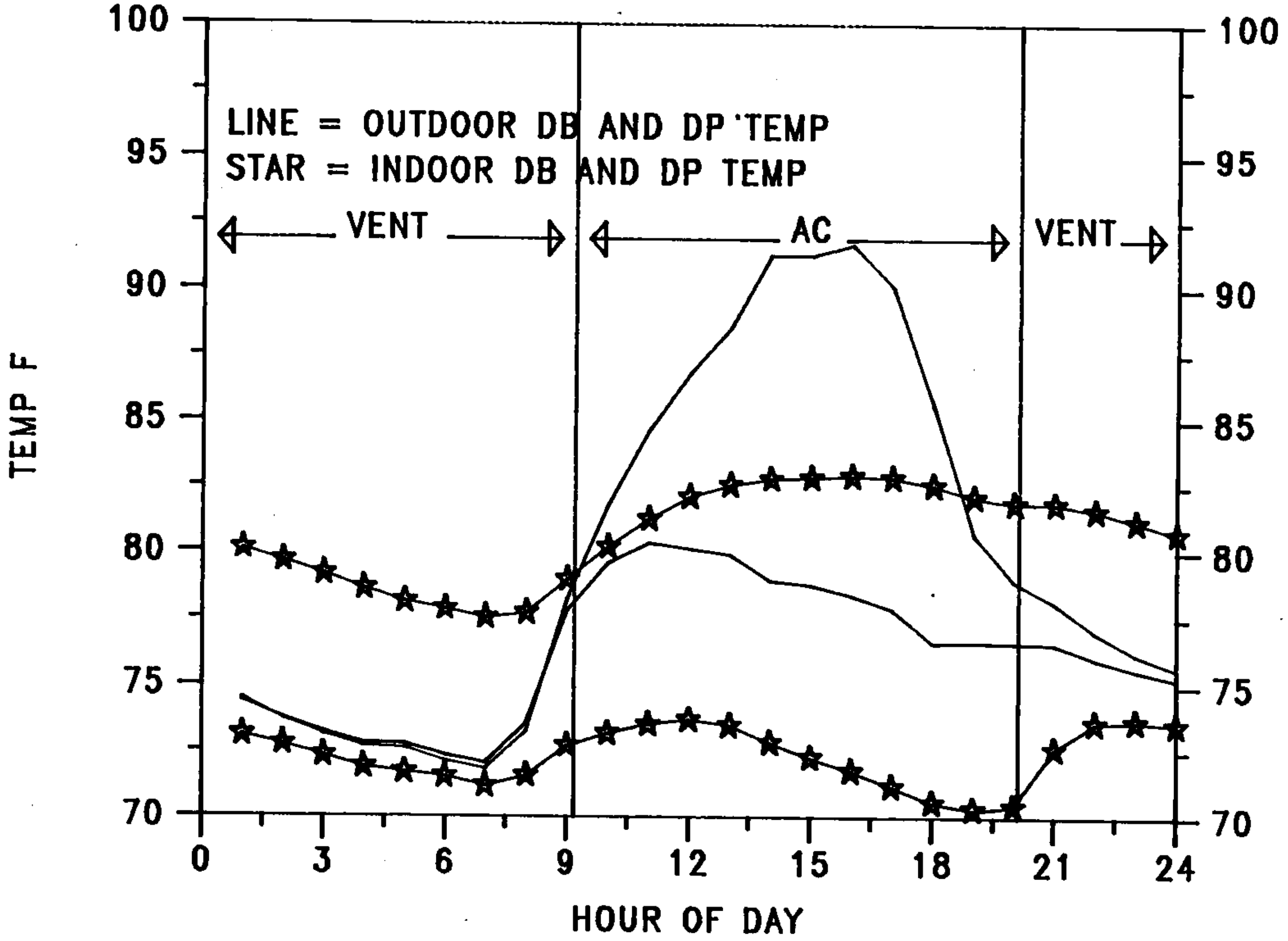
THERMOCOUPLE TREE								ZONE TEMPERATURES			
SHIN-GLE	TOP SHEATH	BOT SHEATH	TOP DENNY BOARD	BOT DENNY BOARD	TOP GLASS BATT	BOT GLASS BATT	BOT GYP-SUM	LR ZONE 1	BRU ZONE 2	ATTIC ZONE 3	BRD
xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
401	402	403	404	405	406	407	408	501	502	503	504

OCTOBER 11 - 17, 1985



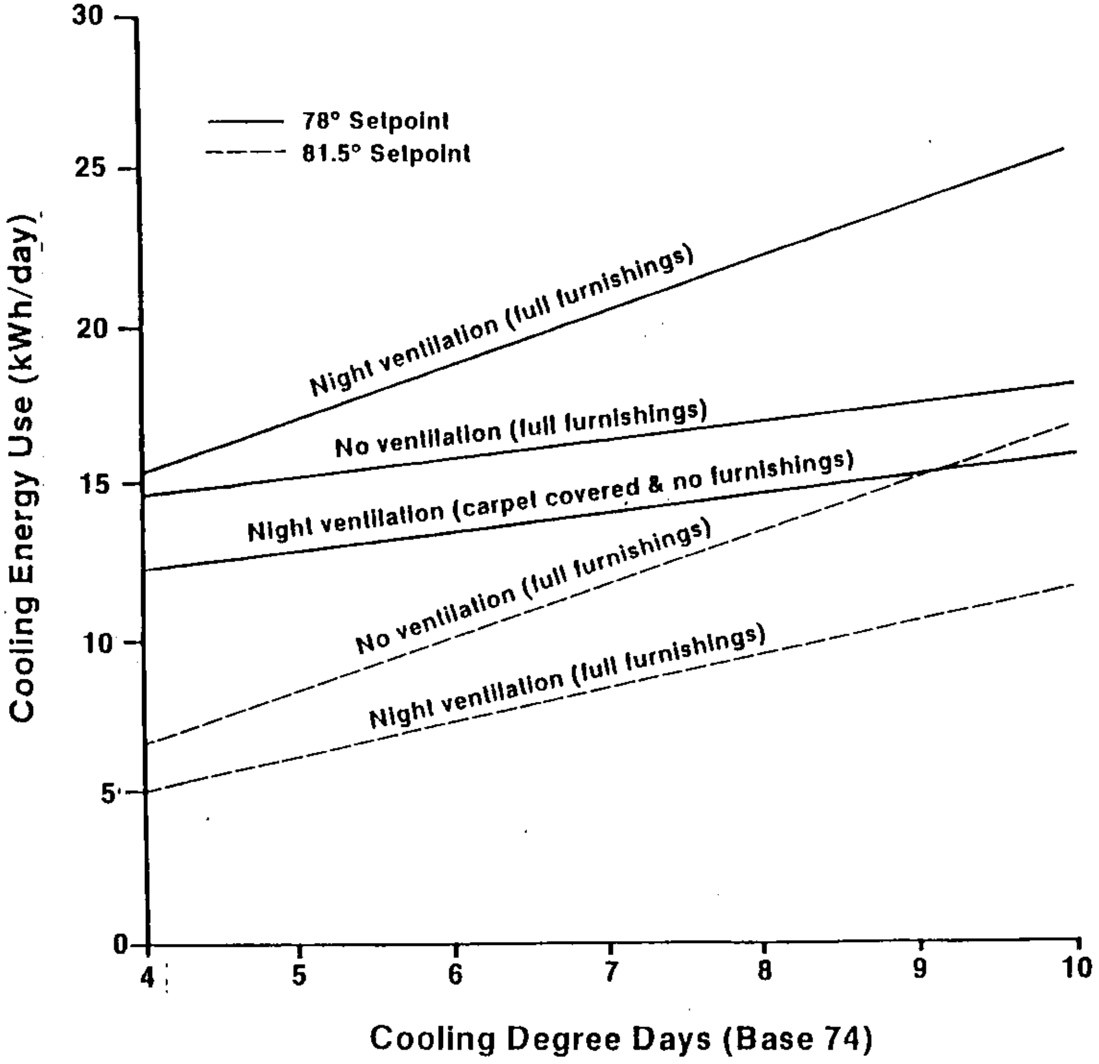
RANGEWOOD VILLAS COCOA, FLORIDA

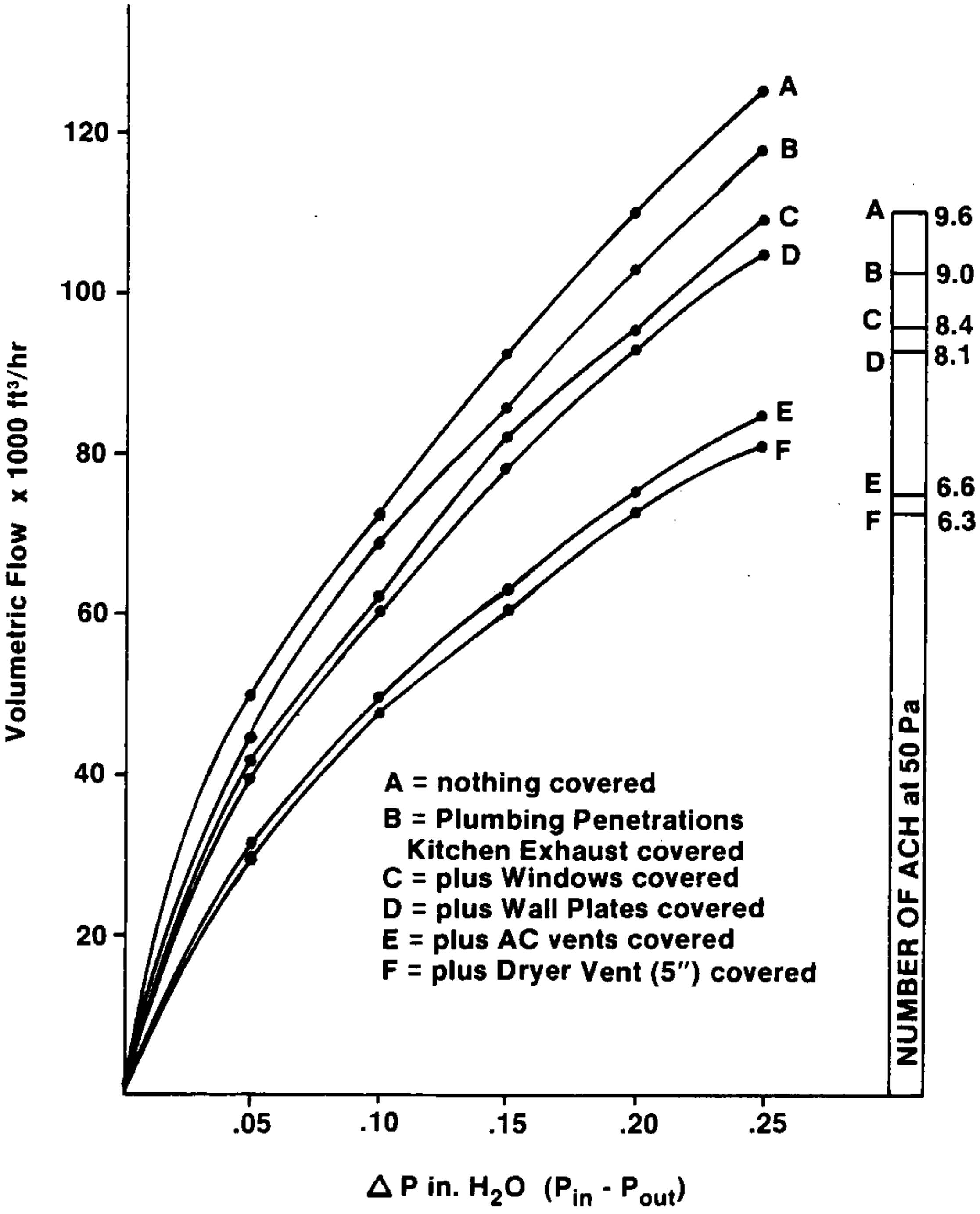
OCTOBER 11 - 17, 1985

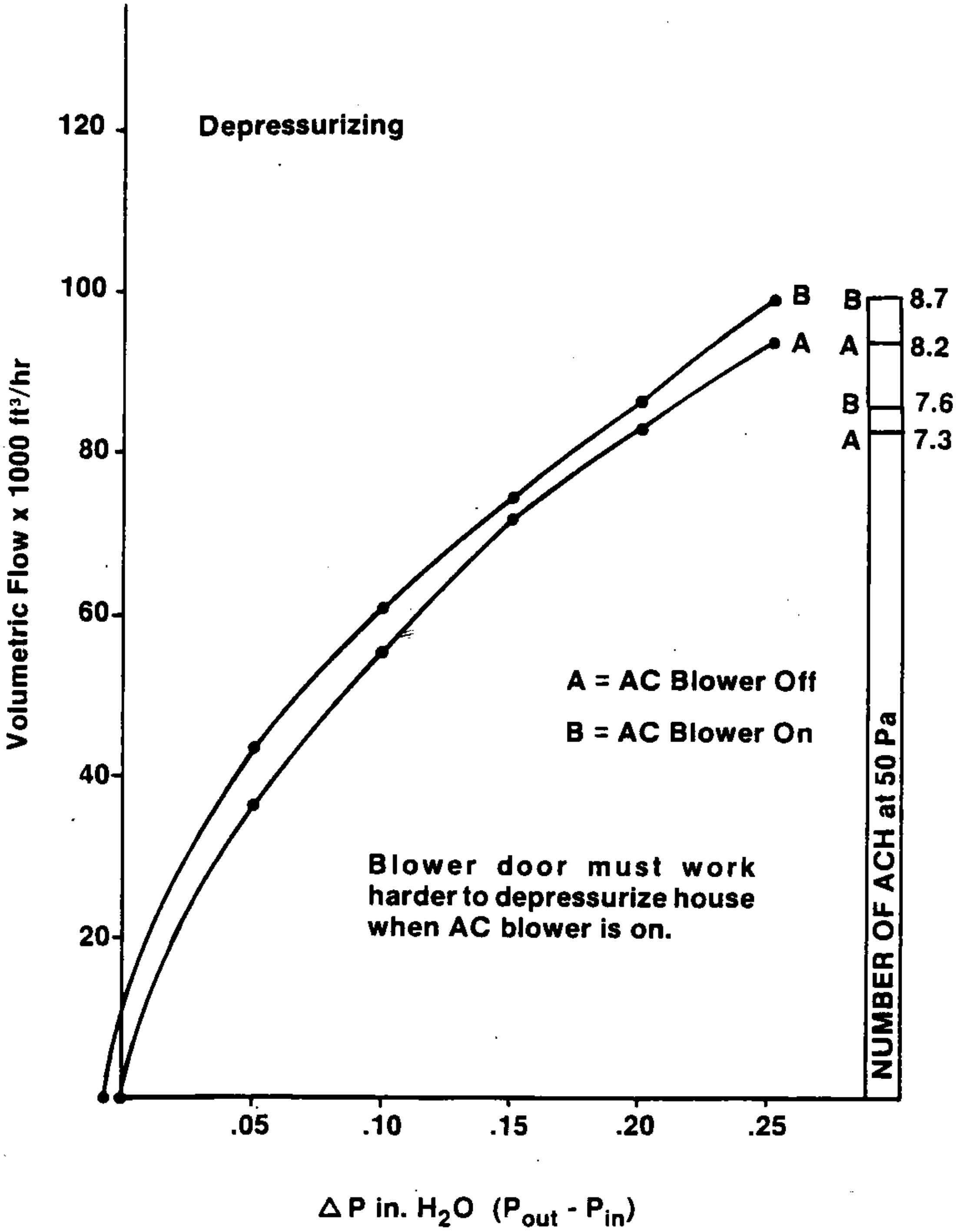


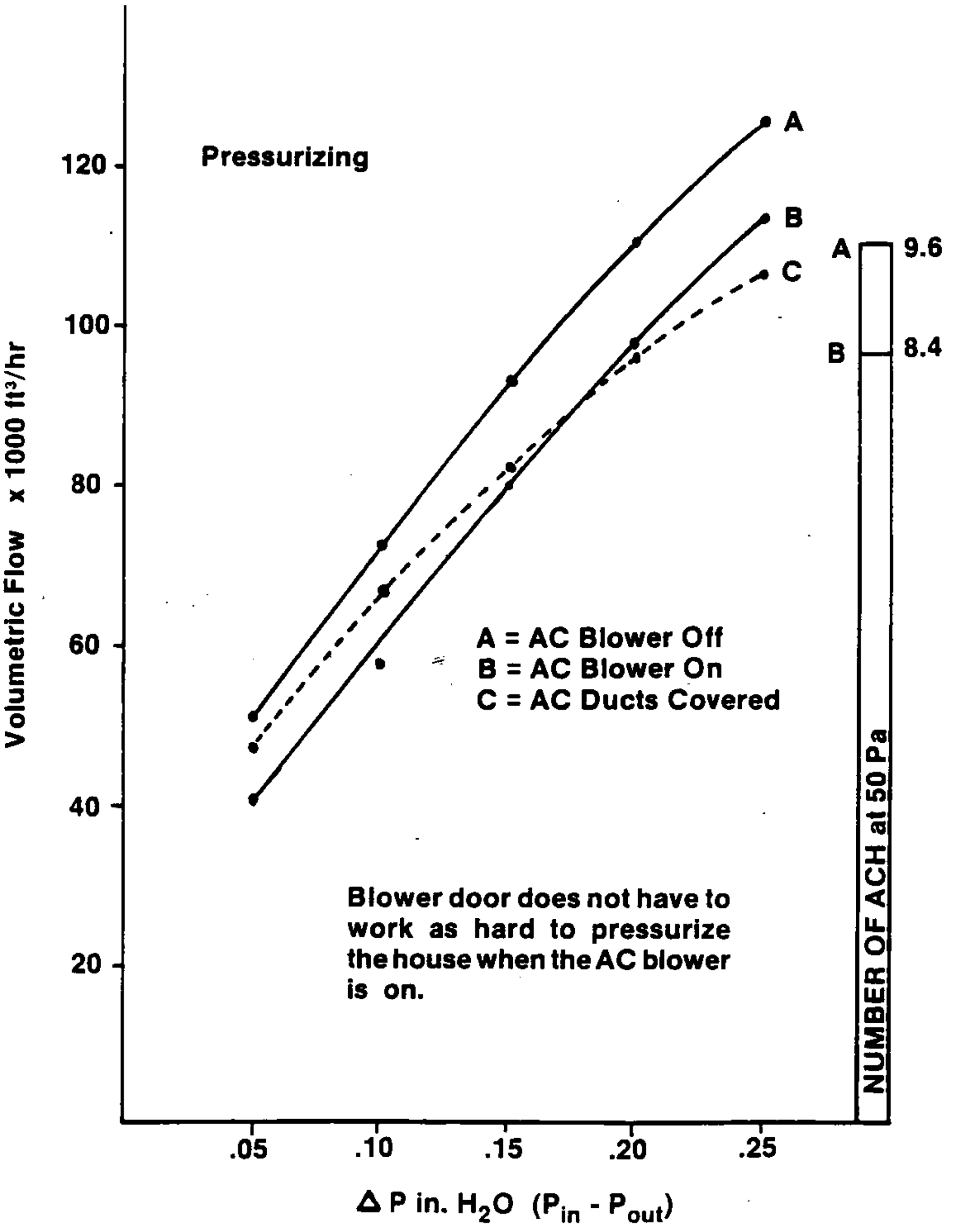
RANGEWOOD VILLAS COCOA, FLORIDA

Cooling energy use at Rangewood Villas for two setpoints (78 & 81.5°F) for night ventilation and no ventilation during 1985 and 1986



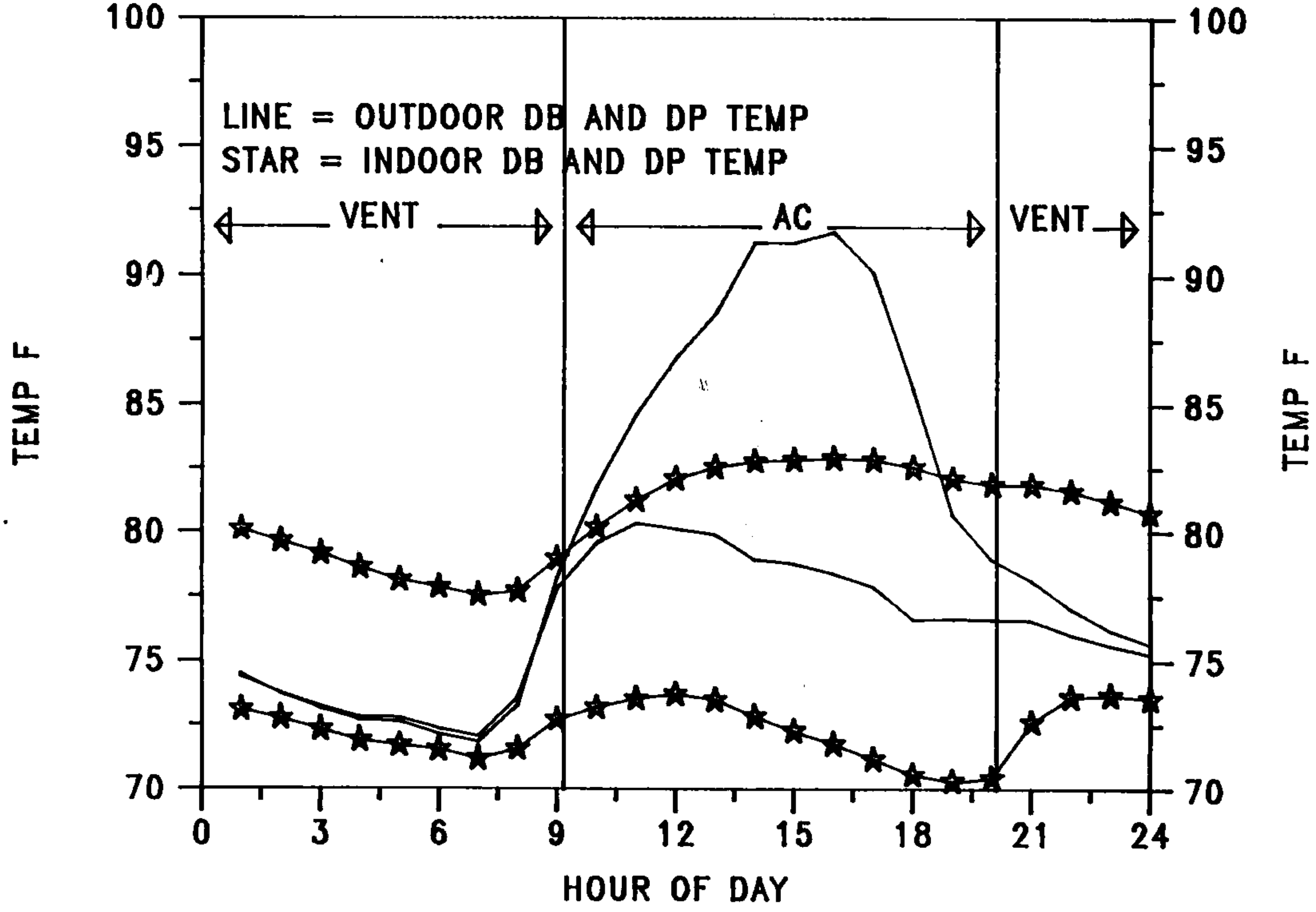

Volumetric Flow x 1000 ft³/hr
120
100
80
60
40
20
.05
.10
.15
.20
.25
Δ P in. H₂O (P_in - P_out)
A
B
C
D
E
F
A = nothing covered
B = Plumbing Penetrations
Kitchen Exhaust covered
C = plus Windows covered
D = plus Wall Plates covered
E = plus AC vents covered
F = plus Dryer Vent (5″) covered
NUMBER OF ACH at 50 Pa
A 9.6
B 9.0
C 8.4
D 8.1
E 6.6
F 6.3


Depressurizing
Volumetric Flow x 1000 ft³/hr
120
100
80
60
40
20
.05
.10
.15
.20
.25
ΔP in. H₂O (P_out - P_in)
B
A
B 8.7
A 8.2
B 7.6
A 7.3
NUMBER OF ACH at 50 Pa
A = AC Blower Off
B = AC Blower On
Blower door must work harder to depressurize house when AC blower is on.

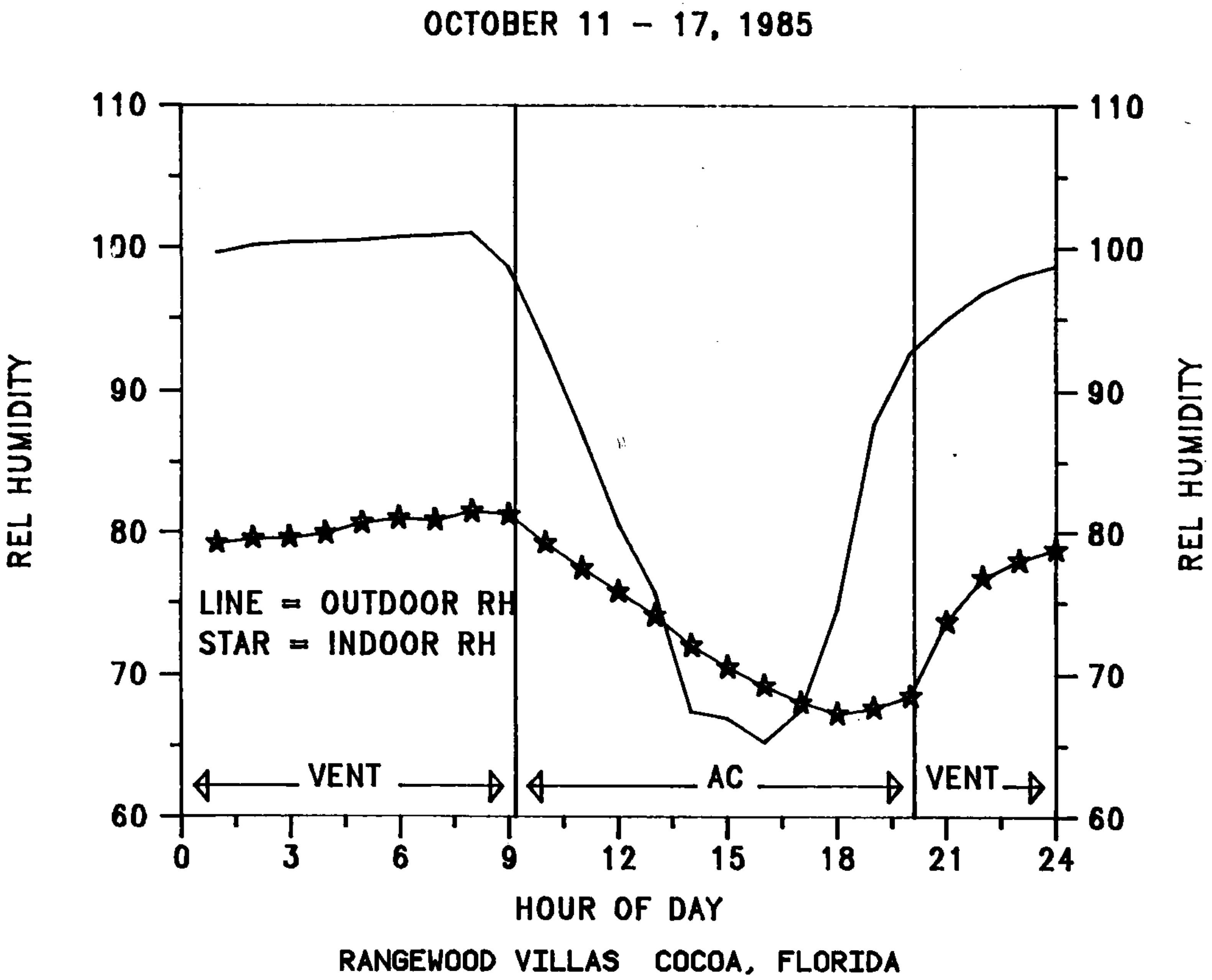


Blower door does not have to work as hard to pressurize the house when the AC blower is on.

OCTOBER 11 - 17, 1985

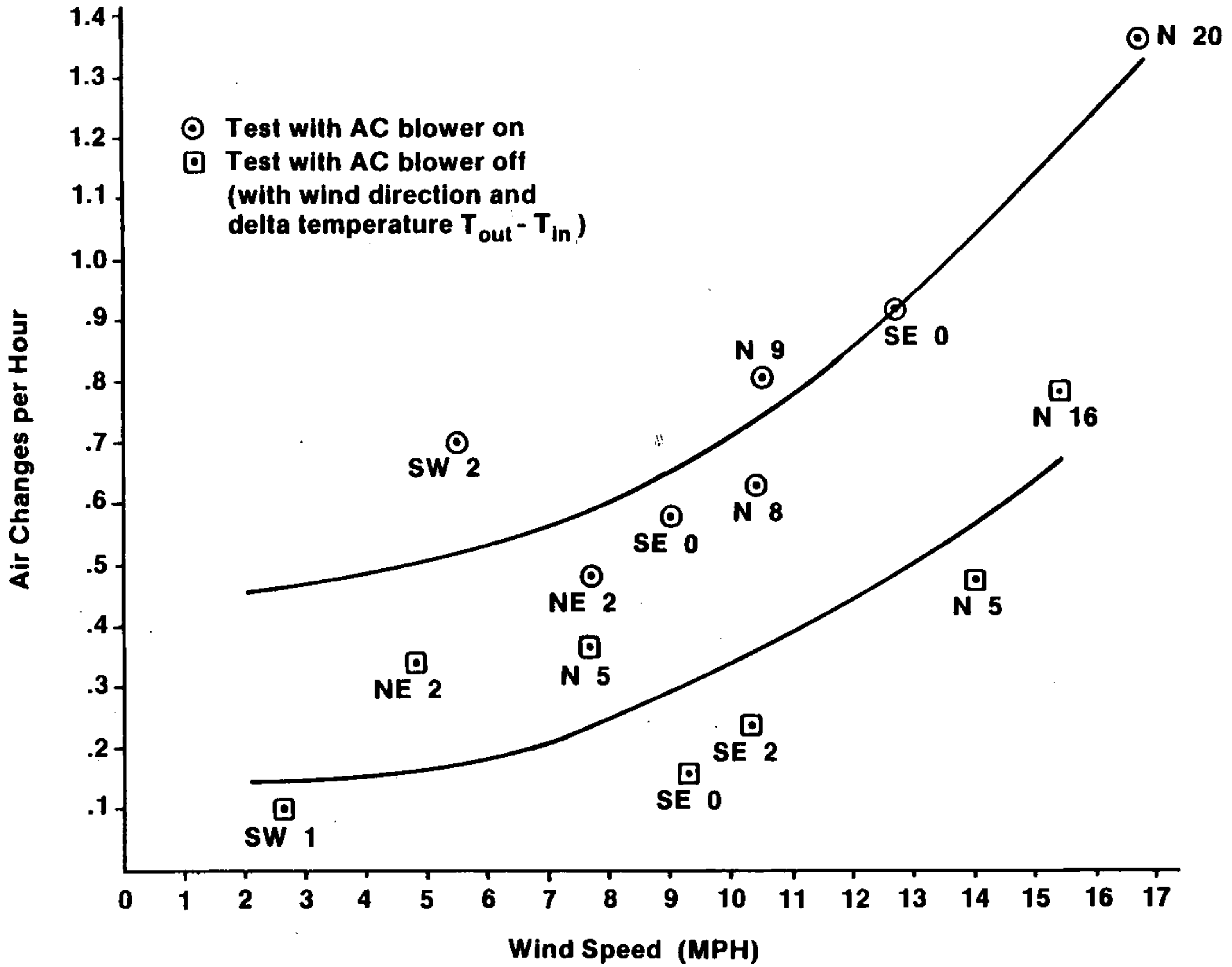


RANGEWOOD VILLAS COCOA, FLORIDA


OCTOBER 11 - 17, 1985
110
100
90
80
70
60
REL HUMIDITY
REL HUMIDITY
LINE = OUTDOOR RH
STAR = INDOOR RH
VENT
AC
VENT
0
3
6
9
12
15
18
21
24
HOUR OF DAY
RANGEWOOD VILLAS COCOA, FLORIDA

Rangewood Villas Statistics

	Dates	Days	Outdoor Dry Bulb	Outdoor RH	Sun (Btu/ ft^{2}Day)	Indoor Dry Bulb	Indoor RH	Int. Load (kWh/Day)
1.	5/26-7/22/85	58	80.2	87.9	1847	73.4	58.8	7.60
2.	8/29-9/20/84	19	79.7	78.7	NA	74.1	60.6	11.20
3.	8/4-8/19/84	16	81.4	78.6	NA	77.9	59.0	10.48
4.	7/24-9/9/85	43	81.9	86.7	1630	77.7	58.5	6.48
5.	9/11-9/28/85	18	79.1	89.0	1433	81.5	57.0	9.84
6.	10/2-10/13/85	7	81.4	90.7	1525	81.4	73.3	9.76



Air Changes per Hour
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Wind Speed (MPH)
⊙ Test with AC blower on
▣ Test with AC blower off (with wind direction and delta temperature $T_{out} - T_{in}$)
N 20
SE 0
N 9
SW 2
N 8
SE 0
NE 2
N 16
N 5
NE 2
N 5
SE 2
SE 0
SW 1

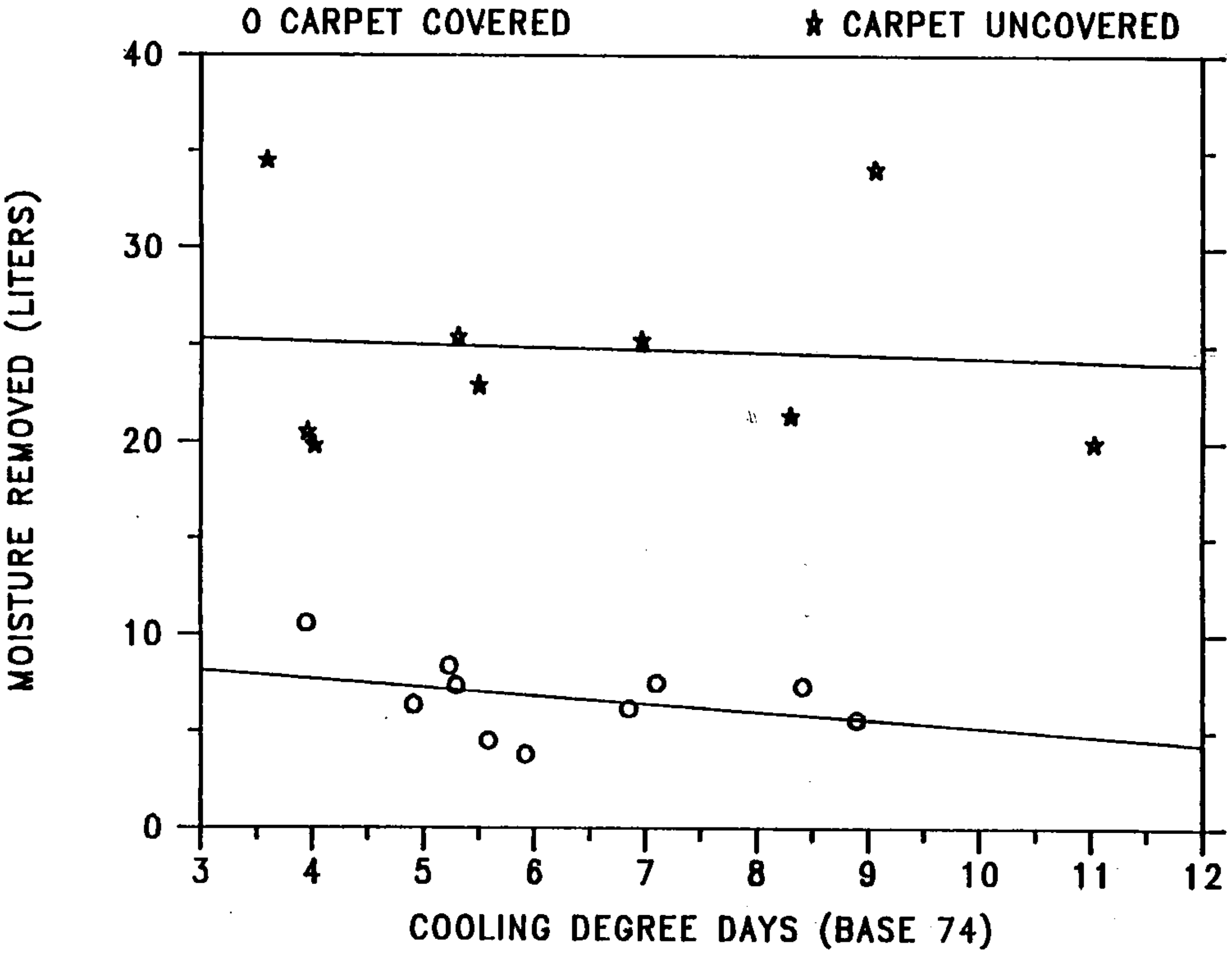


Figure 8. A/C MOISTURE REMOVAL FOR RANGEWOOD VILLA WITH AND WITHOUT CARPET

Table 12. BUILDING File Formant

TAPE FIELD NUMBER	TAPE POSITIONS	NUMBER OF DECIMAL PLACES	ELEMENT
Unit A			
001	001 - 004		Tape Deck Number
002	005 - 009		WBAN Station Number
003	010 - 019	(0)	Solar Time (YR, MO, DY, HR, MN)
004	020 - 023	(0)	Local Standard Time
101	024 - 027	(2)	Temperature dry-bulb zone 1 living room
102	028 - 031	(2)	Temperature dry-bulb zone 2 upstairs
103	032 - 035	(2)	Temperature dry-bulb zone 3 attic
104	036 - 039	(2)	Temperature dry-bulb downstairs bedroom
105	040 - 043	(2)	Temperature dry-bulb thermostat (down)
106	044 - 047	(2)	Temperature dewpoint zone 1 living room
107	048 - 051	(2)	Temperature dewpoint zone 2 upstairs
108	052 - 055	(2)	Temperature dewpoint zone 3 attic
109	056 - 059	(2)	Relative Humidity zone 1
110	060 - 063	(2)	Relative Humidity zone 2
111	064 - 067	(2)	Relative Humidity zone 3
201	068 - 071	(2)	Temperature dry-bulb into coil
202	072 - 075	(2)	Temperature dry-bulb out of coil
203	076 - 079	(2)	Temperature dewpoint into coil
204	080 - 083	(2)	Temperature dewpoint out of coil
205	084 - 087	(2)	Temperature dry-bulb return grill
206	088 - 091	(0)	Condensate ml
207	092 - 094	(1)	Fan run time (minutes)
208	095 - 098	(2)	DHW temperature
301	099 - 103	(1)	Total energy Wh
302	104 - 108	(1)	Heat pump energy Wh
303	109 - 113	(1)	DHW energy Wh
304	114 - 118	(1)	Zone 1 energy Wh
305	119 - 123	(1)	Zone 2 energy Wh
401	124 - 127	(2)	Roof shingle temperature
402	128 - 131	(2)	Top of sheath temperature
403	132 - 135	(2)	Bottom of sheath temperature
404	136 - 139	(2)	Top of denny board temperature
405	140 - 143	(2)	Bottom of denny board temperature
406	144 - 147	(2)	Top of glass batt temperature
407	148 - 151	(2)	Bottom of glass batt temperature
408	152 - 155	(2)	Bottom of gypsum temperature
Unit B			
501 144 - 147	156 - 159	(2)	Temperature dry-bulb zone 1 living room
502 148 - 151	160 - 163	(2)	Temperature dry-bulb zone 2 upstairs
503 152 - 155	164 - 167	(2)	Temperature dry-bulb zone 3 attic
504 156 - 159	168 - 171	(2)	Temperature dry-bulb downstairs bedroom

through the various layers of the south roof. The BUILDING data was generally very accurate and reliable. The dew point probes occasionally drifted high but were generally corrected within a day or two by cleaning and rebalancing the optical feedback system. The dew point temperatures can be checked against the RH probes.

VI. References

1. Jones Jr., Robert E., "Effects of Overhang Shading of Windows Having Arbitrary Azimuth," Solar Energy, Vol. 24 (1980), pp. 305-312.

2. Klein, S. A. and J. C. Theilacker, "An Algorithm for Calculating Monthly-Average Radiation on Inclined Surfaces," Journal of Solar Energy Engineering, February 1981, Vol. 103, pp. 29-33.

3. Kasuda, T., M. Mizuno, and J. W. Bean, "Seasonal Heat Loss Calculation for Slab-On-Grade Floors," U.S. Department of Commerce, National Bureau of Standards, NBSIR 81-2410, March 1982.

4. Khattar, Mukesh K., "Residential Air-Conditioning Energy Calculations," Florida Solar Energy Center Professional Paper FSEC-PF-55-84, June, 1984.

Appendix A

Description of materials used to furnish Rangewood Villas townhouse Unit A during Phase III (moderately furnished) and Phase IV (heavily furnished) of the 1986 tests.

Phase III

I. Living Room:

A. Furniture

sofa	110 lbs	12 lbs cushions
love seat	80 lbs	8.5 lbs cushions
coffee table	23 lbs	metal & glass
2 end tables	13 lbs	metal & glass
2 lamps	5 lbs	china & plastic wrapped shade

B. Additional furnishings

8 magazines	3 lbs 10 oz	S. end table
5 magazines	3 lbs 15 oz	N. end table
1 weekday newspaper	6 oz	coffee table

II. Dining Room:

A. Furniture

table	25 lbs	glass & metal
4 cloth seat chairs	4x11 lbs	metal, foam, cloth

III. Downstairs Bedroom:

A. Furniture

1. metal bed frame
2. wood head board
3. box spring (wrapped in plastic) 52 lbs
4. full mattress (wrapped in plastic) 66 lbs

Particle board:

5. night stand (white plastic veneer) 30 lbs
6. tall dresser (" ") 75 lbs
7. long dresser (" ") 80 lbs
8. mirror (wood frame, card-board back) 15 lbs

B. Additional furnishings:

1. Clothing in tall dresser

a. 5 shirts	1 lb 4 oz
b. 2 shorts	13 oz
c. 1 short	7 oz
d. 2 shirts	11 oz

2. Clothing in Closet (hanging)

a. 3 coats	total of 15 lbs 0 oz
b. 3 jackets	
c. 2 shirts	
d. 1 pair slacks	

3. Boxes in closet	
a. 4 cartons	4 lbs 14 oz
b. 1 carton (filled w/plastic)	2 lbs 8 oz
4. Bathroom	
a. 2 towels hanging	1 lb 0 oz
5. Utility area	
a. 3 cartons	2 lb 12 oz

IV. Upstairs Bedroom:

A. Furniture

1. massive headboard (containing shelves)	250 lbs
2. pressed board pedestal (bed)	80 lbs
3. 2 pressed board platform sections	2 x 80 lbs
4. mattress (full)	66 lbs
5. 26 magazines in closet head of stairs	14 lbs 8 oz
6. 2" rolled foam in closet head of stairs	3 lbs 13 oz
7. Mexican blanket drapped over railing	4 lbs 0 oz
8. flanel sheet in closet at head of stairs	1 lb 5 oz
9. large closet has 2 jackets	1 lb 12 oz
10. blanket over mattress	3 lb 8 oz

Phase IV. (added furnishings to Phase III).

I. Clothes:

A. 15 pieces of men's clothing	5 lbs 3 oz
B. 1 overcoat	2 lbs 14 oz

II. Carpet sections (1.5' x 2.2')

A. 8 sections (downstairs bath)	13 lbs 0 oz
B. 9 sections (upstairs bath)	12 lbs 13 oz
C. 12 bound together sections	9 lbs 7 oz

III. Boxes:

A. 8 cereal boxes (kitches)	1 lb 7 oz
B. 4 cardboard (downstairs closet)	2 lbs 7 oz
C. 15 cardboard (washer closet)	15 lbs 5 oz
D. 9 cardboard (upstairs closet)	4 lbs 0 oz
E. 5 cardboard (front closet)	5 lbs 7 oz

IV. Miscellaneous:

A. 1 5'x5' wool blanket	3 lbs 0 oz
B. 4 towels hanging (upstairs bath)	5 lbs 0 oz
C. 1 large sofa cushion	3 lbs 0 oz

Appendix B

Dates for 1986 night ventilation test periods are listed below:

Phase	Thermostat Set Point 78°	Thermostat Set Point 80°	Dry-out Period[1] 80°
I	6/26 - 7/05	7/06 - 7/11	7/12 - 7/18
II	7/19 - 7/27	7/28 - 8/14[2]	8/15 - 8/19 (1 P.M.)
III	9/01 - 9/06	9/07 - 9/11	9/12 - 9/18 (11 A.M.)
IV	9/20 - 9/30	10/01 - 10/13	NA

1. AC on day and night to dry out the townhouse.

2.

7/27 - 8/04	no ceiling fans on
8/05 - 8/09	two ceiling fans on at night
8/10 - 8/14	two ceiling fans on day & night

Before August 5 no ceiling fans were used. After August 5, two ceiling fans (upstairs bedroom and living room) were turned on during nighttime ventilation to enhance distribution.

Appendix C

Dates for five thermostat set point periods during 1984 and 1985:

Period	Room Temperature	Year	Dates	Number of Days
I	73.5	1985	June 18- July 22	35
II	74.8	1984	August 29- September 20	22
III	77.8	1985	July 26- September 9	39
IV	78.8	1984	August 4- August 19	16
V	81.3	1985	September 11- September 28	18

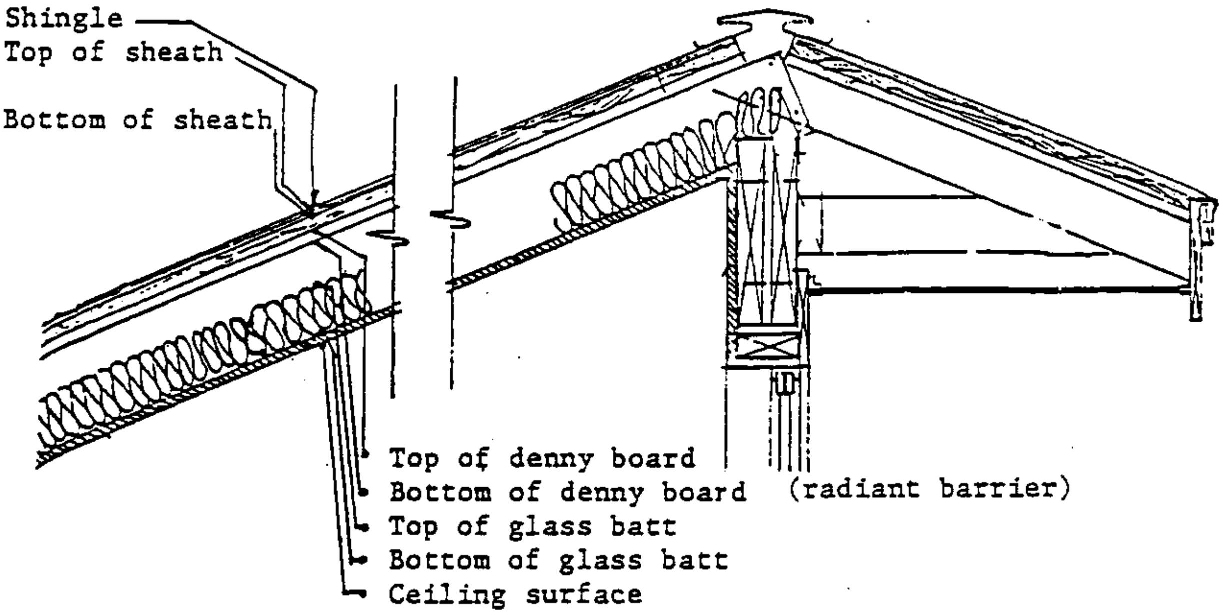


Figure 3. Thermocouple tree in roof.

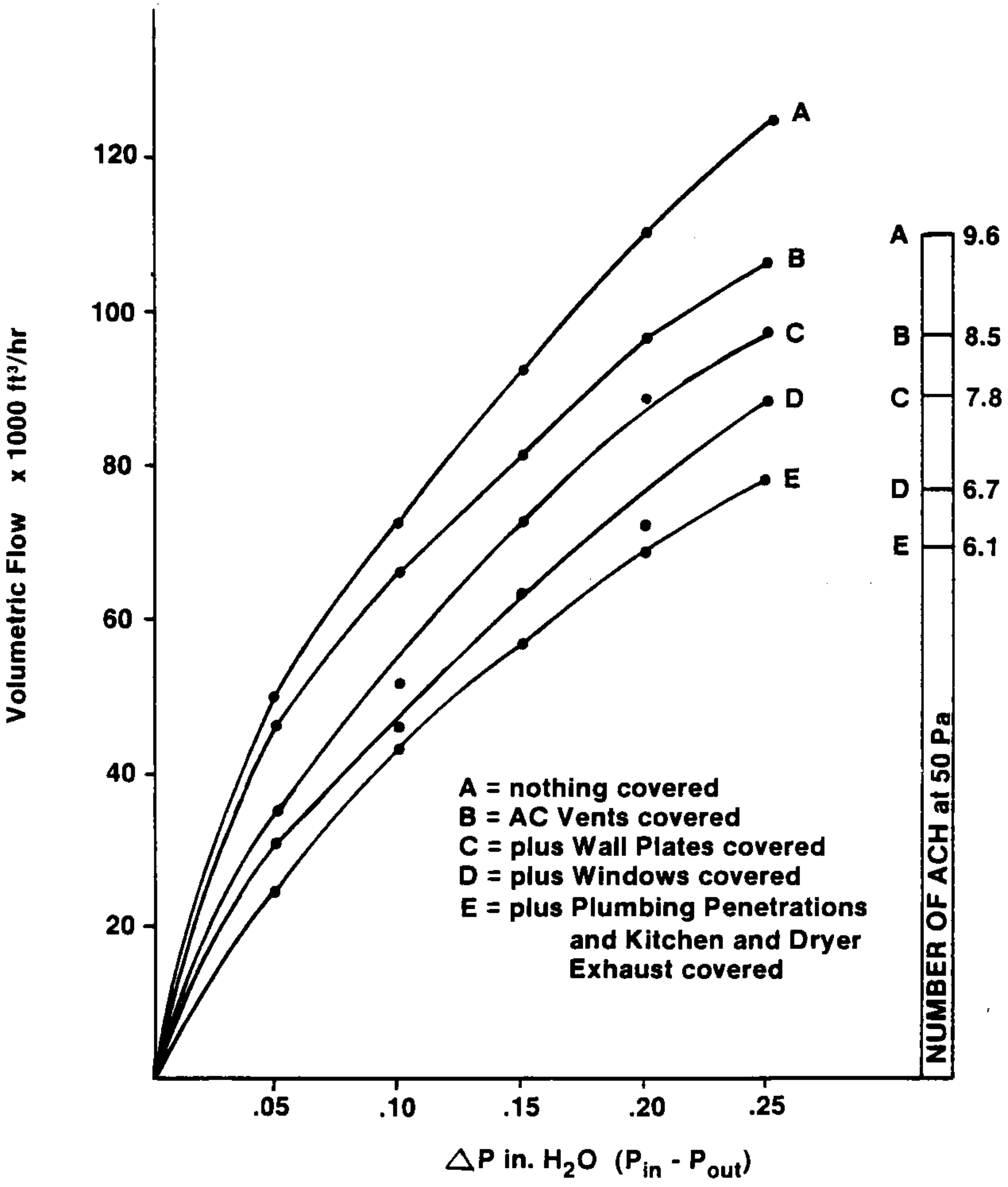


Figure 5. Blower Door Tests at Rangewood Villas (Covering Sources of Infiltration)

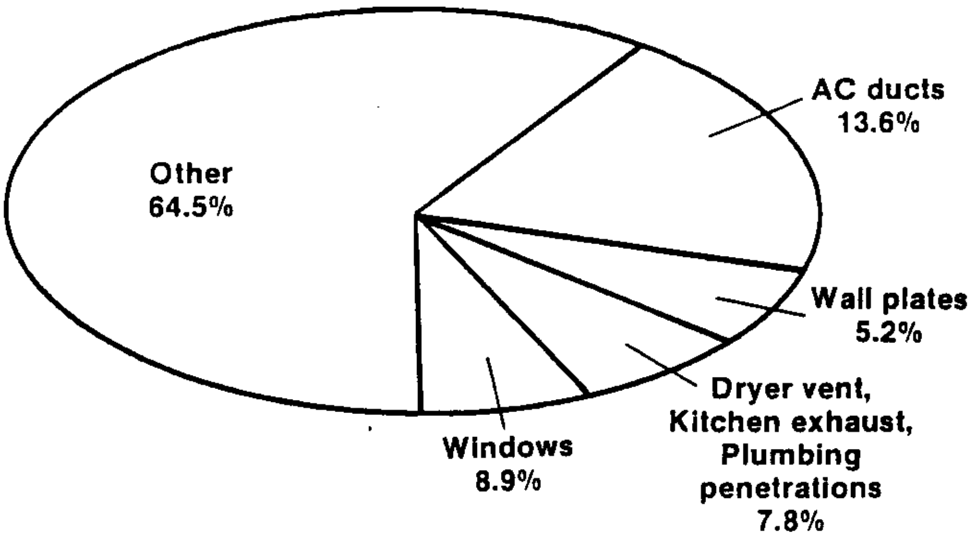


Figure 6. Sources of Infiltration at Rangewood Villas Unit A

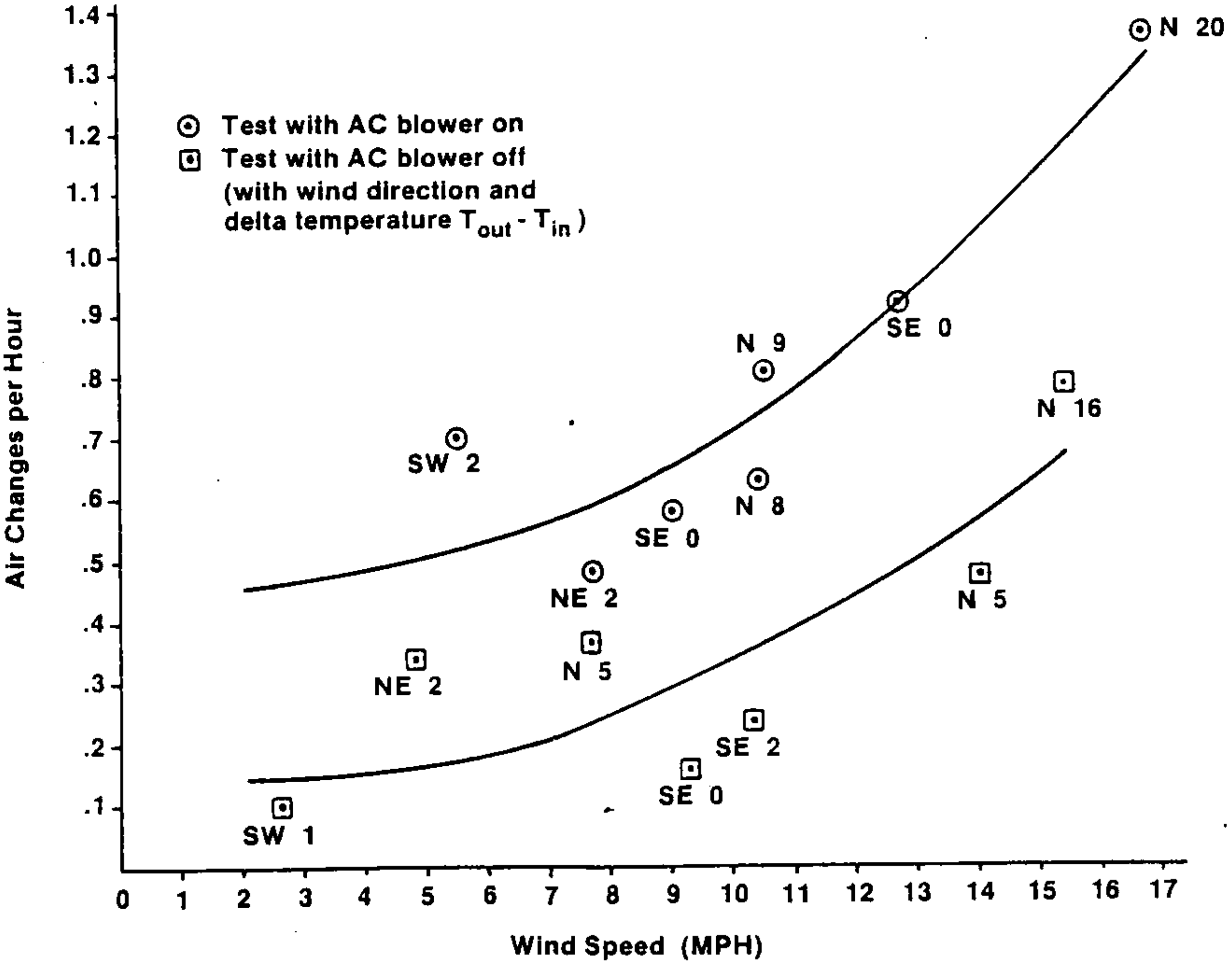


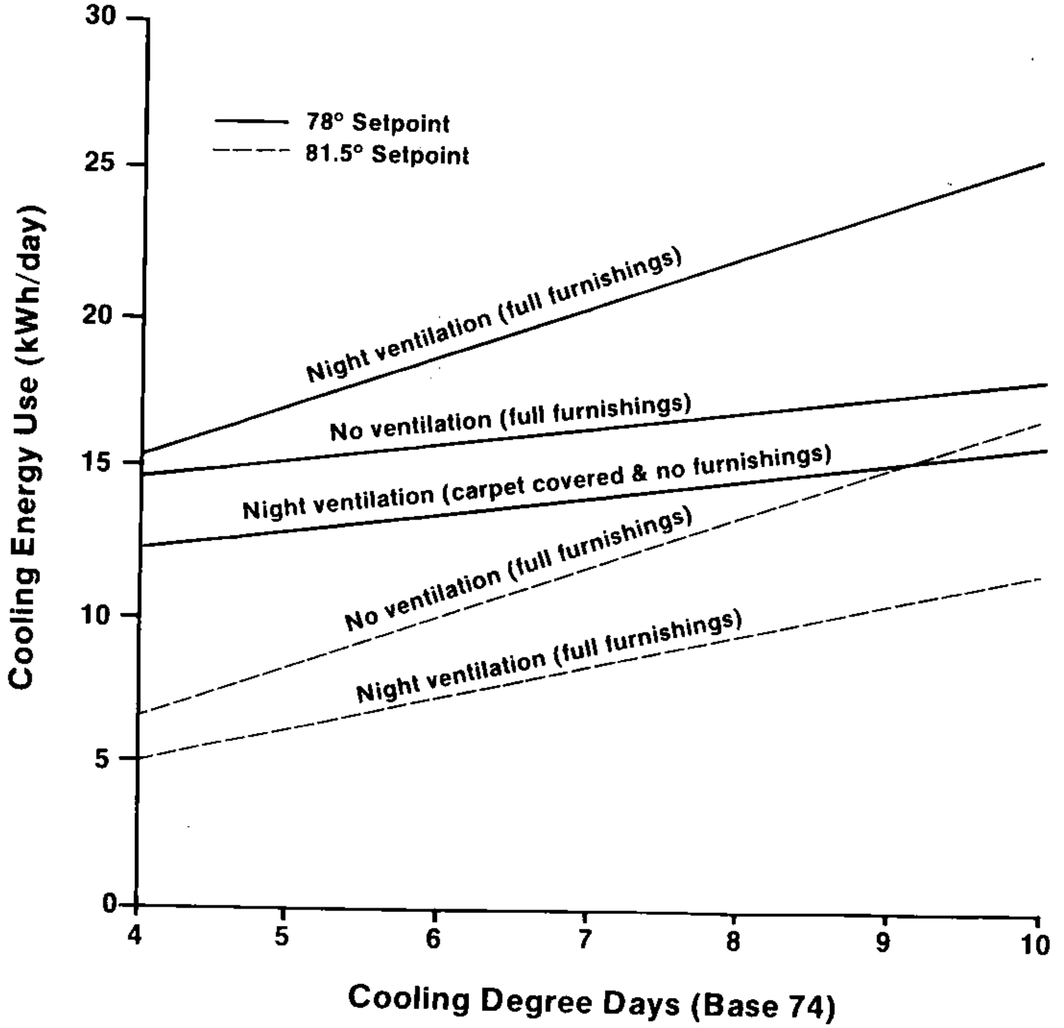
Figure 7. SF_6 Measured Infiltration vs. Wind Speed at Rangewood Villas

Table 1. Ambient Conditions, Energy Use, and Air Conditioner Moisture Removal for Four Furnishing Levels at Rangewod Villas in 1986

Phase	Ambient Dry-bulb (C)	Cooling Degree Days	Ambient Dew point (C)	AC Energy Use (kWh/Day)	Condensate Moisture (l/day)
I	26.8	6.2	23.5	14.4	6.8
II	27.4	7.3	24.0	17.9	25.9
III	27.4	7.3	24.3	17.4	29.0
IV	27.0	6.6	22.5	16.4	23.8

FSEC

Figure 11. **Cooling energy use at Rangewood Villas for two setpoints (78 & 81.5°F) for night ventilation and no ventilation during 1985 and 1986**



FSEC

Figure 12. **Measured A/C energy use vs cooling degree days**

Rangewood Villas
Cocoa, Florida 1984-85

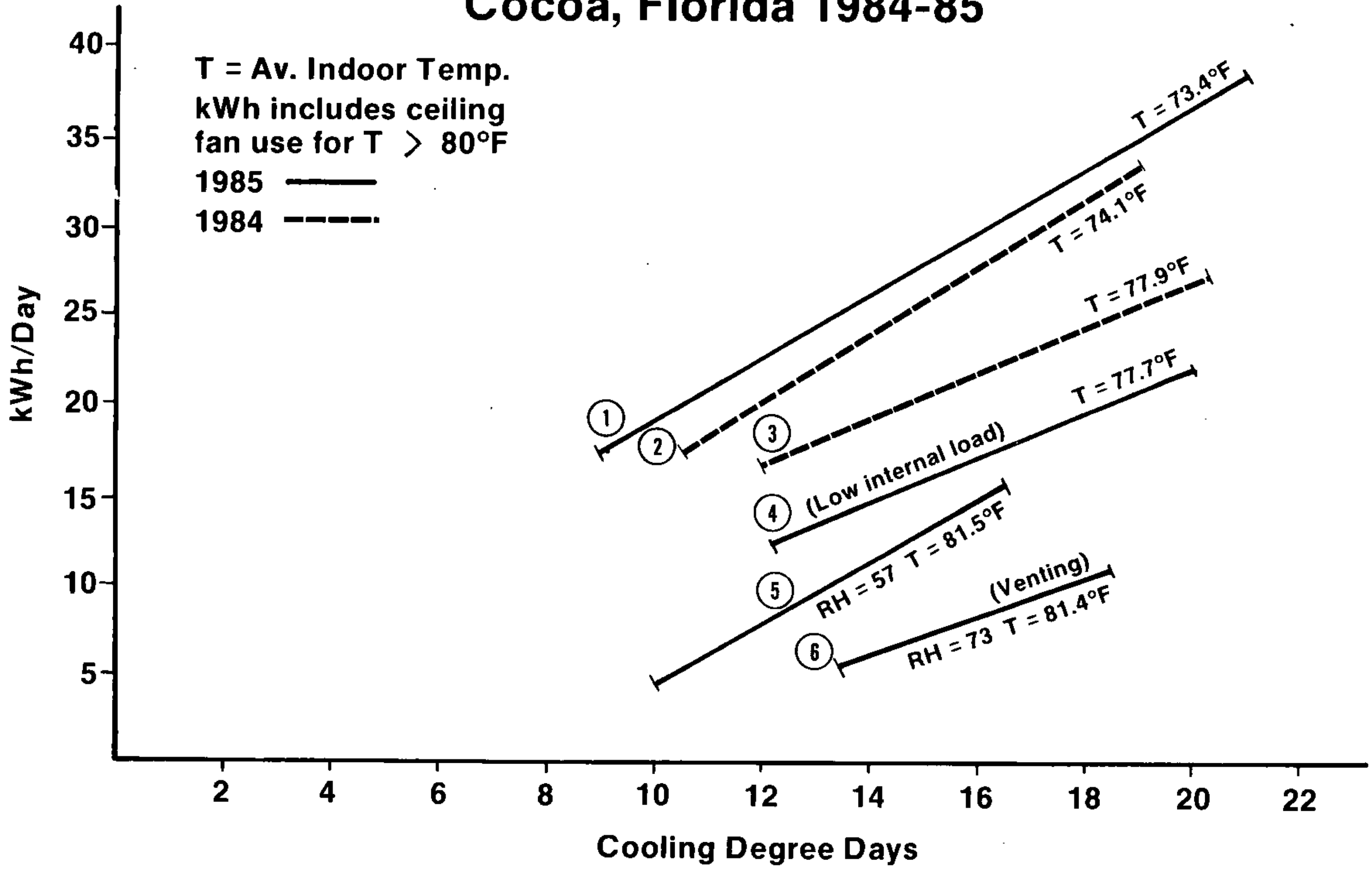


Table 2. Measured and Calculated Sensible Cooling Load at Rangewood Villas for Five Thermostat Set Points

Date	Room Temp.	Ambient Temp.	Weighted Envelope Temp.	COP		HP Energy kWH/day	HP Sens. Load kBtu/day	Internal Load kBtu/day	Envelope Load kBtu/day	Common Wall Load kBtu/day	Window Solar Gain kBtu/day	Infiltration Sens. Load kBtu/day	Slab Gain kBtu/day	Calculated load kBtu/day	Percent of Actual Load
				Sensible	Total										
6/18-7/22/85	73.5	80.2	82.9	1.656	2.400	25.24	142.6	21.4	65.2 (52.4)	4.3 (3.5)	27.9 (22.4)	12.9 (10.4)	14.1 (11.3)	145.8	102.2
8/29-9/20/84	74.8	79.7	82.3	1.759	2.385	23.72	142.4	33.9	52.3 (49.4)	3.7 (3.5)	30.7 (29.0)	10.5 (9.9)	8.6 (8.1)	139.7	98.1
7/26-9/09/85	77.8	81.7	84.5	1.615	2.359	16.70	92.0	19.4	46.8 (55.6)	- .1 (-.1)	28.6 (34.0)	6.1 (7.2)	2.8 (3.3)	103.6	112.6
8/04-8/19/84	78.8	81.4	84.3	1.736	2.363	20.90	123.8	32.9	38.2 (48.0)	-1.2 (-1.5)	35.8 (45.0)	5.9 (7.4)	0.9 (1.1)	112.3	90.7
9/11-9/28/85	81.3	79.1	81.6	1.620	2.518	7.96	44.0	30.1	2.1 (17.6)	-2.0 (-16.8)	25.8 (217.0)	- .2 (-1.7)	-13.8 (-116.0)	42.0	95.5
Average	77.2	80.4	83.1	1.677	2.405	18.90	109.01	27.5	40.9	+ .9	29.8	7.0	2.5	108.7	99.7

In parentheses is a percent breakdown of the non-internal load portion of the calculated sensible load.

Table 3. Rangewood Villas Statistics

	Dates	Days	Outdoor		Sun	Indoor		Int.
			Dry Bulb	RH	(Btu/ ft^{2}Day)	Dry Bulb	RH	Load (kWh/Day)
1.	5/26-7/22/85	58	80.2	87.9	1847	73.4	58.8	7.60
2.	8/29-9/20/84	19	79.7	78.7	NA	74.1	60.6	11.20
3.	8/4-8/19/84	16	81.4	78.6	NA	77.9	59.0	10.48
4.	7/24-9/9/85	43	81.9	86.7	1630	77.7	58.5	6.48
5.	9/11-9/28/85	18	79.1	89.0	1433	81.5	57.0	9.84
6.	10/2-10/13/85	7	81.4	90.7	1525	81.4	73.3	9.76

Table 9. Detailed Calculations of Latent Cooling at Rangewood Villas for Five Periods

	Date	Room Temp.	Ambient Temp.	Ambient Dew Point	Room Dew Point	Ambient Humidity Ratio	Room Humidity Ratio	Wind Speed MPH	Fan Run Fraction	Air Changes/ Hour	Air Spec. Volume ft^3/lb	Pounds Dry Air/Day	Calculated Latent Load kBtu/Day	Measured Latent Load kBtu/Day
I	6/18-7/22/85	73.5	80.2	74.1	58.1	.0183	.0104	3.8	.524	.300	13.65	6257	57.6	64.1
II	8/29-9/20/84	74.8	79.7	75.2	59.4	.0190	.0110	4.4	.494	.311	13.70	6237	50.6	50.6
III	7/26-8/09/85	77.8	81.7	75.7	61.5	.0194	.0116	2.8	.343	.233	13.79	4640	40.1	42.4
IV	8/04-8/19/84	78.8	81.4	75.6	62.6	.0193	.0122	3.8	.425	.274	13.83	5441	42.2	44.7
V	9/11-9/28/84	81.3	79.1	74.1	63.5	.0183	.0126	4.6	.165	.192	13.89	3796	27.0	24.4
Ave.		77.2	80.4	74.9	61.0	.0189	.0116	3.9	.390	.262	13.77	5274	43.5	45.2