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Dr. 2876

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M.L.

Prepared For:
U.S. Department of Energy
Assistant Secretary for Conservation
and Renewable Energy
Office of Building & Community Systems
Under Contract No. AC03-78CS20418

July 1981

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Minimum Energy Dwelling Final Report I

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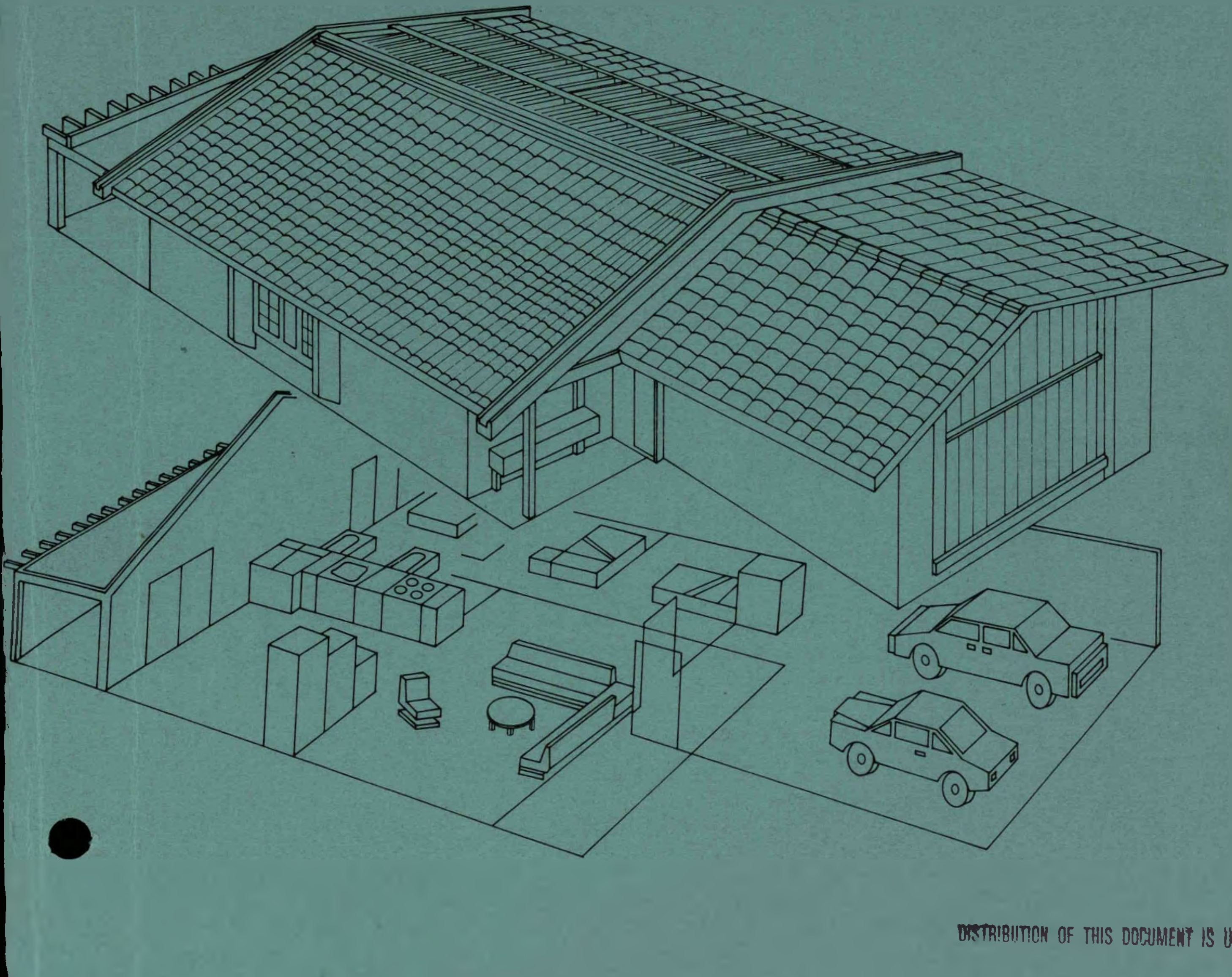

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Minimum Energy Dwelling
Final Report I

July 1981

Prepared by a Joint Venture of:
Southern California Gas Company and Mission
Viejo Company

Bur t Hill Kosar Rittelmann Associates
Washington, D.C. 20001

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U.S. Department of Energy
Assistant Secretary for Conservation
and Renewable Energy
Office of Building & Community Systems
Washington, D.C. 20585

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APPENDICES

INTRODUCTION 1

The Minimum Energy Dwelling (MED) research project was conceived in 1975 by the Southern California Gas Company. The primary purpose of the project is to investigate energy conservation techniques, building materials and current technologies available to today's home builders, and to assess the influence of occupant lifestyles on residential energy consumption. The MED project and others like it are products of the Southern California Gas Company's philosophy of supporting and conducting research directed to energy conservation and an improved environment through more efficient and appropriate use of natural gas.

In order to execute and administer the project, the Southern California Gas Company entered into a joint venture with the Mission Viejo Company of Mission Viejo, California. As a progressive residential building developer, Mission Viejo is interested in exploring ways of conserving energy in its' homes. Mission Viejo's expertise in residential construction, marketing and cost control were of vital importance to the MED effort. Mission Viejo was responsible for the design and construction of the two 1,150 square foot MED homes in the Mission Viejo communnity. One of the MED homes is a demonstration model identical in every way to the counterpart. It was left unoccupied to provide a base against which the impact of the residents in the remaining MED home could be compared. The performance of the MED homes will also be compared with data acquired in a similar conventional or "non-MED" home in the same area.

After an agreement was signed between Mission Viejo and the Southern California Gas Company, the utility secured a contract with ERDA, now the Department of Energy. Funds were obtained from DOE as a result of that agency's commitment to energy conservation and the fostering of solar technology through private industry, educational institutions and other government agencies.

At the beginning of the MED project, the architectural firm of Burt Hill Kosar Rittelmann Associates (formerly Burt Hill and Associates) was contracted as energy conservation consultants and solar system designers. Burt Hill Kosar Rittelmann Associates personnel have worked throughout the program assisting in all phases of the energy conservation analysis and solar system design. Burt Hill Kosar Rittelmann Associates is also responsible for the preparation of the Minimum Energy Dwelling Workbook which chronicles each aspect of the design, development, and construction of the MED homes. It relates in lay terms the logic and energy conservation strategies incorporated in the Minimum Energy Dwelling and serves as the main vehicle through which information gathered during the MED project is disseminated to the building industry and general public.

Other parties involved in the MED project whose participation and services are recorded in this report include the Honeywell Corporation, Marylander Marketing Research Incorporated, Lawrence Berkeley Laboratories, also Carnegie-Mellon University.

The Minimum Energy Dwelling project focuses on two detached single family dwellings at the Mission Viejo community of Southern California. Located 50 miles south of Los Angeles, the energy conscious design of the home is tuned to the generally mild climate of that region. Although many of the goals established in the MED program are project specific, the majority of the energy conservation techniques, if suitably modified, are applicable to residential construction elsewhere in the country. The primary goal, energy conservation, is fast becoming the central issue in all new construction and adaptive re-use projects.

The following is a list of those goals which are central to the Minimum Energy Dwelling project:

1) Reduce net energy consumption in a typical detached, single family dwelling in Southern California by 50 percent. This was to be accomplished using materials and technology that are currently on the market without sacrificing the quality of living or creature comforts obtainable in a comparable Southern California home. These parameters were satisfied by choosing a standard Cordova model home from the Mission Viejo selection of single family units and modifying it especially for the MED project.

2) Investigate and document the overall effectiveness and economic feasibility of those materials and techniques used to reduce energy consumption. These tasks were performed using a variety of methods ranging from a sophisticated data acquisition system to a marketing evaluation conducted through a telephone survey of people who have toured the MED home.

3) Determine the impact of occupancy and lifestyle on energy consumption. The human element has long been recognized as a critical factor in determining how much and during what times energy is used. Determining the amount of energy consumed as a function of lifestyle and occupancy profiles of the Minimum Energy Dwelling residents holds a high priority in the MED project.

4) Verify initial design calculations and analytic assumptions formulated during the MED design phase. This was accomplished by different project participants using such techniques as thermography, methane gas infiltration tests, and moisture and odor detection methods in addition to the data acquisition system.

5) Investigate the energy conservation potential and working interrelationships of the selected mechanical system components. This includes the solar-gas absorption cooling system, the economizer cooling option and the solar domestic hot water system which features a heat pipe domestic hot water tank and Ultraflo potable water distribution system.

6) Distribute the information gathered in all phases of the MED project to architects, builders, developers and the general public to promote the understanding and use of the various energy conservation features incorporated in the MED homes.

The following is a listing of general project results. A variety of methods was used to procure and interpret project data, many of which served as crosschecks or confirmation of related procedures. Detailed explanation of the methods used to formulate these results can be found elsewhere in this report under the appropriate headings. The appendix includes reproduced copies of the original investigative project works.

1) The MED homes exceeded their goal of reducing net energy consumption by 50 percent. This is a collective result of an extremely tight, well insulated structure, the sophisticated mechanical system, and the use of energy conserving appliances. Exact thermal performance profiles and detailed energy consumption patterns are included in the system analysis section of this report.

2) Many of the energy conservation ideas used in the MED homes have proven cost effective and desirable from either a construction or marketing viewpoint. Most of the more typical conservation items used in the MED homes have already gained widespread acceptance in the building industry as salable features. These include deeper wall and roof framing members with increased insulation throughout, more effective vapor barriers, insulated steel entrance doors, quality windows and weatherstripping.

   The project has also spurred interest and subsequent research on other MED conservation techniques. The most promising seems to be the use of outside air for economizer cooling. The MED homes use the principle of building mass to delay the mid-afternoon peak cooling demand to the evening hours when ambient conditions permit the use of outside air to cool the structure. The Southern California Gas Company is currently conducting research to develop this concept further. Other items which piqued public interest are the energy conserving appliances, the domestic hot water component of the solar system, the refrigerator compressor heat exhaust option and other lesser features such as the mastic sill plate sealer and shading devices.

3) The influence of occupancy in the Minimum Energy Dwelling was, as expected, the most difficult factor to discern and analyze. Many of the parameters controlling the end use of energy consumed in the MED rental unit were pre-determined by design. Thermostat setting, day-night setback and a network of temperature and humidity sensors and electronic controls provided automatic system operation and response to variable climatic and comfort conditions. Therefore, the interaction of the residents with the mechanical system and the energy consumed therein was limited.

   The residents did add a human dimension to the project in general, however, and were essential to the task of determining the impact of domestic functions on the various utilities. Hot water consumption is of particular importance in this regard both in terms of heating energy and the amount of water used. The Minimum Energy Dwelling residents were also instrumental for evaluating the energy conserving appliances and the overall living environment of the MED homes. Public reaction to many of these features can be obtained from the MMR survey contained in the appendix of this report. Energy consumption data and use profiles are included in the Systems Description section. The data obtained which links energy consumption and occupancy is compared in turn to the unoccupied MED demonstration home.

4) One of the most valuable results of the MED project was the opportunity to confirm initial design calculations and intuitive assumptions formulated in the early stages of the project. Honeywell's involvement provided the tests necessary to analytically examine such items as transient heat loss, air infiltration and passive solar gain. These experiments resulted in test information that was both expected and surprising. Some of the more significant results are as follows:

   a) The overall thermal resistance of the MED homes was found to be R=16.2 compared to R=7.6 for the standard Cordova. In fact, the Honeywell measurements indicated a slightly higher R value than that calculated, but the test results are within the realm of experimental uncertainty. This confirms initial predictions of a minimum 50 percent reduction in energy consumption when viewed conjunctively with other aspects of the MED models thermal performance. It also verified the preconstruction predictions of both computer programs used in the project of Burt Hill Kosar Rittelmann Associates and the Westinghouse Corporation.

   b) Methane decay infiltration tests conducted by the Honeywell Corporation indicated standing infiltration rates of .25 air changes per hour or an average of 41 cfm in the MED units. This is approximately one fifth that of conventional construction and is indicative of an extremely tight structure. However, during these tests it was discovered that infiltration increased during fan operation to 1.7 air changes or 278 cfm. The tests indicate that the 237 cfm increase is due to roughly equal amounts of leakage in both the economizer intake damper and joints in the fiberglass ductwork. Thermographic observations by the IR division of the AGA Corporation confirmed this occurrence which is addressed further in the Conclusions and Recommendations section of this report. Each observation indicates that a minimum infiltration structure can be achieved through quality construction and currently available materials. Each confirms initial predictions of the structure's performance.

   c) The mechanical system as a whole has functioned as predicted. A detailed look at monthly and yearly system performance is included in the System Analysis section of this report. It should be noted that there has been comparatively little trouble with the control logic and subsequent system operation considering the experimental status of the collectors and the sophisticated nature of the components. This suggests that solar-gas space conditioning systems of this complexity are technically feasible from an operations standpoint. Much work must be done, however, to optimize mechanical equipment for low tonnage cooling and small heating demands in energy conscious dwellings of the MED caliber. This would include serious investigation into packaged components and system controls.

5) From its conception, the MED project has been viewed as a highly valuable educational resource. As one of the most heavily instrumented and monitored projects of its kind, the homes have supplied continuous data on a multitude of building envelope and mechanical system functions. Summaries of the data are included in the appropriate sections of this report. Of equal importance is the degree of public awareness which has resulted from the MED project, and the quality of information which has been made available to the public.

6) The Minimum Energy Dwelling Workbook is the primary vehicle through which information gathered during the research, planning and execution of the MED homes has been distributed. This publication has gained national recognition as a research work and has been widely distributed by the Department of Energy, through the National Technical Information Service. The MED Workbook is discussed further in the following section of this report.

The MED project has also been featured in numerous magazines and television spots have been produced and newspapers have reported various aspects of the projects development. In addition, thousands of people have toured the MED homes and have learned first hand of the homes energy conservation features through lectures given by Southern California Gas Company Officials.

Through the involvement of Marylander Marketing Research, public response to the MED homes has been recorded. This information provides valuable insight to developers, manufacturers and other related parties as to what the general public perceives as cost effective desirable conservation features. Professionals and government officials were isolated through the survey to provide yet another viewpoint of the projects energy conservation features and other market items. The majority of the people interviewed following their visit to the MED homes viewed the project as both worthwhile and educational. The level of recall and appreciation of the energy conservation methods indicated a positive influence and definite heightening of public awareness.

In addition to the public education efforts undertaken thus far, the Department of Energy and Southern California Gas intend to make available the final summary and explanation of project results contained in this report.

In summary, the MED project has realized its original intentions in a manner that is both positive and informative. The subsequent sections of this report deal in greater detail with specific areas of interest and performance.

WHAT'S HAPPENED WITH MED 4

Since the completion of the construction phase of the Minimum Energy Dwelling in the summer of 1976, both the rental unit and the demonstration unit have undergone extensive analysis. The houses have been monitored for the temperature and flow rate of water and air at some 45 points throughout the domestic hot water, mechanical conditioning and solar energy systems. On site weather data has been collected since operation began. Testing of levels of odor and moisture was performed to determine the effect of the tighter than average construction methods used in the MED houses. Electric consumption data for the mechanical system and household consumption has been recorded separately. Utility cost records have been maintained as a measure of savings between the MED houses and the standard Cordova model. The designers of the Minimum Energy Dwelling have written a MED Workbook to record and communicate the energy saving techniques investigated during the design process. Visitors to the Minimum Energy Dwelling demonstration unit have been interviewed and their opinions recorded as a measure of public opinion and interpretation of the various energy conserving features of the project. The following discussions are a summary of these activities.

4.1 The Minimum Energy Dwelling Workbook

The Minimum Energy Dwelling Workbook was prepared by the designers to record and communicate the techniques investigated for use in the Minimum Energy Dwelling. The primary purpose of the workbook is to disseminate this information to the general population and building professionals. While the workbook was developed specifically during the design of an energy saving house for the mild Southern California climate, the concepts presented are applicable, if suitably modified, to other regions of the country. This quality of the MED research project has made the "Workbook" ideally suited to communicate MED energy saving techniques to the public.

The workbook discusses energy conservation at four levels:

- General Considerations
- Building Design
- Mechanical Design
- Construction Experiences

The discussion involving general considerations deals with larger issues of a community or regional level. These issues include community planning vs. sprawl, high density housing vs. low density, climate and architecture and residential energy use. The building design discussions deal with energy conserving techniques that are built into the building itself. These techniques often called "passive" include the use of insulation, mass, shading devices, ventilation and infiltration, and internal loads. These techniques may often be the most cost effective in that they are not energy consuming and can often serve other purposes - structural, aesthetic, etc. The third type of energy conserving technique discussed involves the use of "active" (mechanically assisted) solar systems in combination with sophisticated mechanical equipment. The construction experiences section relates the actual construction process, problems encountered, unforeseen costs etc., in the construction of these two sophisticated residences.

The MED Workbook has been distributed to the public through the National Technical Information Service. Currently, a condensed version of the MED Workbook called the "MED Mini-Workbook" is being developed. This version is to provide a quick reference for the homeowner and builder alike. It is of a size that is suited for extensive distribution. With these efforts to communicate the energy conservation techniques of the MED houses, the influence of the project has reached beyond its Southern California locale.

4.2 Consumer Reaction Survey

A report was prepared by Marylander Marketing Research, Inc. as a summary of the 215 visitor interviews they conducted. A copy of the report is included in the Appendix of this summary. The report also identifies those 215 people interviewed according to three types:

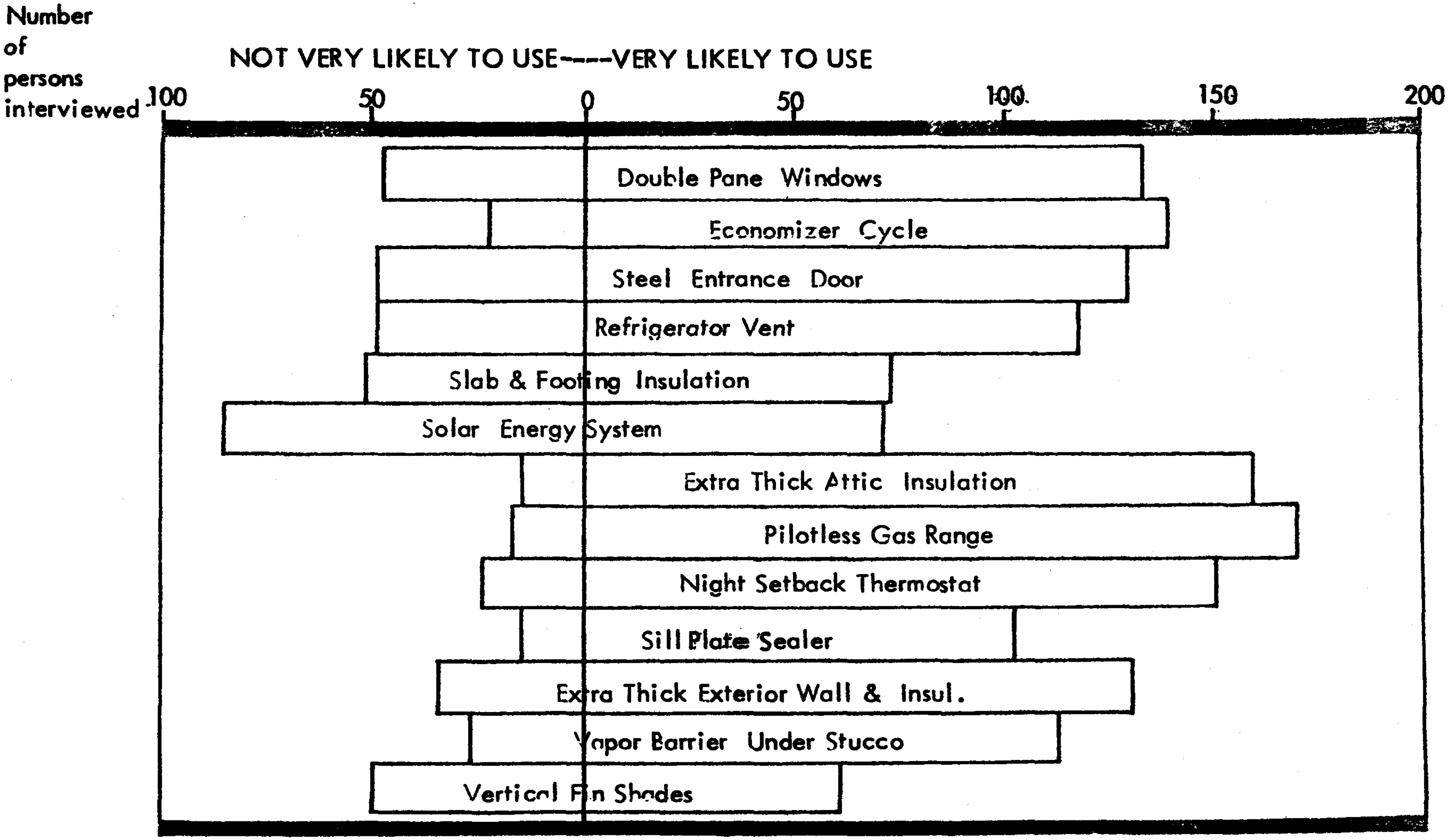
	Number Interviewed
Builders/Architects	87
Government Officials	58
General Population	70
TOTAL	215

All interviews were limited to those whose place of business or residence was in Los Angeles or Orange Counties. This limitation provides a control in that the respondents are at least familiar with the local issues that the MED project addresses. Interviews of Government Officials were limited to those associated with agencies involved in building and energy issues.

Of the three visitor types, the Builders/Architects were, as expected, more knowledgeable and consequently most concerned about costs of the various MED features. Government officials voiced the same concern as the building professionals and were only slightly less concerned about cost. The general public was least concerned about cost.

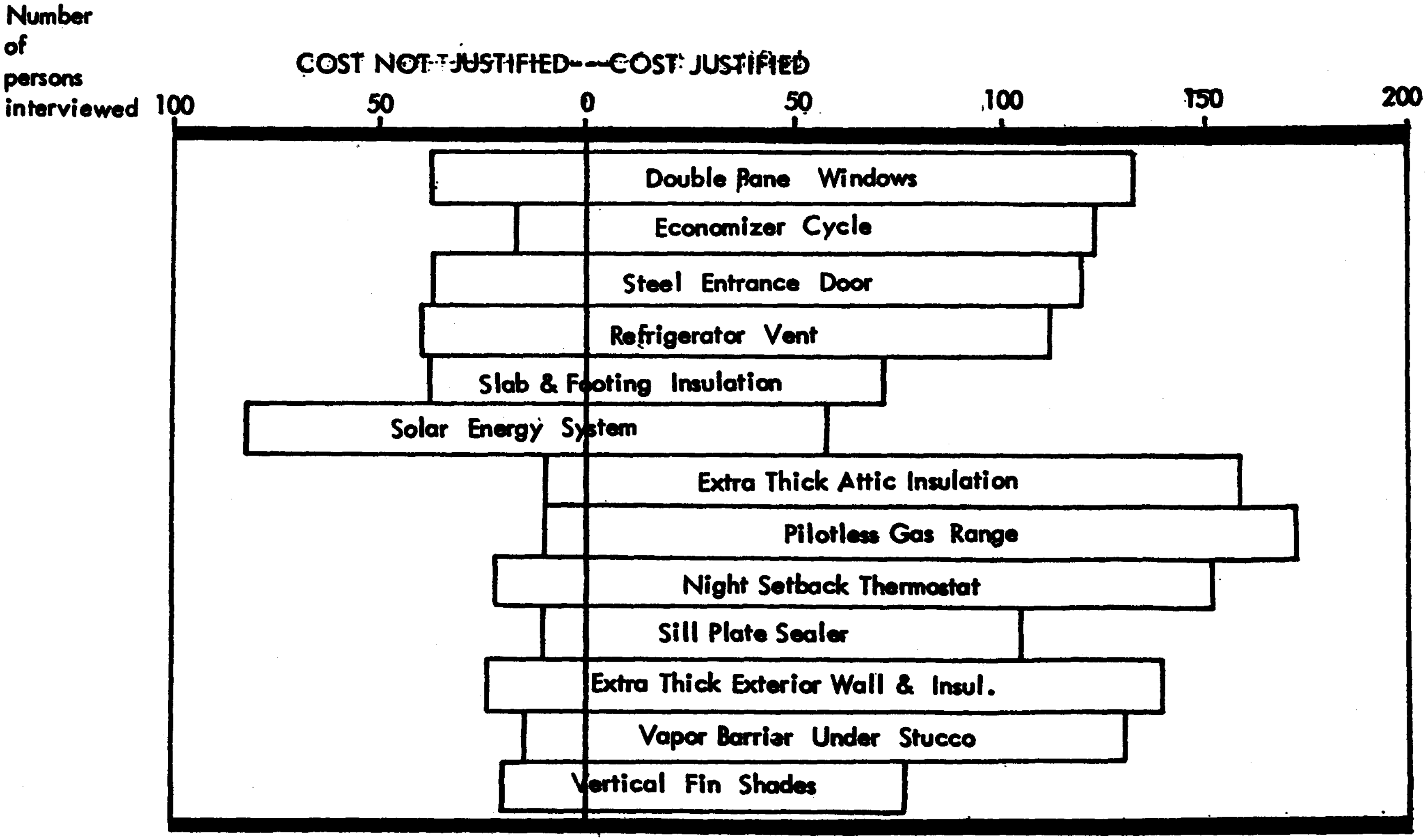
An overview of the opinions of the composite group is illustrated in Figures 1 and 2. These illustrations, adapted from the Marylander Marketing Research Inc. report, graphically reinforce their findings that there was a strong correlation between perceived economic soundness of a feature and the likelihood of using it. A more specific breakdown of this survey is included in the report copy in the Appendix that further breaks down visitor responses according to the three visitor types.

Of all the features included in this survey, the use of extra thick attic insulation, night setback thermostat and pilotless range ignition were felt to be the most economically feasible and had the highest number of people willing to use them. The amount of perceived economic justification bears a strong relationship to willingness to



LIKELIHOOD OF USING SPECIFIC FEATURES

FIGURE 4.1



PERCEIVED COST JUSTIFICATION OF SPECIFIC FEATURES

FIGURE 4.2

use any particular feature. According to the report, economic soundness may be the key determinant of whether or not a particular feature may be used.

According to Marylander Marketing Research, a "rule of thumb" which is employed in the evaluation of negative responses is that those ideas mentioned by more than 10% of the sample are at sufficiently high levels to warrant some concern. These aspects of the MED house that were of concern to 10% or more of those interviewed were cost, smaller than average floor area, the Ultraflow pushbutton water distribution system, bulkiness of the solar panels and the smallness of the windows. A detailed breakdown according to visitor type may be found on page 5 of the Appendix.

Although some of the 215 visitors interviewed expressed the preceeding concerns, the overall response was very favorable. More than 80% of those visiting the Minimum Energy Dwelling said that they were more likely to use conservation features in the future as a result of their tour. Over 75% of the visitors indicated that something new was learned as a result of their visit. This percentage was somewhat higher among the general population and slightly lower among the building professionals and government officials. (See Table Page 8 of the Appendix) Of 15 features measured, the average visitor recalled almost 12.

4.3 Honeywell Evaluation and AGA Thermography Evaluation

These two studies deal primarily with the thermal performance of the MED structure. The Honeywell effort determined the infiltration rates by the use of methane decay. Other testing procedures involving the use of twenty-four thermocouples installed in the walls, ceilings, and floors of each of the two MED dwellings during construction, were performed to determine potential condensation situations, thermal resistance and time lag. The thermography evaluation was performed on both a standard Cordova (non-MED) house and a MED house. A comparison of the two sets of thermographs indicates that the improvements in the quality of construction and insulation are evident in the MED house. Temperatures are much more even and consistent throughout the house. Also, energy losses from the concrete pad and glass areas were reduced to less than half when compared to the standard dwelling. The following is a summary of the findings of these two reports:

1) Building Thermal Resistance - It was found that the MED structure did achieve its goal of a thermal resistance twice that of conventional construction. The MED had a calculated R=16.2 as compared to R=7.6 for the El Jardin. The transient measurements confirmed each of these calculations as shown in Table 4.3. In fact, the measurements indicated a slightly higher R value than the calculated. This was within experimental uncertainty, however.

TABLE 4.3

BUILDING THERMAL RESISTANCE

NO.	HOUSE	DATE	SENSOR LOC.	SYSTEM	WEATHER			INFIL. LOAD BTU/HR.	HEAT SUPP. BTU/HR.	Q_{net} BTU/HR.	R_h	
					Cond.	Temp.	Wind				Meas.	Calc.
1.	MED I (D)	1-19-77	Return Air	Fan on Recirc.	Clear Night	55-68	5-10	1,642	20,894	19,285	18.2	16.2
2.	MED I (D)	3-17-77	Kitchen	Fan off during cool down	Rain Night	36-44	0-3	5,216	41,603	36,387	16.2	16.2
3.	El Jardin	1-20-77	Kitchen	Fan on	Clear Night	64	3-8	7,992	64,000	53,806	8.5	7.6

TABLE 4.4

INFILTRATION

NO.	HOUSE	DATE	CONDITIONS	TEMP °F	WIND mph	INFILTRATION		HOUSE CALC.	VOLUME MEASURED
						AC/Hr	Cfm		
1.	MED(R)	10-26-76	Fan on recirculation	80	30	1.82	295	9,739	
2.	MED(R)	10-26-76	Fan on recirculation Foyer doors closed Economizer intake sealed Refrig. louvers closed	80	18	1.33	216	9,739	
3.	MED(R)	10-27-76	Same as no. 2 except fan in vent position and attic scuttle sealed	70	14	.86	140	9,739	
4.	MED(R)	10-27-76	Same as no. 2 except attic scuttle sealed and kitchen pressure relief vent sealed	78	12	1.28	208	9,739	
5.	MED(R)	10-27-76	Same as no. 4 except intermittent fan - 1.5 min. on at 15 min. intervals to make reading	81	25	.36	58	9,739	
6.	MED(R)	10-27-76	Same as no. 5 except range vent sealed	81	15-20	.34	55	9,739	
7.	MED(D)	01-19-77	Fan on recirculation Foyer isolated Economizer damper closed Garage outlet sealed	72	1-2	1.72	278	9,739	11,560
8.	MED I(D)	01-19-77	Same as no. 7 except economizer intake sealed	79	3-4	.99	161	9,739	9,292
9.	MED I(D)	01-19-77	Same as no. 8 except intermittent fan	78	5-6	.25	41	9,739	
10.	MED I(D)	09-12-77	Fan on 100% recirculation Foyer isolated Economizer intake sealed Garage outlet sealed	72	3-5	1.48	240	9,739	10,834
11.	MED I(D)	09-12-77	Same as no. 10 except intermittent fan	72	3-5	.32	52	9,739	
12.	MED I(D)	09-13-77	Same as no. 10	76	3-5	1.45	235	9,739	9,691
13.	MED I(D)	09-13-77	Same as no. 9 except sample taken from living room; fan off	76	3-5	.28	45	9,739	
14.	MED I(D)	09-15-77	Same as no. 10	70	1-3	1.44	234	9,739	9,650
15.	El Jardin	10-28-76	As is; fan on recirculation	68	1	1.30	208	9,582	
16.	El Jardin	01-21-77	As is; people entering and leaving on 3 occasions; fan on	64	5-8	1.22	195	9,582	9,778

TABLE 4.5

INSULATION MOISTURE LEVEL

LOCATION	DATE	DISPLAY HOME				OCCUPIED HOME				
		RH %	IWT °F	DP °F	OWT °F		RH %	IWT °F	DP °F	OWT °F
Kit Ceil	01-17-77	28	69	35	69 ?(1)		<5	70	<2	(2)
	01-20-77	15	72	24	57 ?					
	03-16-77	5	69	3	34 ?					
	03-17-77	5	63	0	73 ?		5	72	4	81
	03-18-77	>5	67	3	66 ?		~1	72	<0	74
	09-13-77	13	70	20	75	09-15-77	5			
Kit Wall	01-17-77	56	68	51	71		28	70	35	(2)
	01-20-77	49	72	52	54					
	03-16-77	41	59	35	49					
	03-17-77	40	62	37	55		30	70	36	60
	03-18-77	45	61	39	58		30	71	37	61
	09-13-77	70	70	59	68	09-15-77	43	76	51	74
M BR	01-17-77	51	67	48	89		42	70	46	(2)
	01-20-77	48	71	43	53					
	03-16-77	40	60	35	49					
	03-17-77	47	61	41	50		50	69	50	60
	03-18-77	47	59	39	59					
	09-13-77	66	71	58	69	09-15-77	59	75	59	76

NOTE: IWT = Inside Wall Temperature

OWT = Outside Wall Temperature

DP = Dew Point Temperature

1. Roof temperature thermocouple in the display home must be incorrect. These temperatures were unreasonably low.
2. Thermocouples were not read in the occupied home in January.

2) Infiltration - Special precautions were taken in the construction of the Minimum Energy Dwellings to assure minimum infiltration. Initial testing of both houses indicates an infiltration rate of 278 cfm or 1.7 air changes per hour. This is extremely high and leakage was suspected through the fresh air dampers. Therefore, the fresh air intake was sealed with plastic. This decreased the infiltration rate to 161 cfm or .99 air changes per hour. (See Table 4.4) Next, the fan was operated intermittently, turning it on for about 1.5 minutes out of 15 to be able to get an air sample from the duct. When operating the fan intermittently, it was noted that when the fan was turned off, the tracer concentration in the return duct decayed very rapidly. This indicates that there was leakage in the fiberglass ducts that go through the attic. This observation was confirmed in the AGA thermography tests also. With intermittent use of the fan, the infiltration rate dropped to 41 cfm or 0.25 air changes. This represents a very tight structure.

3) Wall Moisture - Table 4.5 presents the results of the Honeywell humidity measurements in the insulation of each of the MED houses. In all cases the dew point temperatures are lower than the outside wall termperatures indicating no condensation. The dew point in the master bedroom in the occupied house was 50 degrees in March. This is high enough to lead to some condensation when outdoor temperature drops rapidly. The total quantity of moisture is small and the rate of migration is slow. Therefore, an extended cold period of perhaps a week or more would be needed to have any serious amount of condensation.

Since the Mission Viejo climate is very mild and extended cold wet periods do not occur, the sealed stud space produced by using plastic rather than tar paper under the stucco does not appear to present a problem. This type of construction would most likely cause condensation problems in a cooler and damper climate. The plastic vapor barrier does not offer enough advantage to justify its use.

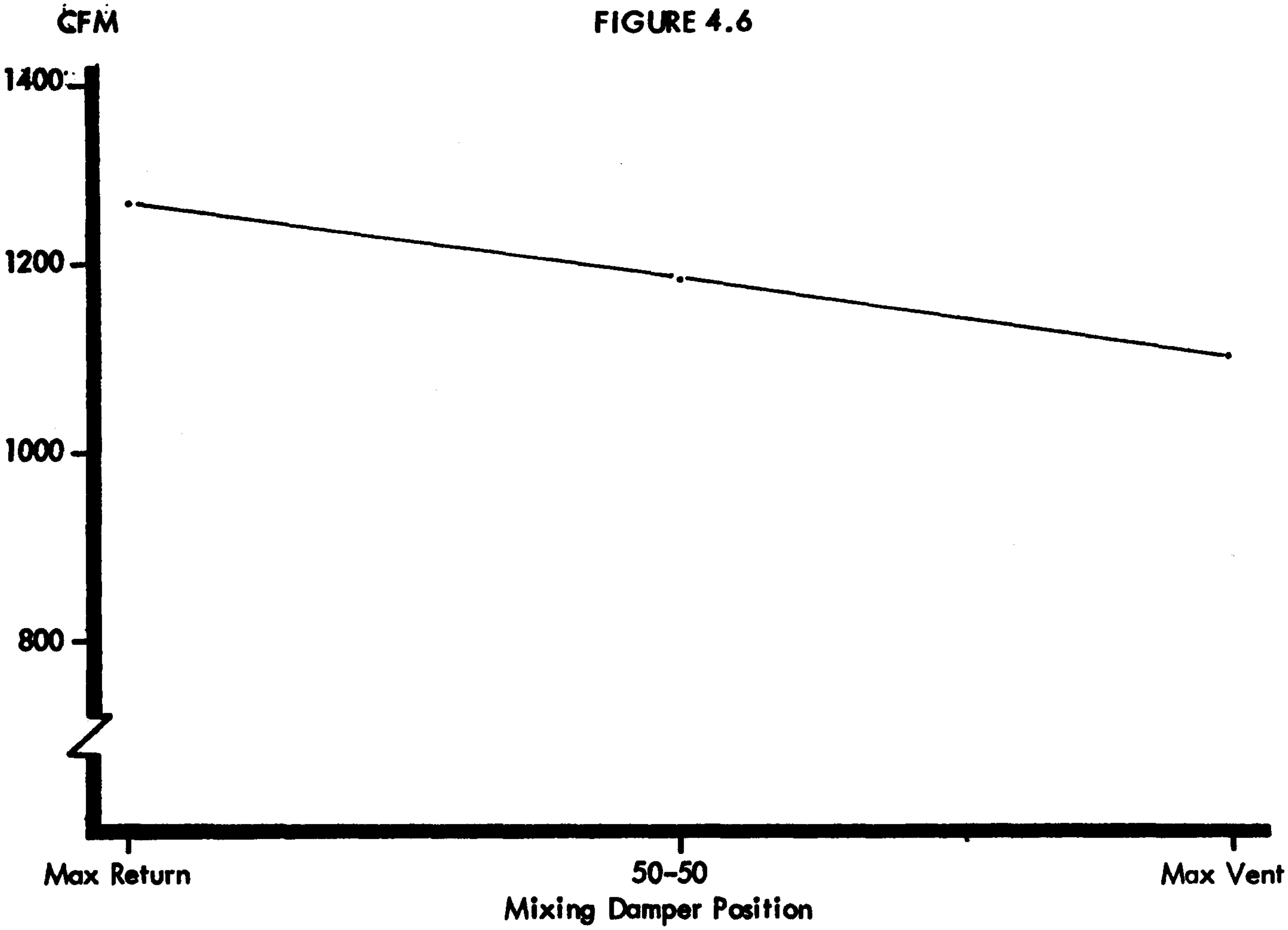
4) Turbine Flowmeter Calibration - The tracer technique was used to calibrate the turbine flow meters in the ventilation duct and the return air duct. Methane was introduced in the ventilation duct or at a return air register in the house. The flow rate of the methane was measured. The concentration it produced was measured at the air handler just upstream of where the two ducts meet. The results of the measurements presented in Figure 4.6 indicate that the flow across the coil was relatively constant at 1200 cfm.

5) Passive Solar Gain - Using 16.1 as the average R value for the MED structure, it was possible to estimate the passive solar input. Figure 4.7 shows the warm up transient due to solar effects for the display home. It was first cooled to a controlled

temperature of 67.4 degrees F on September 15, 1977. From 1230 to 1500 hours with bright sun and stable outdoor temperature, the indoor temperature rose from 66.0 degrees F at 1200 hours to 70.7 degrees F at 1500 hours when the cooling system was turned off. The outdoor air temperature measured by a thermocouple on the North side of the house, was nearly constant at 73.3 degrees F. The air temperature measured by the data logger on the south side seemed to be influenced by the solar heating of the south wall.

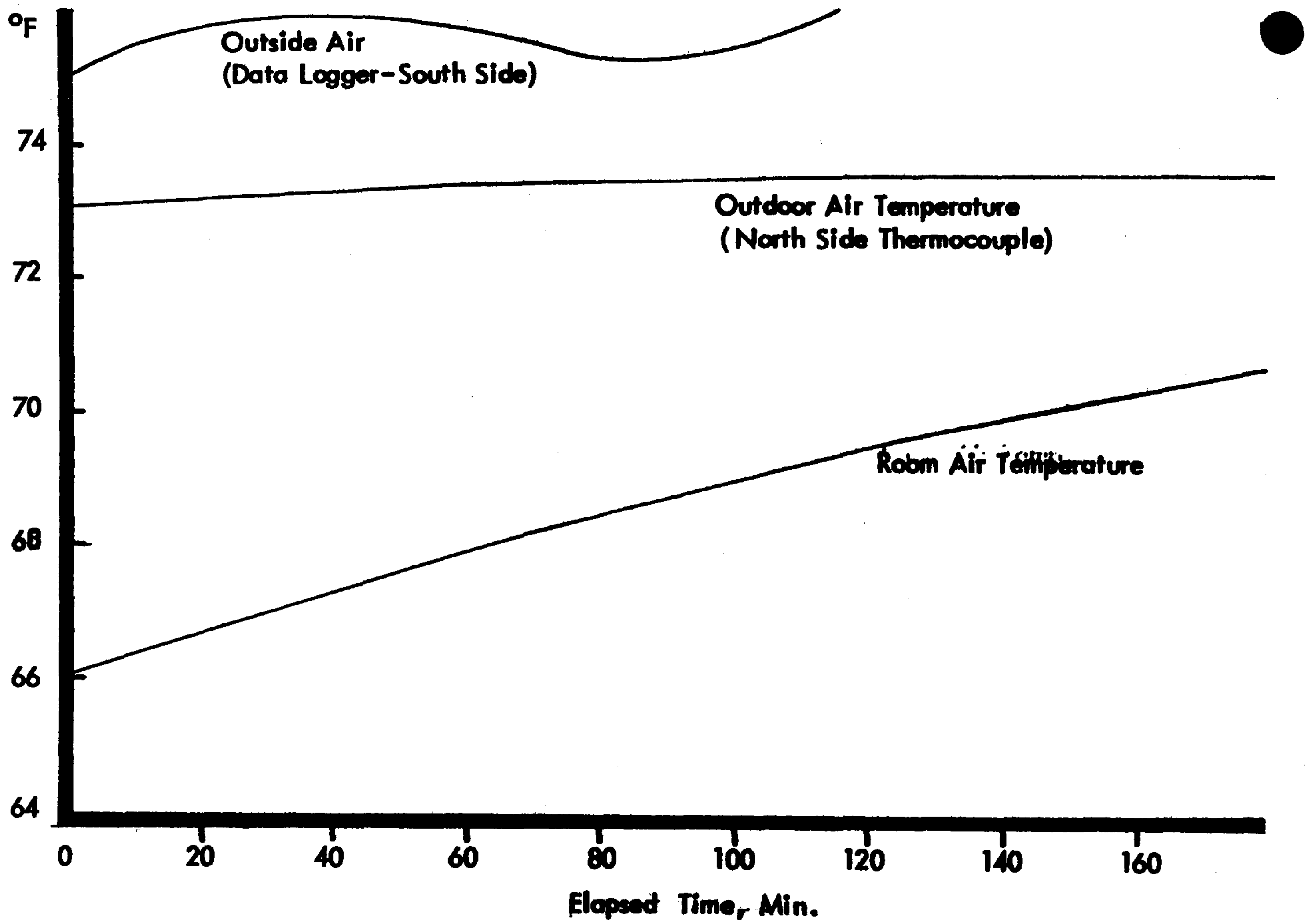
With this information, it was estimated that the total solar load coming through windows and absorbed through the walls is 6000 BTU/Hr. This is the only set of data available for this calculation. Weather conditions and the effect of visitors entering and leaving the house negated other measurements.

FIGURE 4.6



TOTAL AIR FLOW ACROSS COIL

FIGURE 4.7



WARM-UP TRANSIENT DUE TO SOLAR GAIN, MED (D)

SYSTEM DESCRIPTION 5

5.1 Mechanical System

The primary elements of the Minimum Energy Dwelling mechanical system are the solar collector, its heat storage tank, the gas fired boiler, the absorption unit, the air handling unit and the economizer. During periods of collector production, water is circulated from the storage tank through the collector array to be heated with the sun's energy and then returned to the storage tank for use when any part of the heating or cooling equipment requires it. During periods of low collector production, the gas fired boiler provides auxiliary heating capacity to maintain storage tank temperatures as required for efficient operation. When water enroute to the solar collectors is above 180 degrees F, it is automatically diverted through the heat disapator This unit consists of a 40' length of bare fin tube mounted along the ridge of the roof. Assuming a temperature rise through the collectors of 20 degrees, the temperature in the storage tank effectively is kept below the boiling point. Cooling by solar energy is accomplished by the use of an absorption chiller - a device that requires a fairly low temperature heat (about 195 degrees) to extract moisture from a salt solution. This 195 degree temperature is within the abilities of the evacuated tube solar collectors. (See Figure 5.1)

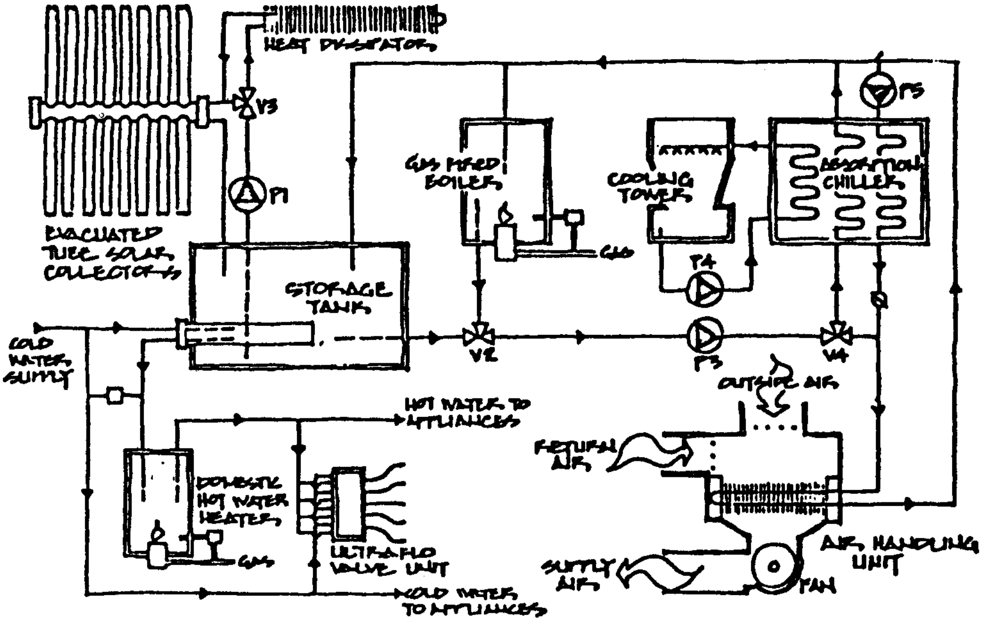


FIGURE 5.1

Condenser water leaving the chiller is circulated through the cooling tower to reject a maximum of 96,000 BTUH. Heating is accomplished when the absorption chiller is bypassed and hot water is directly circulated from storage or the boiler through the heat exchanger located in the air handling unit. Domestic hot water heating is augmented by preheating supply water by circulating it through the heat exchanger inserted in the storage tank.

The following is a more detailed description of each piece of equipment used in the MED:

1) Solar Collectors - The collector selected is the "Sun Pak" evacuated tube collector manufactured by Owens-Illinois. The system consists of ten 24 tube modules for a total effective collector area of 275 square feet. The high performance characteristics of this collector type is due primarily to the use of a vacuum to insulate the collector's absorber surface from the exterior. The manifold is encased in a moulded foam insulation shell to further eliminate heat loss. Performance of the collector has been further enhanced by placing a reflector below the collectors to reflect radiation that falls between the absorber tubes back into them for greater production.

2) Storage Tank - The storage tank is made of galvanized steel and is mounted in a below grade concrete pit, located in the garage. The space between the tank and the concrete side walls varies from 12" to 18" and is completely filled with loose fill mineral wool insulation. The tank is supported by two steel saddles on non-conductive asbestos pads to isolate the tank and prevent the conduction of heat out of storage.

3) Boiler - Auxiliary heat is provided by a Peerless Series G-360 W gas fired boiler. Total output is rated at 72,000 BTUH when fired at a rate of 90 cubic feet of natural gas per hour. Due to varying output requirements (95 degrees storage temperature for heating - 195 degrees storage temperature for cooling) the boiler has been fitted with a two stage burner. Electronic ignition is used rather than a standing pilot-saving approximately 9.6 cubic feet of gas per day.

4) Heat Dissipator - As described previously, the heat dissipator consists simply of 40" length of bare fin tube mounted along the ridge of the roof. The fin tube consists of 1-1/4" O.D. copper pipe with 4-1/4" square copper fins spaced at 40 per foot. The fin tube is typically used for hot water space heating, and has been adapted for this application because of its efficient heat conductance characteristics.

5) Absorption Chiller - The MED absorption chiller is a 3 ton (36,000 BTUH) unit manufactured by the ARKLA Air Conditioning Corp. This chiller, although the smallest unit available at that time is approximately twice the capacity needed. This

maximum production is based on a supply of hot water at a rate of 11 gpm at 195 degrees F. This need for hot water of course resulted in increased solar system size and boiler size. The unit could be operated at 1-1/2 ton capacity by reducing the supply water temperature to 170 degrees F. This possibility was ruled out because insufficient dehumidification would occur at lower operating temperatures.

6) Cooling Tower - An integral component of the absorption cooling system is the cooling tower. A Marley #6305 "Aqua Cooler" provides heat rejection from the absorption chiller. The unit has a capacity of 99,000 BTUH at 19.8 gpm, assuming condenser water is entering at 19.8 gpm. The fan circulates 1700 cfm of air against 25 inches of internal static pressure. The fan is operated by a 1/2 h.p. motor.

7) Air Handling Unit - Air handling is provided by a Trane size 3 vertical draw through "Climate Master". This unit, equipped with a mixing box, provides economizer cooling. Outdoor and indoor air dampers activated by a single motor operator regulate air intake to the coil through the mixing box. A Honeywell electronic air filter removes impurities from the air before the coil. Mechanical cooling and heating whether from the chiller storage or the auxiliary boiler is also accomplished through this unit. Water, the heat transfer fluid, is circulated through the coil located in the air handler to provide both heating and cooling.

5.2 Data Aquisition System - The success of the Minimum Energy Dwelling project has been measured by a system of instrumentation designed and installed by Honeywell. Objectives for the instrumentation system set during design were primarily to measure total energy input to the dwellings. This included total gas and electric energy as well as water (a very critical resource in Southern California). Secondary objectives required a more complex data acquisition system (DAS) to provide a measure of temperature, flow, energy consumption, position of valves and dampers, wind and solar insolation at a very finite level. That is not to provide total energy consumption figures, but a detailed accounting of energy consumed by each system component. This data collection required the placement of 45 sensors at strategic locations throughout the mechanical system and structure of each dwelling. Sampling of all the sensors and correlation of data with time is accomplished by computer.

The DAS was installed as indicated in Table 5.2 and Figure 5.3. The sensors are located so that flow through any given piece of equipment is measured and temperature sensors are located on both the inlet and outlet sides of equipment. This arrangement provides for the measurement of any given unit of equipment.

TABLE 5.2

Sensor List

TEMPERATURE SENSORS

TS1 - Return from Collectors at Storage Tank
TS2 - Supply to Collectors at Storage Tank
TR1 - Supply to Solar Heat Rejection Loop
TR2 - Return from Solar Heat Rejection Loop
TX1 - Hot Water Supply from Solar Storage at Tank
TX2 - Hot Water Return to Solar Storage at Tank
TB1 - Auxiliary Water Heater Outlet
TB2 - Supply to Auxiliary Water Heater
TC1 - Chilled Water Outlet of Arkla
TC2 - Chilled Water Return to Arkla
TT1 - Water Inlet to Tower
TT2 - Water Outlet from Tower
TM1 - Make Up Water
TD1 - Domestic Water Heater Inlet
TD2 - Domestic Water Heater Outlet
TAD - Ambient Temperature (Dry Bulb)
TAW - Ambient Temperature (Wet Bulb)
TRD - Dwelling Return Air

FLOW SENSORS

FSC - Flow Rate of Solar Collector Loop
FSS - Flow Rate of Solar Storage Loop
FAH - Flow Rate of Auxiliary Heater Loop
FT - Flow Rate of Cooling Tower Loop
FC - Flow Rate of Chilled Water Loop
FDW - Flow Rate of Domestic Hot Water
FCW - Flow Rate of Cold Water Make Up
FGA - Gas Flow Rate to Auxiliary Water Heater
FGD - Gas Flow Rate to Domestic Water Heater
FOA - Flow Rate of Outside Make Up Air
FRA - Flow Rate of Return Air

WEATHER

WV - Wind Velocity
WD - Wind Direction
HPC - Total Solar Insolation Perpendicular to Solar Collectors
HH - Solar Insolation on Horizontal Plane (Direct)
HHD - Solar Insolation on Horizontal Plane (Diffuse)

Table 5.2 (Continued)

ELECTRICAL

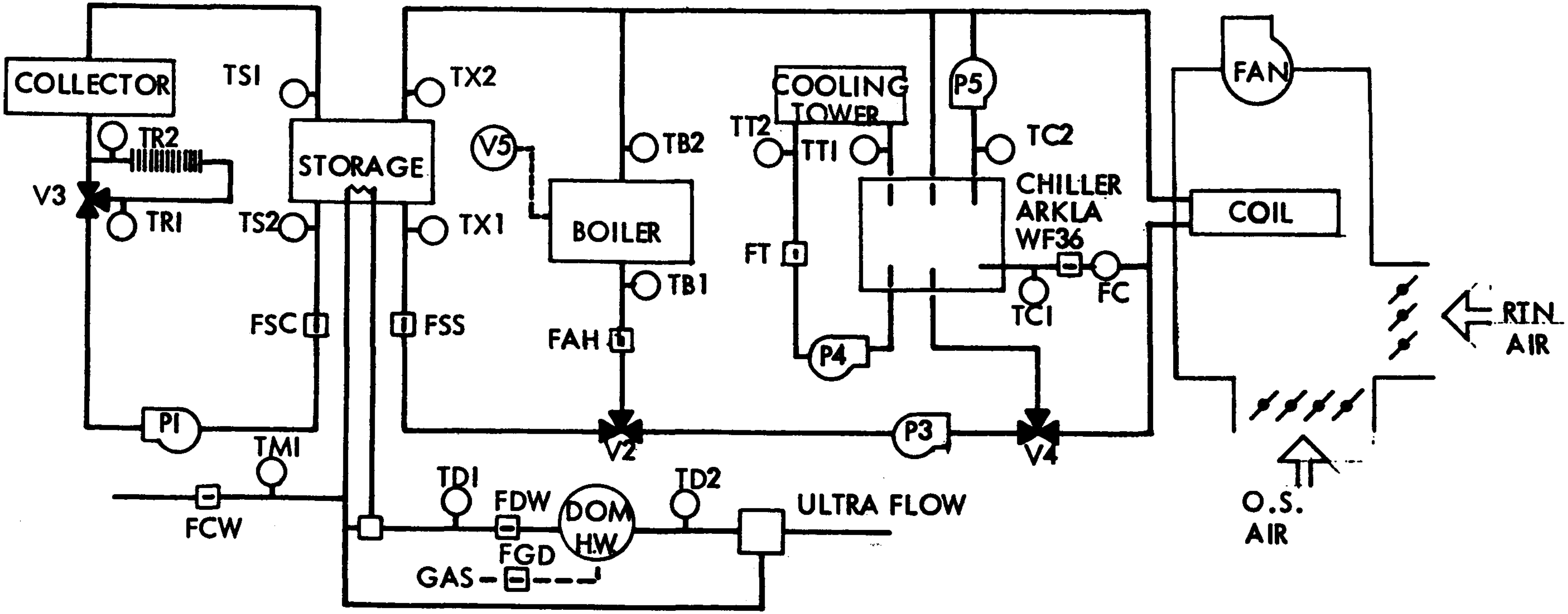
EP1 - Electrical Consumption of Pump P1
EP3 - Electrical Consumption of Pump P3
EP4 - Electrical Consumption of Pump P4
EP5 - Electrical Consumption of Pump P5
ES6 - Electrical Consumption of Air Handler Fan
ECP - Electrical Consumption of Central Plant
ETF - Electrical Consumption of Cooling Tower Fan

INDICATIONS

V2 - Position of Valve V2
V3 - Position of Valve V3
D1 - Position of Damper Motor D1, Hours in Position
SF - High or Low Air Handler Fan Speed

FIGURE 5.3

SENSOR LOCATIONS



6.1 Data Collection and Quality

Approximately 95 instrument readings were monitored every two seconds, averaged or cumulated over a 30 minute or 1 hour period, and recorded on cassette tape. A Hewlett Packard 98-25 computer performed this task. Later, the cassettes were transferred to a seven inch, nine track tape and shipped to CMU. There, the data was analyzed on a DEC 20 with heavy use of the SPSS statistical analysis program.

The data appears to be in good condition from September, 1977, to August, 1978. A few earlier months, and to some degree September-October of 1977, contain suspect data. The main difficulty is that when the data was recorded, the interval which it represented was not recorded. The assumption must therefore be made that a recording of, e.g., 25 gallons of flow (cumulative) must have occurred since the previous data record (times were indicated). In the earlier months (July-August 1977) record times were somewhat sporadic and flow data was not consistent, so this information was not used. Although most graphs presenting data by month show the sequence January, February ... December, in fact the September-December data is for 1977, and January-August data is for 1978.

The data also contains several calibration measurements. Since most sensing devices provided electrical responses to phenomena, e.g. current as a function of temperature, and the devices were connected in series, each observation included line voltage readings. If the absolute voltage differed by more than ± 10,000 mv from 100,000 mv or the voltage differential in either house across the sensors in series exceeded ± 1.0 mv, the observations were discarded. With the exception of October 1977, few observations were rejected for calibration reasons.

All data was checked during preliminary analysis, as best as possible, to identify inconsistencies in data definitions and instrument calibrations. One concern is that a number defined as representing, e.g. temperature of water out of the solar collector, was exactly that, and not, e.g. temperature of water into the storage tank. Secondly, the data was checked for individual instrument calibration. The only observations that appeared out of line in this respect were the temperature sensors for the solar rejection loop and the water coil in the air handler. The rejection loop sensors may be acceptable for one or two months of data in late summer, 1978. Otherwise, difficulties in sealing them from inclement weather make their measurements erroneous. The coil temperature sensors were not calibrated until September, 1978.

Generally, however, the data appears to be in excellent condition with respect to representing how the system performed. The MED houses represent an extraordinary opportunity to examine how a house and its mechanical equipment perform under normal practice, i.e. non-laboratory, conditions.

6.2 Data Analysis

The data on which much of the CMU Report is based included approximately 1,000,000 recorded instrument measurements. The bulk of these measurements were zeros, reflecting that most of the time few systems were in operation. The MED houses are located in a mild climate so that the only mechanical subsystem that operated frequently was the solar collector. Nevertheless, when subsystems operated, sufficient data was collected to reach conclusions on their performance.

Ideally, individual subsystems performance should be studied by examining the data on an observation by observation basis. One could then check for consistency in system operating conditions, e.g., the temperature maintained during nights in winter. This depth of study was beyond the scope of this effort; recommendations are made elsewhere regarding potentially valuable additional analysis.

In the study, most of the analyses were performed by blocking the data into two and one-half hour intervals over two month time periods. For example, the ambient temperature is reported as the average of all observations recorded between 12:00 Noon and 14:30, say, during the months of January and February. This approach assures that most numbers reported as averages are reasonably reliable, yet one still observes changes in performance over a daily cycle and throughout a year. The only area where this approach did not work very well was domestic hot water use in the rental unit (it was not studied at all in the demo unit). Evidently, over any two month period the consumption of hot water, while essentially consistant for a day, occurred in large amounts during a few events each day. Further, the events were scattered throughout the day.

6.3 MED Performance

The Southern California climate is quite mild, and the MED houses are constructed with special consideration given to insulation, effective use of sunlight, and the application of active solar energy collection for space heating/cooling and domestic water heating. As a result, the houses required little heating or cooling if managed properly. Nevertheless the alternative operating conditions that occurred or were imposed on the houses, coupled with elaborate mechanical systems and extensive data collection have created an extraordinary opportunity for evaluating energy use and conservation potential for homes in Southern California.

Figure 6.1 presents a first pass perspective on how well the rental home performed for the months of January-August, 1978. The demonstration unit cannot be shown because of poor data. The dashed lines represent alternative houses, based on electric and gas meter readings. For the MED home, the lower line represents the electric and gas consumption (including solar collector pump - 15,000 BTU/day) as indicated by meter readings. The top line adds solar energy used, supplied by the collectors to derive a total energy consumption curve.

FIGURE 6.1

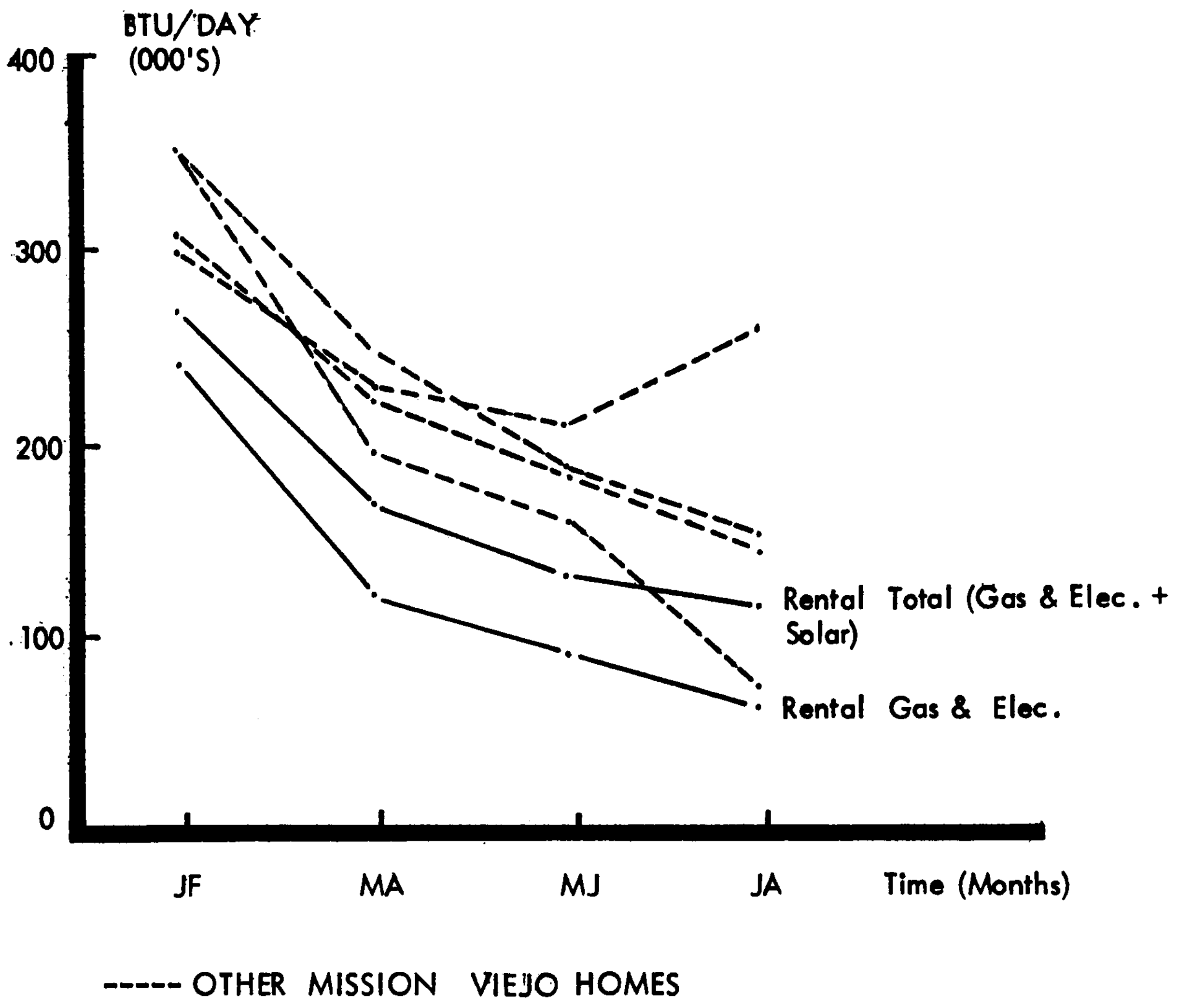


FIGURE 6.1

One can argue that the MED houses outperform all of the other units, although the results do not imply that all systems in the MED houses are economically feasible. For example, heating in the demonstration unit permitted too great a variation in interior temperature, apparently as a result of control problems. Whereas the demo also performed better than the comparable unit that employed conventional air conditioning in summer, its good performance is attributable to a well constructed house rather than an efficient air conditioning system.

Finally, this illustration should be treated gingerly because much of the variation may be attributable to differences among households rather than houses. Research at Princeton for a similar situation (i.e., "identical" housing) indicates that 2/3's of the variation in household energy consumption is attributable to household behavior.

6.4 Space Heating/Cooling

1) The space heating/cooling analysis is constrained to examination of heating in the rental unit in January-February, 1978, and cooling in the demo unit for May-August, 1978 for the following reasons:

   a) Heating in the demo unit occurred only in the afternoons occasionally, as if it operated only when someone forced it on. Temperatures in the demo floated between 41 degrees F and 75 degrees F in January-February, 1978.

   b) The data indicates only a few observations of air conditioning in the rental house in July-October, 1978.

   c) Economizer cycle data is limited. In the demo, the economizer was intentionally prevented from operating. In the rental unit, fan times but not air flow data is available so that analysis is constrained.

   Figures 6.2 - 6.4 illustrate heating/cooling performance in the two houses.

2) In the rental unit, heating occurred mostly in the morning at a rate of 29,000 BTU's per day and 3,000 BTU/Hr. The thermostat was not set back at night and temperatures seldom dropped below 68 degrees F. The demo unit, when it did demand heating, operated at a maximum rate of 4,500 BTU/Hr., based on 30 minute observations.

3) Eighty percent of the heat supplied in the demo unit came from solar storage. In the rental unit, 100% of the heat came from the boiler, even though solar storage had acceptable temperature levels. A control problem is suspected.

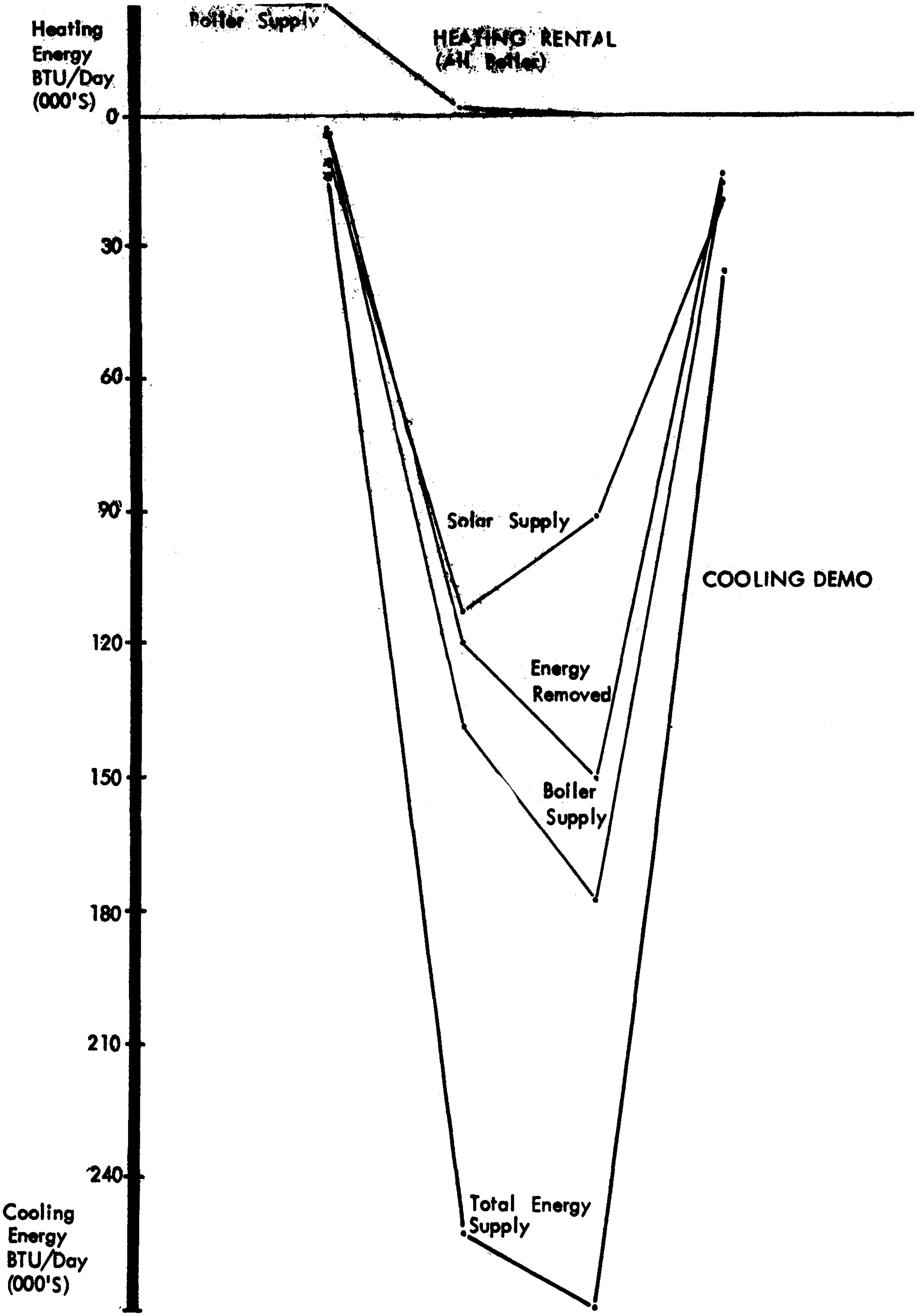

Heating Energy BTU/Day (000'S)
Boiler Supply
HEATING RENTAL (All Boiler)
0
30
60
90
120
150
180
210
240
Solar Supply
Energy Removed
Boiler Supply
Total Energy Supply
COOLING DEMO
Cooling Energy BTU/Day (000'S)

FIGURE 6.2

FIGURE 6.3

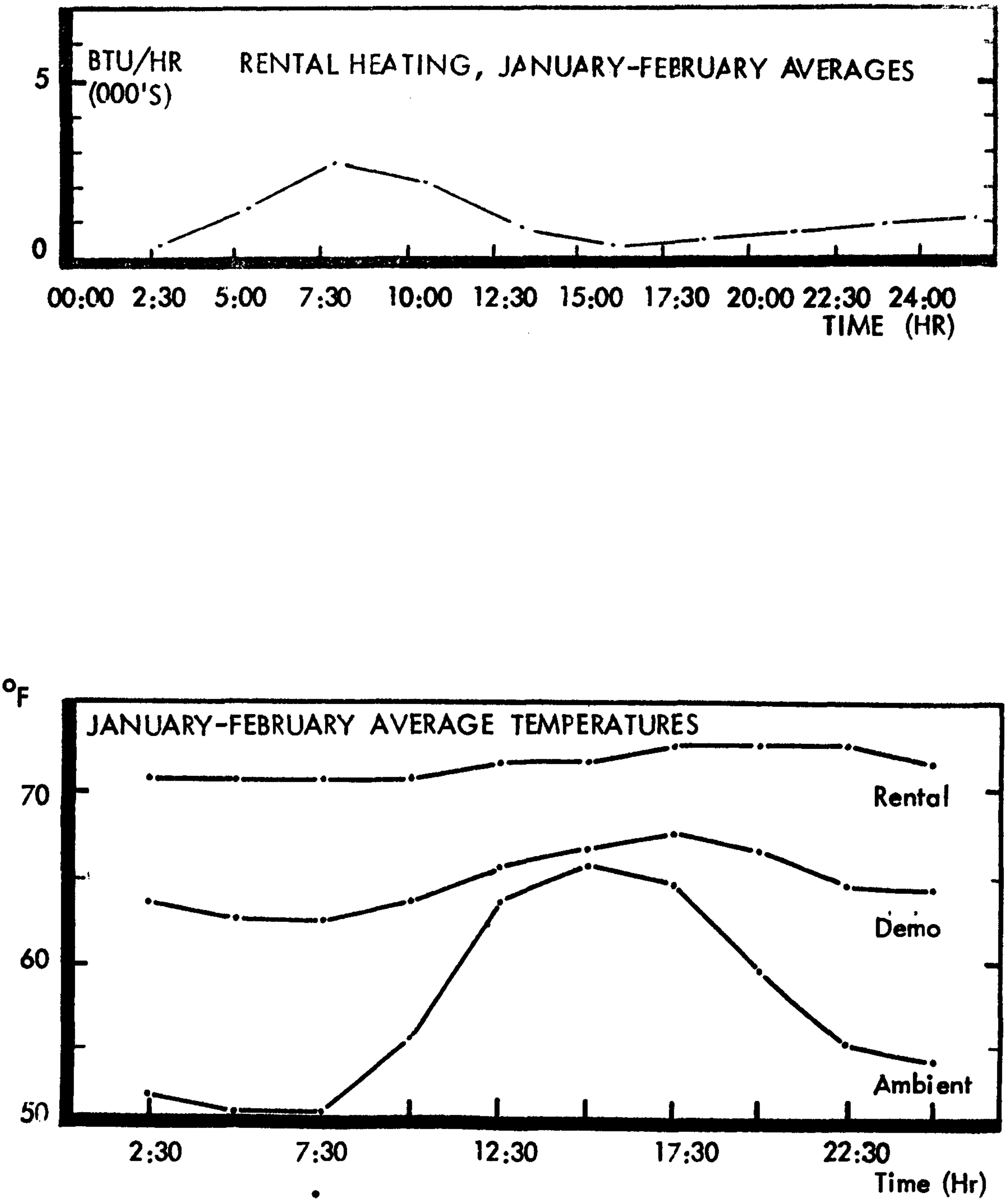
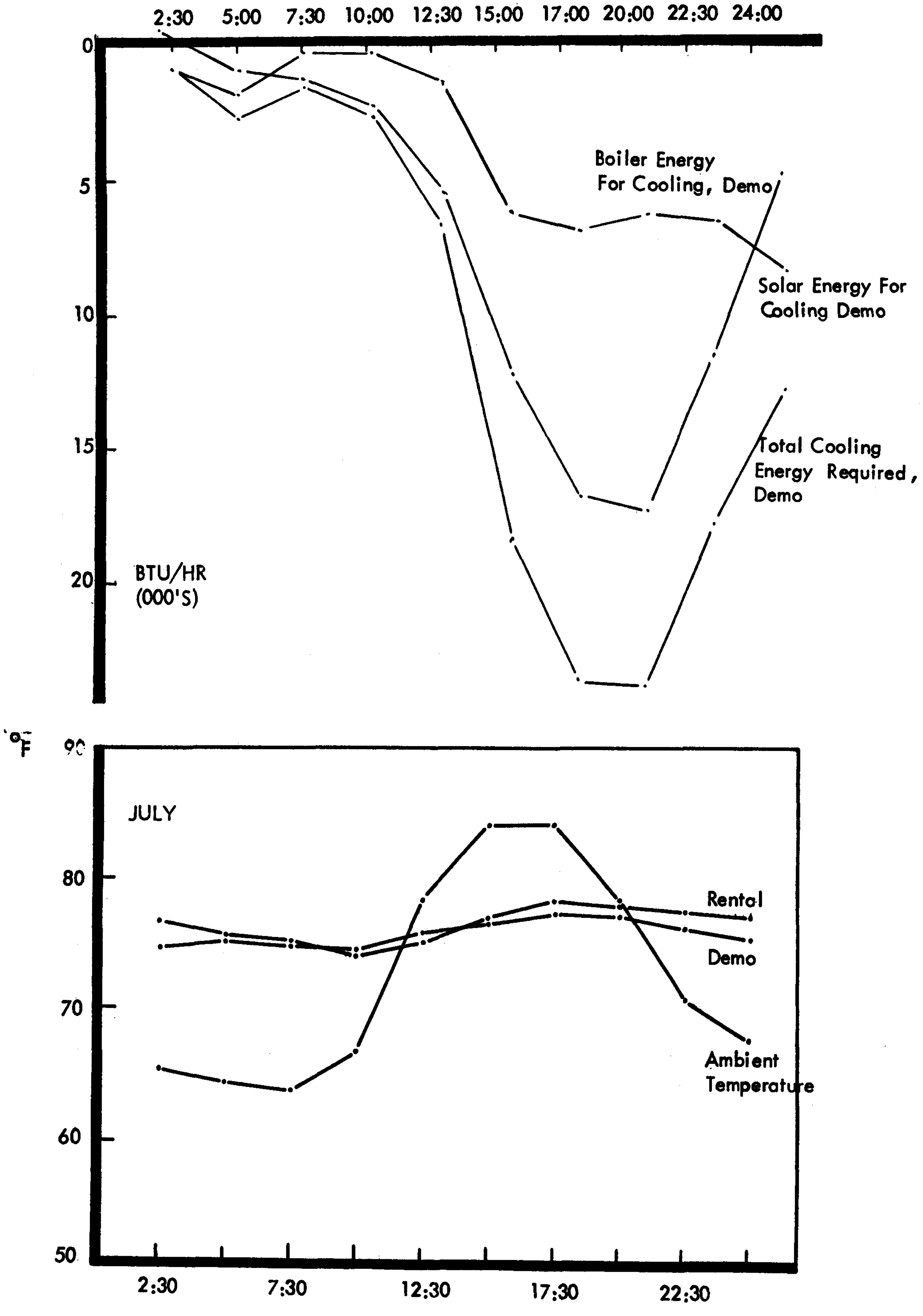

RENTAL HEATING, JANUARY-FEBRUARY AVERAGES
BTU/HR
(000'S)
5
0
00:00
2:30
5:00
7:30
10:00
12:30
15:00
17:30
20:00
22:30
24:00
TIME (HR)
JANUARY-FEBRUARY AVERAGE TEMPERATURES
°F
70
60
50
Rental
Demo
Ambient
2:30
7:30
12:30
17:30
22:30
Time (Hr)

FIGURE 6.4


2:30
5:00
7:30
10:00
12:30
15:00
17:00
20:00
22:30
24:00
0
5
10
15
20
BTU/HR
(000'S)
Boiler Energy
For Cooling, Demo
Solar Energy For
Cooling Demo
Total Cooling
Energy Required,
Demo
°F
90
80
70
60
50
JULY
Rental
Demo
Ambient
Temperature
2:30
7:30
12:30
17:30
22:30

4) The air conditioning load in the demo unit was very heavy in comparison with the rental unit. In July-August, 1978, the demo required 270,000 (150,000) BTU's per day at a maximum rate of 24,000 BTU's per hour. The number in parenthesis is the energy removed from the house, versus thermal energy expended in the air conditioning system. The economizer was not allowed to operate, and presumably windows were closed. The rental unit required almost no air conditioning: 500 BTU's per hour average, only between 8:00 PM and 10:30 PM, totaling 9,000 (3,000) BTU's on the average day.

5) Solar Storage provided 30 - 50% of the air conditioning energy required in the demo unit. It was never used in the rental, possibly because storage temperatures might have been too low, but lending strength to the conclusion expressed in #3.

6) The temperature sensors on the coil were not calibrated, so energy added (heating) or removed (cooling) is reported according to temperature sensors located further from the coil.

7) In conjunction with #6, and other analysis, a mixing of cold coil water with hot chiller water may occur during air conditioning.

8) The boiler sometimes operates so that it is heating water returning to solar storage during air conditioning mode in the demo.

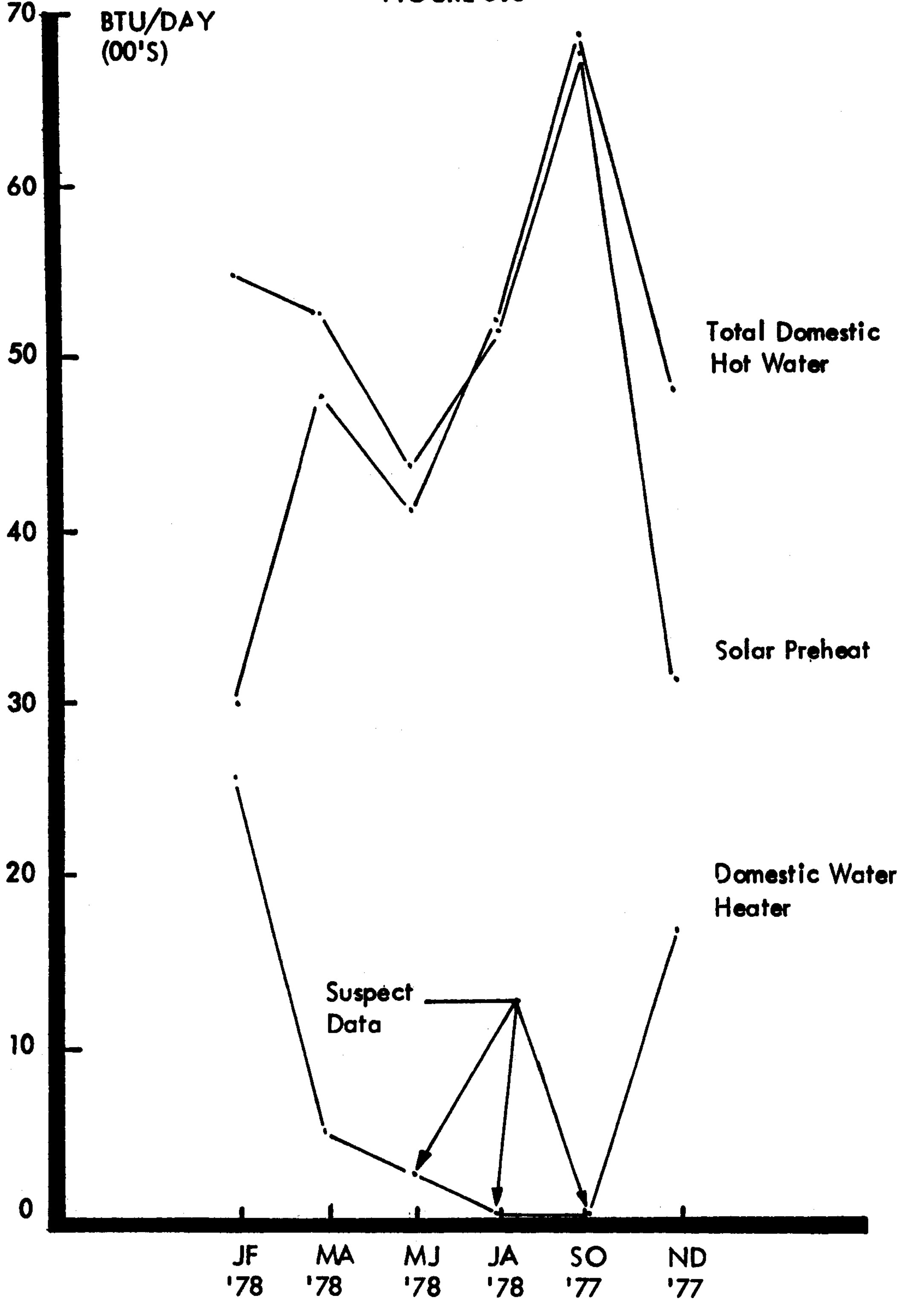
6.5 Domestic Hot Water

1) The demo unit was not examined for domestic hot water preheating and consumption. The volume of use was very low because it was not occupied by a family and the demo hot water heater was turned off.

2) In the rental unit, the total amount of water use, and the amount of hot water use, are roughly in agreement with MED Handbook projections. The distribution of use varies somewhat, apparently attributable to the occupant's lifestyle: usage is essentially shifted 3-4 hours later throughout the day. Some seasonal shifting of use is evident; more water is consumed in early afternoon during winter months, and this use shifts to late afternoon in the summer.

3) Evidently the flow meter for the hot water heater failed in May-August 1978, and September-October, 1977; thus identifying the amount of energy supplied via solar storage preheating versus the heater is difficult. Nevertheless the evidence suggests that preheating supplies 50-60% of hot water energy needs in winter (November-February) and 100% of energy needs in the summer months. Figure 6.5 illustrates these findings.

FIGURE 6.5


70
60
50
40
30
20
10
0
BTU/DAY
(00'S)
Total Domestic
Hot Water
Solar Preheat
Domestic Water
Heater
Suspect
Data
JF
'78
MA
'78
MJ
'78
JA
'78
SO
'77
ND
'77

6.6 Solar Collectors

1) The solar collectors performed with an overall efficiency rate of 40-50% in terms of energy stored versus incident insolation energy, on the basis of observations when the collectors were operating. This rate was achieved consistently throughout the year, except for the rental unit in June-August, 1978.

2) The solar collectors performed with an overall efficiency rate of 30-40% in terms of energy stored versus incident insolation, on the basis of all observations; i.e., including days when the weather was bad or start-up/shut-down difficulties occurred. This rate was consistent for both units throughout the year. Except for the rental unit in June-August 1978, collection rates ranged from 300 BTU/SF-day to 800 BTU/SF-day (January versus July, expected performance).

3) Both units experienced highly variant behavior in early morning and late evening, presumably associated with start-up/shut-down controls. Sometimes the units operated all night.

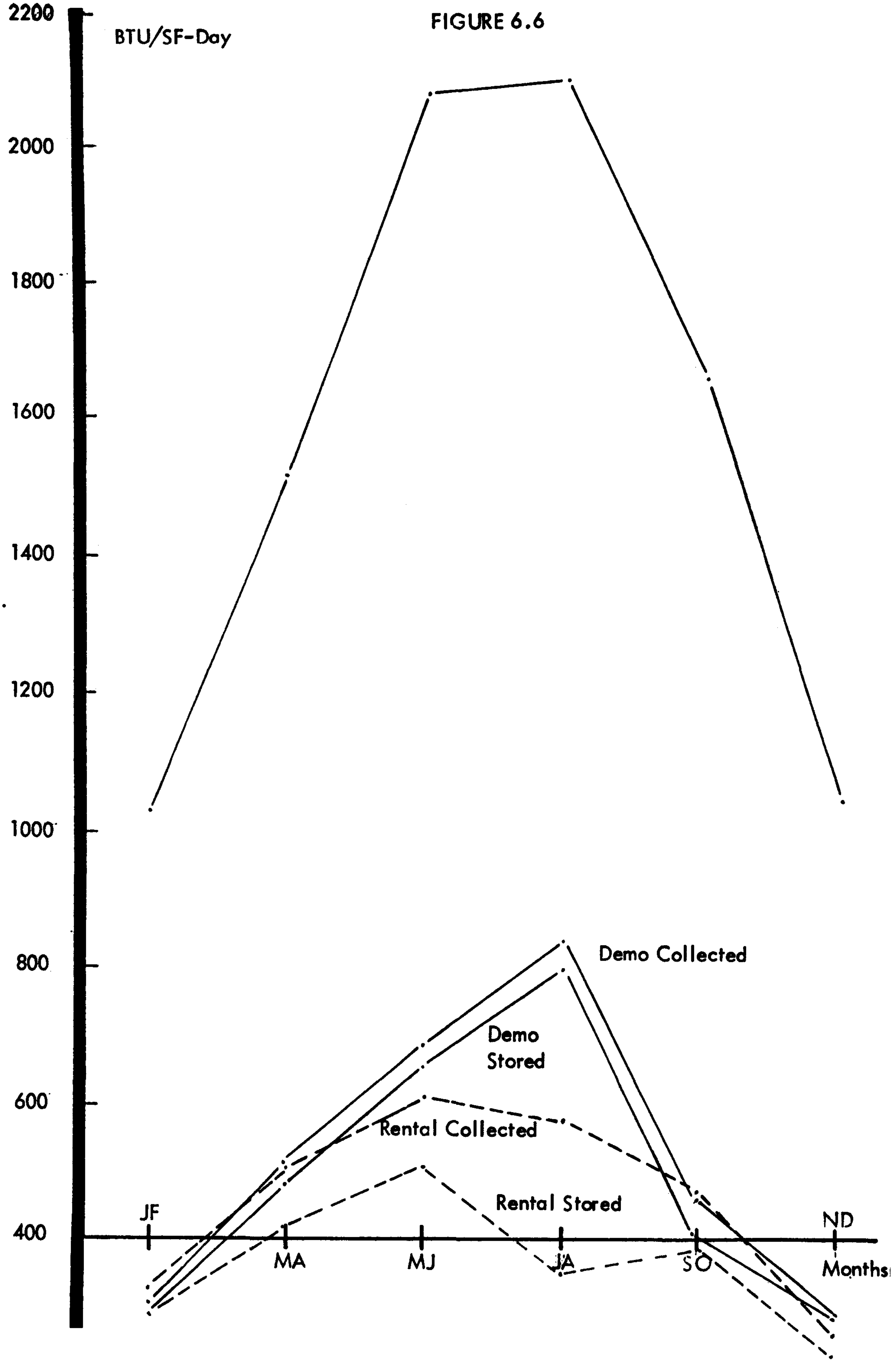
4) The data on the reject loop is too noisy to permit any detailed study, but some very tentative conclusions are that its use is too unstable. Either too much or too little energy is dumped, and the control system probably leads to cycling (off-on) with high frequency.

5) The rental unit apparently experienced difficulties operating in June-August, 1978. The tentative conclusion is that the internal use did not draw off much energy from storage in mid-afternoon, storage temperatures became excessively high, and as a result the reject loop was often needed.

6) Both units experienced a significant loss rate in the lines between the collector and storage, on the order of 5-10% of energy collected. The rental unit consistently lost twice the amount of energy as the demo unit. Losses appear to be related to collector water temperature. They could be explained by a 0.5 degree F drop in temperature over the lines, or by leakage in the rejection loop valve V3.

7) An appreciable amount (50-90%) of the energy calculated as being stored cannot be accounted for in terms of measured use. While a more detailed study should be helpful, the tentative conclusion is that this energy is lost from storage via conduction and thermosiphoning. The "U" factors for the tank and the vault walls could account for 100% of the loss if no insulation existed in the vault. The more likely explanation is that a 6-12 gallon per hour flow from storage through the coil, generated by thermosiphing and undetectable with the flow meters used, can account for 100% of the loss.

FIGURE 6.6


BTU/SF-Day
2200
2000
1800
1600
1400
1200
1000
800
600
400
JF
MA
MJ
JA
SO
ND
Months
Demo Collected
Demo Stored
Rental Collected
Rental Stored

6.7 System Performance: Cost/Benefit Projections

The following comments constitute a rough estimate of operating performance for the two houses. They are based on a synthesis of the material presented here as well as much more extensive studies included in the complete Carnegie-Mellon University report.

Winter Operation

In January-February, the rental house requires approximately 30,000 BTU/day in space heating and 55,000 BTU/day for hot water consumption. The solar storage provides 30,000 BTU/day for domestic water heating, and it could provide more with an altered pre-heating coil design. The tank temperatures are not high enough and the domestic water is not stored long enough for greater transfer to occur. The pre-heating coil is 8" in diameter and extends horizontally through the center of the tank. An improved design might be larger in diameter having greater surface area and take advantage of high temperatures located near the top of a stratified tank.

The rental unit requires an average maximum rate of heating of 5,000 BTU/hr. Based on experience in the demo unit, the current design can supply at least 45,000 BTU/hr. The solar collectors as configured store 80,000 BTU/day in the winter. If the tank loss rate can be reduced, this amount is adequate to cover both domestic water and space heating needs. In addition to system capital costs, the operation requires a solar collector pump, a fan coil pump, and a fan. According to operating times in the rental unit, 30,000-50,000 BTU/day can be supplied for hot water heating at a (pro-rated) cost of 7,600 "electrical" BTUs/day for operation of circulating pumps to transfer solar energy + system amortization. Space heating (30,000 BTU/day) can be supplied at a cost of 10,480 "electrical" BTUs/day for operation of circulating pumps and air handling equipment to transfer solar energy + system amortization. This efficient use of solar energy would yield coefficients of performance of 3.9 for domestic hot water heating and 2.9 for winter space heating.

Summer Operation

In summer, the ideal situation is 100% of hot water supplied from solar storage and use of an economizer cycle. The domestic hot water can be supplied at the rate of 50,000 BTU/day at a cost of 15,245 BTU/day + amortization. Since the collector stores 216,000 BTU/day, gross excess capacity exists. Initial computer modeling during the design of the MED house indicated that 8 modules at 256 sq.ft. would provide adequate heat production with a conservative safety factor. However, due to the experimental nature of the project and the use of an unusual collector that had not been computer modeled before, two collector modules were added during design. This increased the total collector area to 320 sq. ft. It was felt that any overproduction by the collectors could be dumped via the heat rejection loop and that both adequate solar production and collector testing would be insured. The gross excess capacity would indicate that the initial computer modeling was correct.

The economizer is used very little, according to our (somewhat suspect) data. This is because the residents often exercised the option to open the windows to maintain comfort. Nevertheless, economizer use can cost an average of approximately 391 BTU/day in electrical consumption with the use of natural ventilation for cooling when appropriate.

In contrast, an absorption chiller method of cooling is quite expensive. According to the demo unit performance, the chiller would require 260,000 BTU/day in thermal energy to remove 130,000 BTU/day from the house. Of this 260,000 BTU, approximately 100,000 comes from solar collection (MED system - capacity, storage tank size, etc.) at a cost of 15,000 electrical BTU/day, and 160,000 BTUs come from the gas fired boiler at a cost of 200,000 BTU/day in gas consumption. In addition, 3 pumps and two fans consume 80,000 BTU/day. The net result is 265,000 BTU of gas and electricity consumed plus equipment amortization, to remove 130,000 BTU from a house which could have been cooled alternatively with the economizer at a cost of approximately 400 electrical BTU/day averaged (including the opening of windows when appropriate to maintian comfort). The coefficient of performance for the chiller/solar/blower system is approximately 0.5. These numbers, while derived from results of system analysis, check reasonably well against electric meter measurements.

6.8 Additional Research

The MED data collected to date has proven to be invaluable for studying energy use in Southern California housing. Nevertheless, much work can be done as a contribution to energy use/conservation in housing. For example, we have not really probed in depth as to how certain systems have operated; the analysis presented here is more of a summation of aggregate performance rather than an explanation of why performance occurred. In the solar collector analysis, we cannot at this time predict how much energy would be collected or stored even if we knew the supposedly important parameters such as insolation levels, air temperatures, flow rates, water temperatures, tube sizes, etc.

Much of the additional analysis can be performed with data that has been collected already. This situation is true with respect to the solar collectors, for instance. But the temperature sensors at the air handler coil were not calibrated until September, 1978. As a result, we have not been able to calculate the exact amount of energy provided to the house by the air handler coil; instead, our calculations must include line losses, because energy is measured at the source rather than the destination. Examination of data collected since September would provide some insight into the seriousness of line losses, which evidently are significant in the solar collectors.

Another major concern is that we do not know why or how the solar storage tank is losing so much energy. If it is attributable to thermosiphoning, a site study may identify this behavior. Otherwise, more extensive analysis of collector data should provide some insight.

CONCLUSIONS AND RECOMMENDATIONS 7

7.1 Consumer Reaction Survey

The Minimum Energy Dwelling project has been highly successful as a means of communicating energy conservation techniques. This task has been accomplished primarily through the MED Workbook and the accesibility of the MED houses to the public, building professionals and the media. The techniques used by Marylander Marketing Research Inc. have provided a realistic measure of the opinions of visitors to the Minimum Energy Dwelling. The conclusions of the marketing report are as follows:

1) There is a strong correlation between perceived economic soundness of a feature and the likelihood of using it. Economic soundness may be a key determinant of whether or not a feature may be used.

2) Builders and Architects were most concerned about cost. Government officials were slightly less concerned and the general public least concerned.

3) Of all features included in the survey, the use of extra thick attic insulation, night set back thermostat and pilotless range were felt to be the most economically feasible and had the highest number of people willing to use them.

4) According to the report, "Those ideas mentioned by more than 10% of the sample are at sufficiently high levels to warrant some concern." These areas of concern were cost, smaller than average floor area, the Ultra-flow pushbutton water distribution system, bulkiness of the solar panels and smallness of the windows.

5) 80% of those visiting the Minimum Energy Dwelling said that they were more likely to use conservation features as a result of their tour.

6) Over 75% of the visitors indicated that something new was learned as a result of their visit.

7) Of the 15 features measured, the average visitor recalled almost 12.

7.2 Building Shell Performance

The thermal performance of the Minimum Energy Dwelling has been as predicted. This finding is verified by three independent studies by: AGA Corporation, Honeywell Corporation and Carnegie-Mellon University. Conclusions and recommendations of these studies regarding thermal performance of the Minimum Energy Dwellings are as follows:

1) The improvements in the quality of construction and insulation were certainly evident in the thermography evaluation of the Minimum Energy Dwelling. Temperatures were much more even and consistent throughout the MED. Also, energy losses from the concrete pad and glass areas were reduced to less than half when compared to the standard El Jardin dwelling.

2) The MED had a calculated average of R = 16.2 as compared to R = 7.6 for the El Jardin. The Honeywell transient heat flow measurements confirmed both of these calculations.

3) Infiltration in the Minimum Energy Dwellings was reduced to 1/5 or 1/4 of the standard El Jardin model. MED Workbook predictions were for an infiltration rate 1/3 that of the El Jardin. The final methane decay measurements were taken after correcting for leakage through the fresh air dampers and the fiberglass ducts running through the attic. Initial testing prior to correcting testing procedures for the leaking damper and ducts indicated an infiltration rate of 278 cfm or 1.7 air changes. This rate is of course, unusually high and subsequent inspections determined the nature of the problem. Infiltration rates after correcting for this problem were .26 or 41 cfm for the Demonstration House and .34 or 55 cfm for the Rental House. It is recommended that joints in ductwork be effectively sealed especially when they are located in an unconditioned space.

4) Honeywell humidity measurements taken in the insulation of both MED houses indicate that in all cases the dew point temperatures are lower than the outside wall temperatures indicating no condensation. The dew point in the master bedroom in the rental house was 50 degrees in March. This is high enough to lead to some condensation when outdoor temperature drops rapidly.

The sealed stud space resulting from the use of inside and outside vapor barriers does not appear to present a condensation problem in the mild Southern California climate. This construction in a more severe climate could present problems. Tar paper under the stucco is probably adequate and would relieve any danger of moisture condensation.

5) Methane tracer techniques were used to calibrate flow meters and measure flow rates across the coil. The measurements indicate that air flow across the coil was relatively constant at 1200 cfm.

6) The thermal transient measurement technique offers a means for estimating the passive solar input to a structure. The passive solar gain on a clear September day was found to be 5986 BTU/hr.

7) According to the Carnegie-Mellon University studies, the thermal time lag for the MED structure is 5 hours.

7.3 Mechanical System Performance

The Carnegie-Mellon University report is the primary analysis of the Minimum Energy Dwelling mechanical system. The findings of this report are based on the analysis of approximately 1,000,000 recorded instrument measurements. The analysis is very extensive and has yielded considerable information on the performance of each MED subsystem. However, at this time, the results should be interpreted as tentative conclusions. As they are based solely on the data collected, certain conclusions would require on-site examination to confirm situations or conditions implied in the data. The following represents the conclusions and recommendations that can be made from the analysis to date.

1) The Minimum Energy Dwelling Rental Unit when compared to the El Jardin (non-MED) houses consumed 50% less gas and electricity.

2) Heating in the demonstration unit was supplied by 80% solar storage and 20% boiler. Conceivably 100% of the heating need would be provided by solar means if the storage loss condition noted in #11 were corrected. Heating in the rental was provided by the boiler exclusively, even though solar storage temperatures were adequate to provide a heating contribution similar to the demonstration unit. A control problem is suspected.

3) In regard to cooling, each house was operated in a different manner. The occupants of the rental house operated the house with little or no air conditioning or economizer cycle. Windows were opened as required to maintain comfort. As shown in Figure 6.4, the interior temperature tracked very close to the interior temperature of the demonstration unit. This is indicative of the thermal performance of the MED construction, materials and techniques. Average air conditioning load was 500 BTU's per hour average, only between 8:00 PM and 10:30 PM, totaling 4,000 BTU's expended to remove 3,000 BTU from the house per day.

   Information of the performance of the mechanical air conditioning system is gained from the demonstration unit which was operated throughout the same July-August cooling period with windows closed and the economizer locked off. The resultant air conditioning load required 270,000 BTU's per day to remove 150,000 BTU's per day at a maximum rate of 24,000 BTU's per hour. This cooling load may be somewhat inflated due to added cooling required for computer equipment located in the garage. Solar storage provided 30 - 50% of the air conditioning energy required in the demonstration unit. Again, correction for the storage loss situation described in #11 would presumably improve these figures.

4) Temperature sensors on the air handler coil were not calibrated, until September 1978. Therefore, energy added (heating) or removed (cooling) is reported according to a sensor located further from the coil. Line losses between the coil and this more remote sensor cannot be estimated. As a result it is not possible to calculate the exact amount of energy provided to the house via the coil. Data collected since September would provide a more accurate indication of performance.

5) Hot water consumption was studied in the occupied rental house only. The total amount of water use and hot water use are roughly in agreement with the MED workbook projections. Apparently, however, due to the occupants lifestyle, the usage is shifted 3 - 4 hours later throughout the day.

6) The evidence so far, suggests that preheating supplied 50% to 60% of hot water energy needs in winter (November - February) and in excess of 100% of energy needs in the summer months. However, the failure of the hot water heater flow meter in May-August 1978, and September - October 1977, leaving the data incomplete. On-site modifications and further data collection would be invaluable.

7) Solar collector efficiency in terms of energy stored versus incident insolation energy is 40 - 50% based on observations made during collector performance only. Collector efficiency based on all observations (including days when weather was bad or start-up/shut-down difficulties occurred.

8) The data for the heat dissipator is too noisy to permit detailed study. However, it is apparent that its use is unstable. Either too much or too little energy is rejected, and the controls for the system seem to be causing on-off cycling with high frequency. Correction of controls and instruments would yeild more conclusive data.

9) The rental unit collector system encountered operating difficulties in June - August, 1978. The tentative conclusion is that the occupant usage did not draw off much energy from storage in mid-afternoon, storage temperatures became excessively high, and as a result the heat reject loop was often used.

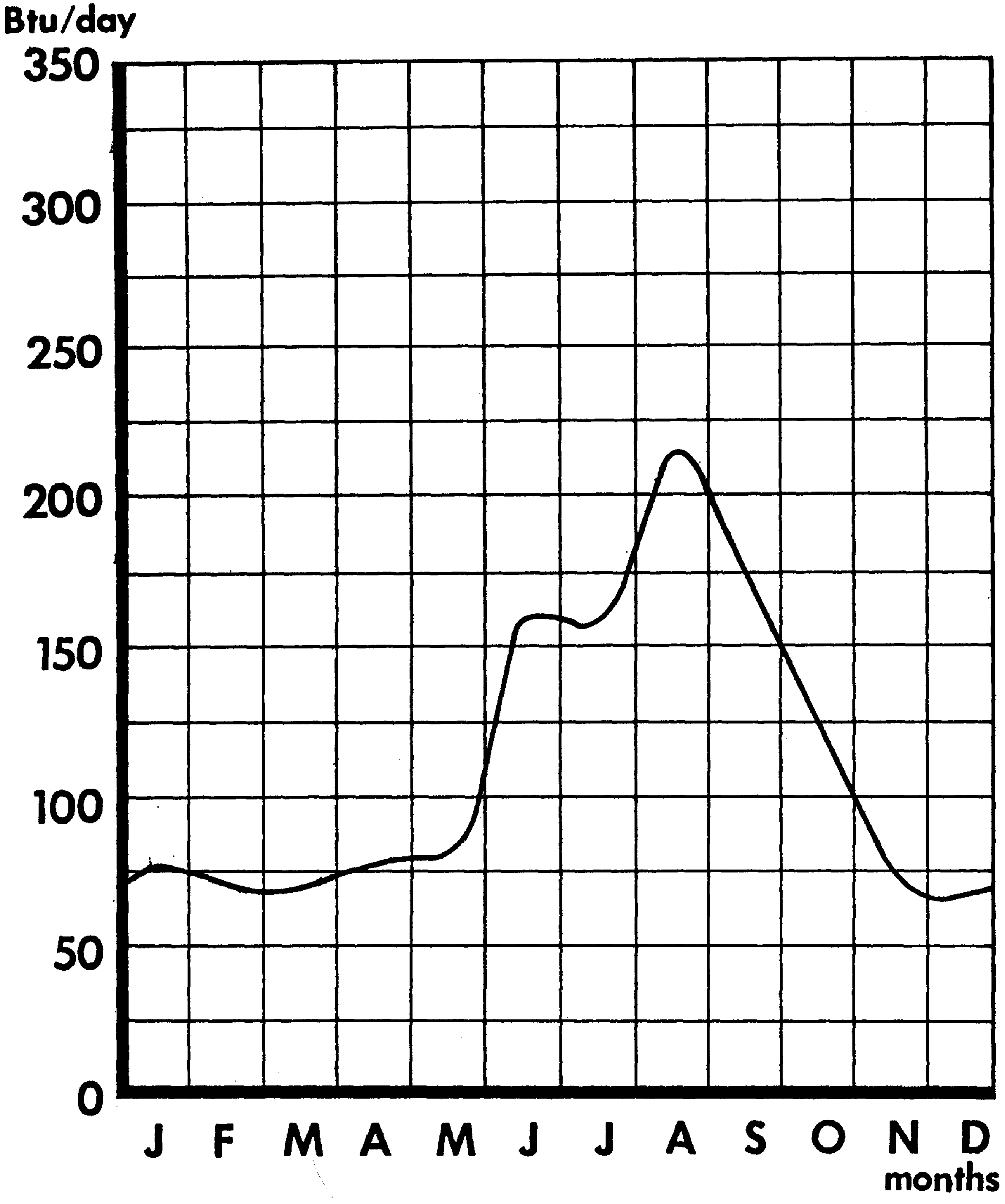
10) Both units experienced a significant loss rate in the lines between the collector and storage. This loss was in the range of 5-10%. The rental unit consistently lost twice the amount of energy as the demo unit. The loss appears to be related to water temperature and could be accounted by missing line insulation that would cause a .5 degree F temperature drop or a leak in rejection loop valve V3.

11) Both units also experienced a significant loss of energy from the solar storage tank. This loss is on the order of 50 - 90% of the energy calculated as being stored that cannot be accounted for in terms of measured use. The tentative conclusion is that this energy is lost from storage via conduction and thermosiphoning. In view of the highly insulated containment of the storage tank, conduction of this amount of energy through the tank is not feasible. It is more likely that the loss is caused by thermosiphoning at a rate of 6 - 12 gallon per hour through the boiler or coil. This 6 - 12 gallon flow rate is below the sensitivity of the flow meters and would therefore be undetected.

On-site investigation would provide some insight into the nature of this problem. If thermosiphoning is, in fact, the cause, it can be remedied by installation of a spring loaded check valve. Modifications of this type and further data collection would be invaluable.

12) Indications are, however, that if this excessive storage loss were corrected, the Minimum Energy Dwelling mechanical system sould have performed as predicted. Figures 7.2 and 7.3 illustrate a year of MED operation assuming a 5% storage loss as would be expected with the heavily insulated storage tank and correction for thermosiphoning or other possible heat losses. Figure 7.2 is a profile based on the rental unit heating and domestic hot water requirements. As illustrated, the yearly heat requirements of a MED house operated without cooling can be supplied nearly 100% by solar means. Figure 7.3 shows that a MED house operated as the demonstration unit, (with economizer locked off and cooling activated throughout the warmer months) has a total heat requirement that also falls within the amount of solar heat collected at a 5% storage loss. Consumption of natural gas then would become purely a function of chiller efficiency without the influence of excess storage loss.

13) The MED houses have performed as predicted. A comparison of the total MED heat requirement (Carnegie-Mellon University Studies) as shown in Figure 7.3 with the curve shown in Figure 7.1 (MED Workbook predicted building heat requirement) will show that actual results bear striking similarity with the predicted performance.



MED WORKBOOK PREDICTED BUILDING HEAT REQUIREMENT

Figure 7.1

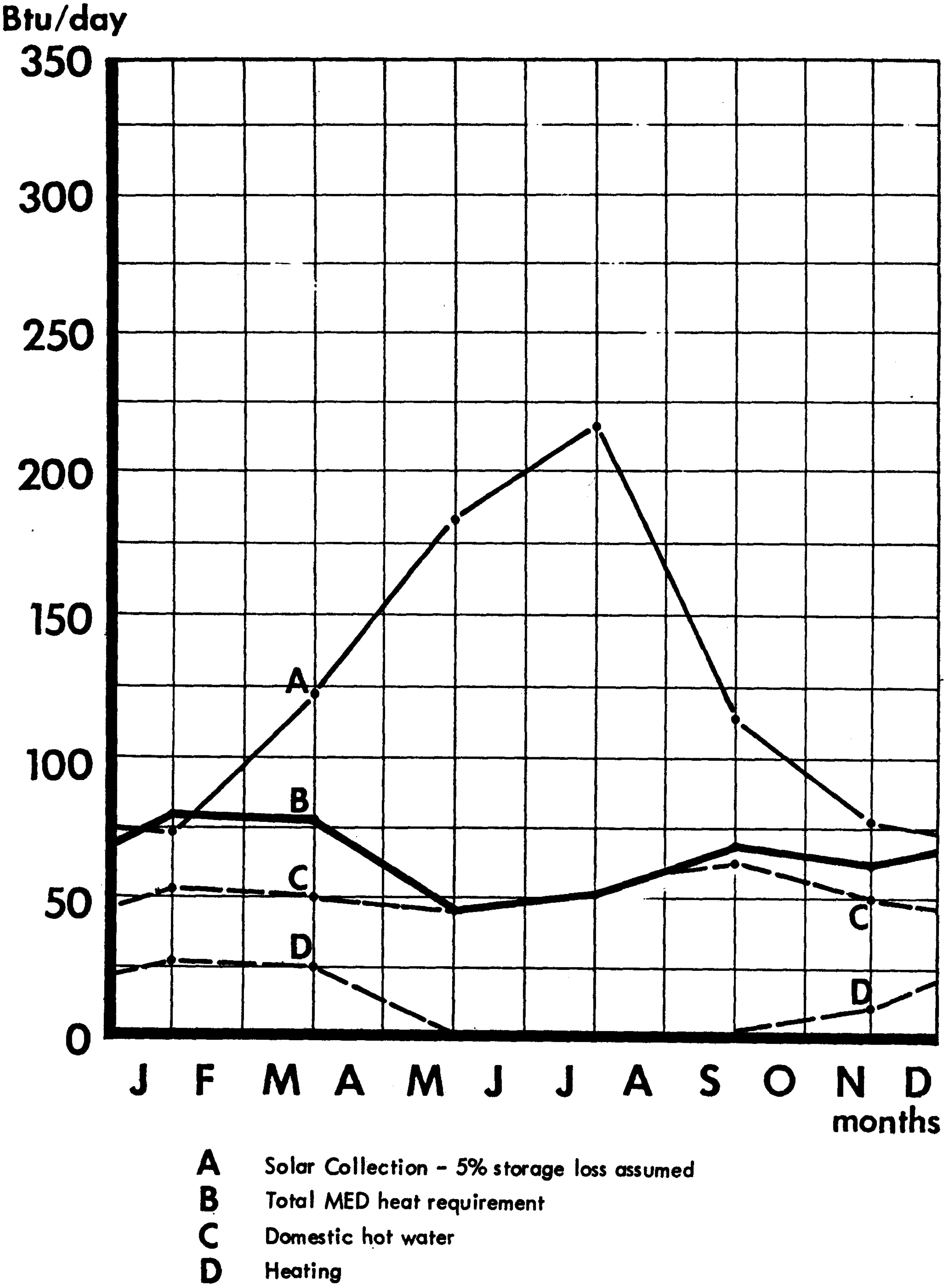

Btu/day
350
300
250
200
150
100
50
0
A
B
C
D
C
D
J F M A M J J A S O N D
months
A Solar Collection - 5% storage loss assumed
B Total MED heat requirement
C Domestic hot water
D Heating

Figure 7.2

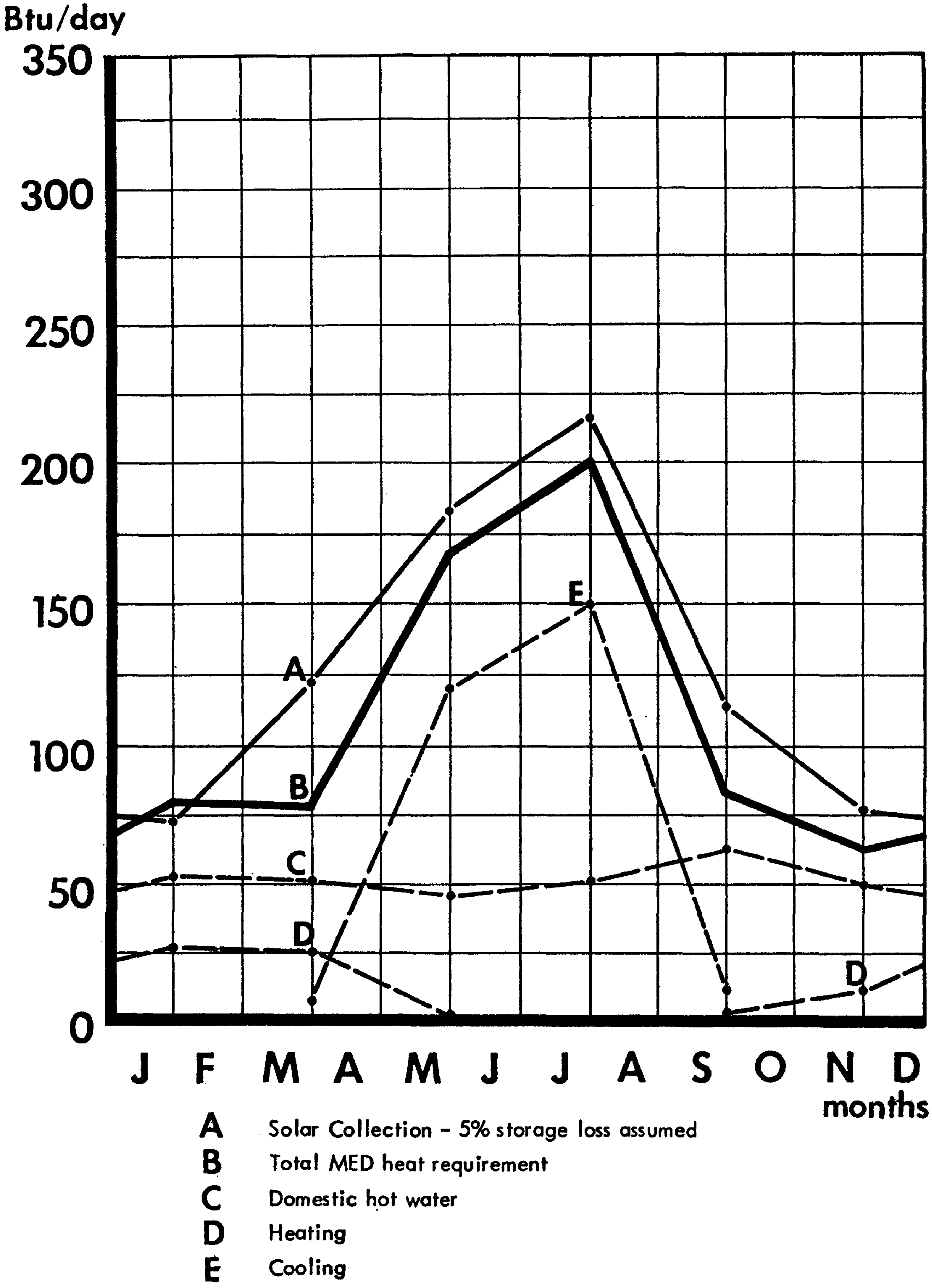

Btu/day
350
300
250
200
150
100
50
0
J F M A M J J A S O N D
months
A
B
C
D
E
D
A Solar Collection - 5% storage loss assumed
B Total MED heat requirement
C Domestic hot water
D Heating
E Cooling

Figure 7.3

APPENDIX 1

MINIMUM ENERGY DWELLING
ATTITUDES OF PERSONS TOURING PROJECT
MARYLANDER MARKETING RESEARCH

A. BRIEF BACKGROUND

The Minimum Energy Dwelling (MED house) is an energy conservation data gathering and demonstration effort sponsored jointly by the Federal Energy Research and Development Administration, Southern California Gas Company, and the Mission Veijo Company.

MED employs available energy-saving building technology and materials, advanced household appliances, and a solar/natural gas system to minimize energy consumption. Its goal is to reduce energy consumption in Southern California by demonstrating to building professionals, the public, and other government agencies, techniques which are available now.

Two single family dwellings have been designed and built for the MED project. Their appearance is consistent with the architecture of Mission Viejo. One of the houses is a demonstration model; the second is occupied.

As part of the demonstration program, groups of building professionals, the general public, and government officials from selected agencies were invited to tour the project. This study was undertaken to measure the attitudes of these visitors after being exposed to the MED project.

B. STUDY OBJECTIVES

The primary purpose of this study was to measure, among Builders/Architects, Government Officials, and the General Population, attitudes toward the MED house and selected conservation features used in the project.

The following specific areas were measured:

...Likes and dislikes concerning the MED house
...New learning which resulted from visit
...Reported impact of MED house on attitudes toward use of conservation features
...Aided recall of specific conservation features included in MED house
...Perceived economic soundness of specific conservation features
...Likelihood of using/specifying/recommending/wanting specific conservation features in a single family dwelling

C. STUDY DESIGN

Following is the methodology employed:

a. The study was conducted with persons who visited the MED house as part of a Gas Company conducted tour.

b. The tours took place over a ten month period. At the conclusion of selected tours, names of participants were chosen for interviewing.

c. Respondents were contacted by telephone between one and three weeks after the tour and interviewed concerning the experience.

Interviewing dates were as follows:

November 30 - December 3, 1976
January 4 - January 7, 1977
February 8 - February 11, 1977
May 13 - May 17, 1977
July 15 - July 18, 1977
July 26 - July 29, 1977
September 5 - September 12, 1977

Interviews were restricted to persons whose place of business (or in the case of the General Population, whose residence) was in Los Angeles or Orange Counties.

d. In total, 215 interviews were completed. Respondent types were as follows:

	Number of Interviews
Builders/Architects	87
Government Officials*	58
General Population	70
Total	215

*Government officials included representatives from the Department of Housing and Urban Development (HUD), the Energy Research & Development Administration (ERDA), and from various city and state Agencies that deal with housing and energy.

D. QUESIONNAIRE AND COMPUTER TABLES

A copy of one of the versions of the questionnaire is included in the Appendix. There were minor word changes for the different categories of respondents.

The computer tables were supplied under separate cover and are referred to by number in the right margin of the analysis.

STUDY HIGHLIGHTS 2

Following are the study highlights and conclusions. A summary of findings is contained in Chapter III.

1. Attitudes. There was a particularly high level of both positive and negative comments expressed about the MED house, indicating that visitors saw many things they liked as well as disliked about the project.

Most frequently mentioned likes were:

future conservation ideas/experimental techniques
double pane windows
insulation

There was considerable concern with several aspects of the dwelling:

- too costly
- floor plan smaller than average house
- push buttons for water temperature
- too small/not enough windows

2. Overall Impact. Although those visiting the MED house voiced many concerns, as well as likes about the dwelling, the overall impact was quite positive. Over 80% of those touring the Minimum Energy Dwelling said that they were more likely to use conservation features in the future as a result of their visit.

	Total Sample N=215	Type of Visitor		
		Builders/ Architects N=87	Government Officials N=58	General Population N=70
More likely to use	82%	75%	83%	91%

Most of the visitors (over 75%) reported that something new was learned at the MED house. Most frequently mentioned areas of newly acquired information were:

- solar energy
- refrigerator/heat exchange system
- insulation
- conservation

3. Visitor Type. For purposes of this study, visitors were categorized into three groups:

- Builders/Architects
- Government Officials
- General Population

As might be expected, Builders/Architects were generally more knowledgeable, more cautious, and more concerned with costs than were others. The General Public was least knowledgeable and less concerned about costs.

Although there were these and other differences in response patterns between the groups, of particular importance were the similarities. For the most part, the three groups liked and disliked the same things. The MED house had a meaningful impact on all three types of visitors. It would appear that this type of demonstration project communicates the same types of information to people of varying levels of sohpistication and involvement with construction.

4. Recall of Conservation Features. On an aided basis, most of the conservation features contained in the MED house were recalled by most respondents. Of 13 features measured, the average visitor recalled almost 12. Only one feature was remembered by fewer than 80% of the sample.

5. Attitudes Toward Specific Features. For each conservation feature recalled from the MED house, respondents were asked whether they felt that the potential savings in energy would justify the cost and whether they would be more likely to use that feature in future homes.

There was a strong correlation between the perceived economic soundness of a feature and the likelihood of using it, suggesting that concern over costs is a primary factor in the use of conservation features.

While several features were seen as economically sound items to include in construction, many were not. Especially concerned about the cost effectiveness of the conservation items were Builders/Architects.

The MED house appears to have had a significant favorable impact on those who visited it. In addition, it effectively communicated its conservation messages to people of varying levels of sophistication.

The primary opportunity for strengthening the demonstration program is to more effectively communicate the practicality and cost efficiency of the conservation features for current construction of single family dwellings.

General Population. Total favorable mentions by those who comprised the General Population segment were at levels somewhere between the other two visitor groups.

A very high proportion of the visitors volunteered one or more negative comments about the MED houses -- over 80%, compared to our norm of 50%.

One guideline which we employ in the evaluation of negative responses is that those ideas mentioned by 10% or more of the sample are at sufficiently high levels to warrant some concern. Using this "rule of thumb", respondents were quite concerned with: costs; the small size of the dwelling; push buttons for water temperature; the bulkiness of the solar panels; and the smallness of the windows.

Builders/Architects. These building professionals were very concerned with the cost of such a dwelling. Almost four out of ten felt that the MED house was too costly to build.

Government Officials. Government Officials voiced approximately the same number of concerns as did Builders/Architects.

General Population. The public voiced the fewest negatives (although the number mentioned was still considerably above the norm). The people in this group were less concerned about costs than were those in the other two visitor segments. They were somewhat more concerned about the use of push buttons for water temperature.

LIKES ABOUT THE MED HOUSE

	Total Sample N=215	Builders/ Architects N=87	Government Officials N=58	General Population N=70
Mentioned one or more likes-net	96%	93%	98%	97%
Future conservation ideas/ experimental techniques	31	31	34	27
Double pane windows	27	20	33	31
Insulation - net	27	22	28	31
Better insulated (unspecified)	19	17	14	24
Use of 2x6 studs to hold more insulation	5	3	7	4
12" of insulation in attic	4	1	9	4
Use of refrigeration/heating exchange system	23	20	29	21
Use of solar water heating system	20	15	21	26
Design of home/appearance	19	21	22	13
Steel insulated doors	13	6	24	14
Tightness of construction	13	9	16	14
Good idea/step in right direction	9	10	14	4
Large overhang on house	8	5	16	7
Extra care in weatherstripping	7	8	9	3
Push button water temperature system	6	5	9	4
System removes hot air/brings in cool air from outside	5	1	2	11
All other likes	19	18	19	21
Mean Number of likes mentioned	2.3	1.9	2.8	2.3

DISLIKES ABOUT THE MED HOUSE

	Total Sample N=215	Builders/ Architects N=87	Government Officials N=58	General Population N=70
Mentioned one or more dislikes - Net	81%	85%	83%	74%
Too costly now	27	38	24	14
Floor plan smaller than average house	22	18	29	20
Push button for water temperature may be a problem	20	13	21	27
Bulkiness of solar panels/ storage tank	17	20	21	11
Not enough windows/windows too small	13	17	7	11
Solar energy system not perfected	8	10	5	9
Architectural design of home/ appearance	7	9	5	6
Poor ventilation with refrigeration/heat exchange system	6	6	5	6
Some ideas not feasible at this time	5	8	3	1
All other dislikes	21	14	36	17
Mean Number of dislikes mentioned	1.5	1.5	1.6	1.2

B. EFFECT ON USE OF CONSERVATION FEATURES IN THE FUTURE

Although visitors voiced many negatives, as well as positives, about the Minimum Energy Dwelling (see preceding section), the overall impact appears to have been positive. Over 80% of the visitors indicated that they were more likely to include/specify/recommend/want conservation features in the future as a result of their visit.*

*Question wording differed by respondent group:

Group	Key Wording of Question
Builders	How likely to include conservation features in future construction projects
Architects	How likely to specify conservation features in future construction projects
Government Officials	How likely to recommend conservation features in construction projects
General Population	How likely to want conservation features included in any new home you buy

It is, of course, possible that this very favorable response is somewhat inflated as a result of the nature of the questioning process and the presumed knowledge by respondents that the survey is being conducted for the sponsors of the MED house. In our opinion, even after reasonable adjustments for possible response inflation, the share of respondents favorably influenced by exposure to the MED house indicates that the experience had a positive impact on the visitors.

Responses of the three groups cannot be directly compared because question wording varied somewhat from group to group. It might be noted, however, that favorable response levels are high among all three segments.

LIKELIHOOD OF USING CONSERVATION FEATURES
AS A RESULT OF VISIT TO MED HOUSE*

	Total Sample N=215	Builders/ Architects N=87	Government Officials N=58	General Population N=70
Yes, more likely to recommend/ want	82%	75%	83%	91%
No, not more likely to recommend/ want	16	22	17	7
Don't know	2	3	--	1
	100%	100%	100%	100%

*Question wording varied slightly by respondent type

Note: Due to rounding, figures may not always add exactly to 100%

C. NEW LEARNING

Consistent with the greater interest in using conservation features which was generated by the visit to the MED house, over three-quarters of the sample indicated that something new was learned as a result of the visit.

The share of General Population visitors reporting new learning was higher than for the other two segments; however, the share was high among the other two as well.

Frequently reported as ideas learned during the visit were:

solar energy
refrigerator/heat exchange system
insulation
conservation

There were considerable similarities in response patterns among the three respondent groups. The major differences were in the higher levels of new learning reported by the General Population in solar energy and insulation.

NEW LEARNING AS A RESULT OF VISITING THE MED HOUSE

	Total Sample N=215	Builders/ Architects N=87	Government Officials N=58	General Poplation N=70
Yes, learned something new	77%	72%	72%	87%
More about use of solar energy homes	29	24	28	37
Use of refrigerator heat exchange system	22	17	26	26
Insulation-Net	18	11	10	31
Insulation ideas	13	6	7	26
Use of 2x6 studs to hold more insulation	5	6	3	6
Conservation of energy/ ideas	11	10	10	11
Double pane windows with louvers	9	6	14	10
Tight construction saves heat and energy	9	8	9	10
Use of push button water system	9	7	10	10
Steel enforced foam filled doors	8	6	9	10
System removed hot air/ brings cool air from outside	6	5	5	9
All others	18	9	16	17
No, did not learn anything new	23	28	28	13
	100%	100%	100%	100%

D. RECALL OF SPECIFIC FEATURES

On an aided basis, the average visitor to the MED house recalled almost 12 of of the 13 features mentioned to him. Ten of the items were recalled by 90% or more of the respondents; only one was recalled by fewer than 80%.

Builders/Architects tended to recall more features than did others; however, recall was so high among Government Officials and the General Population that, in most cases, Builders/Architects could only exceed those levels by a small amount before reaching close to 100%.

The "mastic sealer between the sill plate and the concrete slab" was the feature with the lowest level of recall. While most Builders/Architects remembered it, only about a third of the General Population did.

AIDED RECALL OF FEATURES IN THE MED HOUSE

	Total Sample N=215	Builders/ Architects N=87	Government Officials N=58	General Population N=70
Solar energy system	100%	100%	100%	100%
Double pane windows	90	100	97	100
Pilotless gas range	98	99	95	99
Steel insulated front door with magnetic weatherstripping	97	97	97	99
Refrigerator heat exchange system, which channels heat from refrigerator compressor outside in summer and inside in winter	97	98	95	99
Extra thick exterior walls with more insulation	95	100	90	94
Vertical wings to shade windows	93	94	91	93
Night setback heating thermostat	92	97	88	90
Economizer or enthalpy system which removes hot air and brings in cool outside air when necessary*	92	91	90	94
Plastic membrane beneath stucco for barrier against infiltration	90	89	93	89
Extra thick attic insulation	87	84	88	91
Insulation of slab and footings	81	89	64	87
Mastic sealer between sill plate and concrete slab*	65	84	74	34
Mean number of features recalled	11.9	12.2	11.6	11.7

*Simplified wording used on General Population questionnaire

E. PERCEIVED COST JUSTIFICATION OF SPECIFIC FEATURES

It might be recalled that cost practicality was one of the most frequently expressed negatives concerning the MED project; in particular, it was the dominant concern among Builders/Architects (see Section A).

For each of the 13 previously discussed features of the MED house of which they were aware, respondents were asked their opinions as to whether the potential energy savings would justify the cost.

In the case of all of the features except two -- the solar energy system and the insulation of slab and footings -- at least half of the MED visitors felt that the energy savings justified the cost. The most favorably rated features (in terms of cost justification) tended to be those which already existed rather than those which were completely new to the visitors.

In general, among those who did not consider a feature to be cost efficient, responses were divided between those who felt the feature would not justify its cost and those who were not sure.

This high level of "don't know" response indicate that relatively few people have definitely made up their minds that these features are economically unsound.

PERCEPTION OF WHETHER ENERGY SAVINGS JUSTIFIES COST OF SELECTED FEATURES

	Among Those Aware of Features
Extra thick attic insulation	N = 188
Cost justified	85%
Cost not justified	5
Don't know	10
	100%
Pilotless gas range	N = 210
Cost justified	82%
Cost not justified	5
Don't know	12
	100%
Night Setback Thermostat	N = 198
Cost justified	76%
Cost not justified	11
Don't know	13
	100%
Mastic sealer between sill plate and Concrete slab	N = 140
Cost justified	74%
Cost not justified	9
Don't know	16
	100%
Extra thick exterior walls with more insulation	N = 205
Cost justified	67%
Cost not justified	12
Don't know	20
	100%
Plastic membrane beneath stucco for barrier against infiltration	N = 193
Cost justified	67%
Cost not justified	8
Don't know	25
	100%

Vertical wings to shade windows	N = 123
Cost justified	62%
Cost not justified	17
Don't know	22
	100%

Double pane windows	N = 123
Cost justified	62%
Cost not justified	20
Don't know	18
	100%

Economizer or enthalpy system which removes hot air and brings in cool outside air when necessary	N = 197
Cost justified	62%
Cost not justified	9
Don't know	29
	100%

Steel insulated front door with magnetic weatherstripping	N = 209
Cost justified	57%
Cost not justified	18
Don't know	24
	100%

Refrigerator heat exchange system, which channels heat from refrigerator compressor outside in summer and inside in winter	N = 209
Cost justified	53%
Cost not justified	19
Don't know	28
	100%

Insulation of slab and footings	N = 175
Cost justified	40%
Cost not justified	22
Don't know	38
	100%

Solar Energy System	N = 215
Cost justified	26%
Cost not justified	39
Don't know	35
	100%

A discussion of attitudes toward cost by type of visitor is contained in the following section. However, as has been the case with most of the measures in this study, the building professionals were much more sensitive to and critical in their evaluation of the economic soundness of the various conservation features.

F. INTEREST IN INSTALLING

Those aware of each feature were asked how likely they would be to use/specify recommend/or want* that feature in a new home. There was a strong relationship between likelihood of use and perceived cost efficiency (discussed in preceding section). It appears that economic soundness may be the key determinant of whether or not a particular conservation feature is used.

LIKELIHOOD OF USING SPECIFIC FEATURES*

	Among Those Aware of Feature
Extra thick attic insulation	N = 168
Very likely to use	85%
Not very likely to use	7
Not sure	8
	100%
Pilotless gas range	N = 210
Very likely to use	83%
Not very likely to use	8
Not sure	9
	100%
Night setback heating thermostat	N = 198
Very likely to use	77%
Not very likely to use	11
Not sure	12
	100%
Mastic sealer between sill plate and concrete slab	N = 140
Very likely to use	76%
Not very likely to use	9
Not sure	15
	100%
Economizer or enthalpy system which removes hot air and brings in cool outside air when necessary	N = 197
Very likely to use	71%
Not very likely to use	11
Not sure	18
	100%
Extra thick exterior walls with more insulation	N = 205
Very likely to use	66%
Not very likely to use	16
Not sure	18
	100%
Double pane windows	N = 213
Very likely to use	63%
Not very likely to use	22
Not sure	15
	100%

	Among Those Aware of Feature
Plastic membrane beneath stucco for barrier against infiltration	N = 193
Very likely to use	62%
Not very likely to use	13
Not sure	25
	100%
Steel insulated front door with magnetic weatherstripping	N = 209
Very likely to use	62%
Not very likely to use	23
Not sure	15
	100%
Refrigerator heat exchange system, which channels heat from refrigerator compressor outside in summer and inside in winter.	N = 209
Very likely to use	57%
Not very likely to use	23
Not sure	20
	100%
Vertical wings to shade windows	N = 123
Very likely to use	56%
Not very likely to use	27
Not sure	18
	100%
Insulation of slab and footings	N = 175
Very likely to use	42%
Not very likely to use	30
Not sure	29
	100%
Solar energy system	N = 215
Very likely to use	33%
Not very likely to use	40
Not sure	27
	100%

*Question wording varied slightly by respondent type

A brief discussion of each feature follows. In the case of likelihood of use, a direct comparison between visitor types cannot, technically, be made since question wording varied slightly by visitor type.

The General Population tended to be generally positive toward the cost efficiency of almost all of the conservation features. Builders/Architects were more discriminating; their responses ranged from strongly favorable to strongly unfavorable. The responses of the Government Officials fell somewhere in the middle of the response patterns of the other two groups.

Extra Thick Attic Insulation. Of all the features, this was seen as the most economically sound and had the highest share of people who would use it. This feature is one with which respondents were probably already quite familiar, although the MED visit may have reinforced its benefits. All three respondent segments viewed this feature as economically sound.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING EXTRA THICK ATTIC INSULATION

	Among Those Who Recalled Feature			
	Total Sample N=188	Builders/ Architects N=73	Government Officials N-51	General Population N=64
Perceived economic soundness				
Cost justified	85%	84%	80%	89%
Cost not justified	5	8	2	5
Don't know	10	8	18	6
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	85%	78%	90%	89%
Not very likely to use	7	11	4	5
Not sure	8	11	6	6
	100%	100%	100%	100%

Pilotless Gas Range. At least 80% of the respondents in each of the three visitor segments perceived this type of appliance as economically sound, and about this same percentage indicated that they would use it. This is another appliance with which most visitors would have been familiar prior to their visit to the MED house.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING PILOTLESS GAS RANGE

	Among Those Aware of Feature			
	Total Sample N-210	Builders/ Architects N=86	Government Officials N=55	General Population N-69
Perceived economic soundness				
Cost justified	82%	81%	80%	86%
Cost not justified	5	8	2	4
Don't know	12	10	18	10
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	83%	79%	87%	84%
Not very likely to use	8	10	4	9
Not sure	9	10	9	7
	100%	100%	100%	100%

Night Setback Heating Thermostat. This conservation device scored well both in terms of economic soundness and as a feature which would be used. It is our understanding that many utilities have attempted to merchandise this item to their customers, and that these attempts have met with limited success. This apparent discrepancy between the responses to this study and what is occurring in the marketplace highlights the fact that those visiting the MED house are probably not "typical" consumers.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING NIGHT SETBACK HEATING THERMOSTAT

	Among Those Aware of Feature			
	Total Sample N=198	Builders/ Architects N=84	Government Officials N=51	General Population N=63
Perceived economic soundness				
Cost justified	76%	81%	73%	73%
Cost not justified	11	10	4	17
Don't know	13	10	24	10
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	77%	76%	78%	78%
Not very likely to use	11	10	10	14
Not sure	12	14	12	8
	100%	100%	100%	100%

Mastic Sealer Between Sill Plate and Concrete Slab. Responses to this feature were positive; but, not surprisingly, there is a fairly high level of "don't know" response among the General Population.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING MASTIC SEALER BETWEEN SILL PLATE AND CONCRETE SLAB

	Among Those Aware of Feature			
	Total Sample N=140	Builders/ Architects N=73	Government Officials N=43	General Population N=24
Perceived economic soundness				
Cost justified	74%	77%	77%	63%
Cost not justified	9	11	5	13
Don't know	16	12	19	25
	100%	100%	100	100%

Likelihood of using	Among Those Aware of Feature			
	Total Sample N=140	Builders/ Architects N=73	Government Officials N=43	General Population N=24
Very likely to use	76%	77%	81%	63%
Not very likely to use	9	11	7	8
Not sure	15	12	12	29
	100%	100%	100%	100%

Note: Due to rounding, figures may not always add exactly to 100%.

Economizer System. The economizer system was seen as economically sound by a larger percent of the General Population than by the other two groups. Government Officials were uncertain as to its cost justification.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING
ECONOMIZER OR ENTHALPY SYSTEM WHICH REMOVES HOT AIR
AND BRINGS IN COOL OUTSIDE AIR WHEN NECESSARY

	Among Those Aware of Feature			
	Total Sample N=197	Builders/ Architects N=79	Government Officials N=52	General Population N=66
Perceived economic soundness				
Cost justified	62%	57%	52%	76%
Cost not justified	9	15	6	5
Don't know	29	28	42	20
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	71%	63%	73%	79%
Not very likely to use	11	15	10	6
Not sure	18	22	17	15
	100%	100%	100%	100%

Note: Due to rounding, figures may not always add exactly to 100%.

Thicker Exterior Walls With More Insulation. Building professionals were much less impressed with the financial soundness of this feature than was the General Population. Government Officials were in between these two groups. In terms of use, the General Population and Government Officials were fairly positive, but Builders/Architects were not.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING EXTRA THICK EXTERIOR WALLS WITH MORE INSULATION

	Among Those Who Recalled Feature			
	Total Sample N=205	Builders/ Architects N=87	Government Officials N=52	General Population N=66
Perceived Economic Soundness				
Cost justified	67%	59%	65%	80%
Cost not justified	12	16	12	8
Don't know	20	25	23	12
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	66%	49%	75%	82%
Not very likely to use	16	26	8	8
Not sure	18	24	17	11
	100%	100%	100%	100%

Note: Due to rounding, figures may not always add exactly to 100%.

Double Pane Windows. As with thicker walls, this feature was judged less favorably by Builders/Architects than by the others on both the cost justification and use measures.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING DOUBLE PANE WINDOWS

	Among Those Aware of Feature			
	Total Sample N=213	Builders/ Architects N=87	Government Officials N=56	General Population N=70
Perceived economic soundness				
Cost justified	62%	45%	68%	79%
Cost not justified	20	33	16	6
Don't know	18	22	16	16
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	63%	46%	75%	74%
Not very likely to use	22	39	18	4
Not sure	15	15	7	21
	100%	100%	100%	100%

Note: Due to rounding, figures may not always add exactly to 100%.

Plastic Membrane Beneath Stucco. Builders/Architects did not see this feature as economically sound or one that they would use. However, the high level of "don't know" response suggests that the minds of these building professionals might be changed with additional information.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING PLASTIC MEMBRANE BENEATH STUCCO FOR BARRIER AGAINST INFILTRATION

	Among Those Aware of Feature			
	Total Sample N=193	Builders/ Architects N=77	Government Officials N=54	General Population N=62
Perceived economic soundness				
Cost justified	67%	48%	83%	76%
Cost not justified	8	14	4	3
Don't know	25	38	13	21
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	62%	42%	78%	73%
Not very likely to use	13	22	9	5
Not sure	25	36	13	23
	100%	100%	100%	100%

Note: Due to rounding, figures may not always add exactly to 100%.

Steel Insulated Front Door. As with many of the features, the General Population is quite positive towards the steel door, but Builder/Architects are more skeptical. Government Officials fall somewhere in between. This pattern was true for both economic soundness and use.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING STEEL INSULATED FRONT DOOR WITH MAGNETIC WEATHER STRIPPING

	Among Those Aware of Feature			
Perceived economic soundness	Total Sample N=209	Builders/ Architects N=84	Government Officials N=56	General Population N=69
Cost justified	57%	42%	55%	78%
Cost not justified	18	23	20	12
Don't know	24	36	25	10
	100%	100%	100%	100%
Likelihood of using				
Very like to use	62%	46%	68%	75%
Not very likely to use	23	31	21	14
Not sure	15	23	11	10
	100%	100%	100%	100%

Insulation of Slab and Footings. This was seen as among the least cost efficient and least likely to be used features of those tested.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING INSULATION OF SLAB AND FOOTINGS

	Among Those Aware of Feature			
	Total Sample N=175	Builders/ Architects N=77	Government Officials N=37	General Population N=61
Perceived economic soundness				
Cost justified	40%	25%	43%	57%
Cost not justified	22	34	16	10
Don't know	38	42	41	33
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	42%	22%	51%	61%
Not very likely to use	30	45	30	10
Not sure	29	32	19	30
	100%	100%	100%	100%

Note: Due to rounding, figures may not always add exactly to 100%.

Solar System. All MED visitor groups, but particularly Builders/Architects, did not see the solar system as one which would justify its cost in terms of energy savings. There was a high level of "don't know" response among all three segments.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING SOLAR ENERGY SYSTEM

	Among Those Aware of Feature			
	Total Sample N=215	Builders/ Architects N=87	Government Officials N=58	General Population N=70
Perceived economic soundness				
Cost justified	26%	13%	28%	41%
Cost not justified	39	54	33	26
Don't know	35	33	40	33
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	33%	18%	41%	43%
Not very likely to use	40	54	36	26
Not sure	27	28	22	31
	100%	100%	100%	100%

Refrigerator Heat Exchange System. Consumers, again, are fairly positive on both measures, but Builders/Architects are not.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING REFRIGERATOR HEAT EXCHANGER SYSTEM, WHICH CHANNELS HEAT FROM REFRIGERATOR COMPRESSOR OUTSIDE IN SUMMER AND INSIDE IN WINTER

	Among Those Aware of Featuer			
	Total Sample N=209	Builders/ Architects N=85	Government Officials N=55	General Population N=69
Perceived economic soundness				
Cost justified	53%	40%	49%	72%
Cost not justified	19	28	20	7
Don't know	28	32	31	20
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	57%	40%	60%	77%
Not very likely to use	23	35	25	6
Not sure	20	25	15	17
	100%	100%	100%	100%

Note: Due to rounding, figures may not always add exactly to 100%.

Vertical Wings to Shade Windows. Interest in this idea by the General Population was moderate. Coupled with the more critical attitudes of Builders/ Architects and Government Officials, this conservation feature scored among the lowest of those measured. The interest in using the vertical wings was lower than its perceived cost efficiency score, suggesting that aesthetic considerations may be a factor.

PERCEIVED ECONOMIC SOUNDNESS AND LIKELIHOOD OF USING VERTICAL WINGS TO SHADE WINDOWS

	Among Those Aware of Feature			
Perceived economic soundness	Total Sample N=200	Builders/ Architects N=82	Government Officials N=53	General Population N=65
Cost justified	62%	57%	58%	69%
Cost not justified	17	23	15	9
Don't know	22	20	26	22
	100%	100%	100%	100%
Likelihood of using				
Very likely to use	56%	52%	57%	60%
Not very likely to use	27	32	23	23
Not sure	18	16	21	17
	100%	100%	100%	100%

G. INITIAL SOURCE OF AWARENESS

Respondents reported a variety of different sources as the way they first learned about the MED house. As would be expected, the sources differed by respondent type.

SOURCE OF AWARENESS OF MED HOUSE

	Total Sample N=215	Builders/ Architects N=87	Government Officials N=58	General Population N=70
Gas Company - Net	24%	38%	22%	7%
Gas company representative/ direct contact Gas Company	19	31	17	6
Letter/invitation from Gas Company	5	7	5	1
Newspaper	18	15	10	29
Environmental Office - HUD	15	1	55	--
Through classes at school	13	5	2	31
Builders/construction trade Net	11	13	7	11
Builders	9	13	2	11
Construction trade	1	--	5	--
Southern California Edison	8	17	--	4
We live near it/watched it being built	3	1	--	7
All others	8	9	3	10
Don't know	1	2	--	--
	100%	100%	100%	100%

APPENDIX

Marylander Marketing Research, Inc.
Study #001-023
July, 1977

Visitor Type:

Builder

Government
Official

MED VISITORS STUDY

NAME ________________________ TIME STARTED ____________ AM PM

TITLE ________________________ TIME ENDED ____________ M PM

BUSINESS FIRM ________________________ TELEPHONE ____________

INTERVIEWER ________________________ DATE ____________

VALIDATED BY ________________________ DATE ____________

(TO RESPONDENT ON MED VISITOR'S LIST) Hello, my name is ____________ from MMR an independent opinion firm. We're interviewing people who have visited the Gas Company's MED house -- that is the Minimum Energy Dwelling built by the Gas Company and located in Mission Viejo. I would like to ask you a few questions. Yours answers are strictly confidential. (GO DIRECTLY TO Q.1)

1. I will call the house you visited the "MED" house. This is an abbreviation for "Minimum Energy Dwelling." About how long ago did you visit the MED house?

Less than a week

A week

Over one week less than two

Over two

(TERMINATE)-----------------Never visited

2a. What, if anything did you like about the MED house? (PROBE)

____

____

____

2b. What, if anything, did you dislike about the MED house? (PROBE)

____

____

____

3. Would you say that as a result of your visit to the MED house you are more likely to recommend conservation features in construction projects or not?

Yes

No

4a. Would you say that you learned anything new as a result of your visit to the MED house or not?

Yes

(SKIP TO Q.5) No

4b. In particular, what did you learn?

____

____

5. I am going to read a list of some of the conservation features in the MED house. For each one, please tell me whether or not you recall that feature in the MED house. (READ FEATURES ONE AT A TIME) (RECORD BELOW)

FOR EACH RECALLED IN Q.5 ASK Q.6 and 7 BEFORE GOING ON TO THE NEXT FEATURE

6. As someone familiar with construction, would you say that the energy saving to the homeowner justifies the cost of (FEATURE)? (RECORD BELOW)

7. How likely are you to recommend (FEATURE) in new housing construction, would you say you: <u>are</u> very likely; are <u>not</u> very likely, or are not sure?

	Q.5 Recall		Q.6 Cost			Q.7 Likely		
	Yes	No	Yes	No	DK	Very	Not Very	Not Sure
Extra thick exterior walls with more insulation	18-1	N	20-1	2	Y	33-1	2	3
Extra thick attic insulation	2	N	21-1	2	Y	34-1	2	3
Insulation of slab and footings.	3	N	22-1	2	Y	35-1	2	3
Plastic membrane beneath stucco for barrier against infiltration	4	N	23-1	2	Y	36-1	2	3
Vertical wings to shade windows	5	N	24-1	2	Y	37-1	2	3
Steel insulated front door with magnetic weather-stripping.	6	N	25-1	2	Y	38-1	2	3
Mastic sealer between sill plate and concrete slab	7	N	26-1	2	Y	39-1	2	3
Double pane windows.	8	N	27-1	2	Y	40-1	2	3
Solar energy system.	9	N	28-1	2	Y	41-1	2	3
Pilotless gas range	0	N	29-1	2	Y	42-1	2	3
Night setback heating thermostat	X	N	30-1	2	Y	43-1	2	3
Economizer or enthalpy system which removes hot air and brings in cool air when necessary.	Y	N	31-1	2	Y	44-1	2	3
Refrigerator heat exchange system, which channels heat from refrigerator compressor outside in winter and inside in winter.	19-1	N	32-1	2	Y	45-1	2	3

8. How did you first learn about the MED house?

____

____

____

THANK RESPONDENT. RECORD NAME, ADDRESS, AND PHONE NUMBER ON FIRST PAGE. ALSO RECORD YOUR NAME AND THE TIME ENDED.

APPENDIX II

HONEYWELL
MED EVALUATION

EVALUATION OF A MINIMUM ENERGY DWELLING
AT
MISSION VIEJO, CALIFORNIA

FINAL REPORT

By

J. E. Janssen and R. H. Torborg
HONEYWELL, Energy Resources Center

30 DECEMBER 1977

Under Contract with Southern California Gas Company

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ABSTRACT

A transient heat loss technique is presented which was used to show that the MED structure did achieve its goal of reducing the heat loss 50% from that of a conventional (El Jardin) structure. The passive solar input also was computed from transient measurements and found to be approximately 6,000 BTU per hour on a clear September day.

Infiltration through the MED structure was only 0.26 air changes per hour compared with 1.21 for the El Jardin. However, the ventilation system's damper and duct work in the attic were found to leak quite badly. With the fan operating normally and 100% recirculation, the MED infiltration rate was increased to about 1.7 air changes per hour.

The MED system steady state furnace efficiency was 73% for both hi and lo fire. Thus, a single-stage burner with direct spark ignition would suffice.

Humidity measurements in the wall and ceiling insulation of each MED reveal no serious problem with moisture condensation. The master bedroom wall of the occupied house might experience slight condensation if the temperature remains in the 40° range for an extended period.

SUMMARY

The objectives of this study were to measure the thermal performance of a Minimum Energy Dwelling (MED) to see if it achieved its design goal of requiring 50% less energy for heating and cooling. The long time constant (22.5 hours) for the structure and the normal diurnal temperature swing about the comfort range made steady state measurements of wall conductance impossible. Instead, a transient method was devised that worked quite well. The average thermal resistance, "R" value, for the total structure was measured. Two measurements gave R=16.2 and 18.2° F-ft^2-hr/BTU compared to a value of 16.2 computed by the ASHRAE Handbook method. A comparable (El Jardin) house, built to standard specifications, had R value of 8.5 measured and 7.6 calculated. Thus, the insulation of the MED structure was twice as good as that of a conventional structure.

The transient method was used also to estimate the passive solar input. This was found to be approximately 6,000 BTU per hour on a clear September day.

Special precautions were taken in the MED design to minimize infiltration. It was found that these provisions reduced infiltration from about 1.25 air changes per hour for the standard El Jardin house to 0.25 air changes per hour for the MED. However, leakage in the duct work, air handler and dampers of the MED, all of which were outside the conditioned space, raised the infiltration rate to about 1.7 air changes per hour. Thus, future construction of MED type should locate the ducts within the conditioned space as much as possible. Special precautions should be taken to seal duct work, air handler and furnace against leakage when located outside the conditioned space.

No difference was found in the furnace efficiency on hi or lo fire. Thus, the two-stage burner gave no efficiency advantage. This result could change if the furnace were located within the conditioned space and drew its combustion air from the conditioned space.

The architect specified plastic film on the outside of the studding (under the stucco) to minimize infiltration. Since a vapor barrier was required also on the inside of the studding (under the dry wall), the insulation was located in a sealed cell. Humidity sensors were, therefore, placed in the insulation to check on moisture migration that could lead to condensation in the insulation. The dew point of the air in the insulation did exhibit a seasonal variation. However, the mild climate in Mission Viejo, California prevented any serious condensation problem. A sharp drop in temperature could produce slight condensation for a short period, but this is not believed to be serious. It would be in a colder climate. The standard tar paper in place of the plastic film on the outside of the studding is recommended to reduce this problem.

The methane tracer method was used to calibrate the turbine flowmeters in the ventilation and return air ducts. Air flow across the coil was found to be relatively constant at a value of 1200 cfm.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude for the excellent cooperation from both Southern California Gas Company and Mission Viejo Corporation. The late James Lingwall was very helpful during installation of the thermocouples. Robert Caruthers and Michale Forster gave valuable assistance in working with us during the data-taking period and supplied important measurements with the computerized data logger. Richard Ashworth has been most helpful in making the necessary arrangements.

The project could not have proceeded without the oustanding cooperation of Roy Barnes and James Boulware of Mission Viejo, Inc. Roy not only arranged schedule so that we could install necessary thermocouples dueing construction, but also installed thermocouples under the floor slab when we could not be present. They arranged for us to make comparative measurements in the El Jardin model home, including some work at night which provided a necessary comparison for the MED house. I am also indebted to Roy and his delightful family for several dinners at his home which were evenings to remember.

INTRODUCTION

The Minimum Energy Dwelling (MED) located in Mission Viejo, California is a highly insulated residential structure designed to consume only half the heating and cooling energy of a standard structure. The Honeywell Corporate Research Center entered into a contract with Southern California Gas Company to evaluate the thermal performance of the MED structure.

Twenty-four thermocouples were installed in the walls, ceilings, and floors of each of the two MED Solar Houses during construction. The architect specified plastic sheeting under the stucco to minimize infiltration. Since standard practice also requires a vapor barrier under the dry wall panels on the inside, the insulation in the stud space is in a sealed cell. To answer the question of whether or not this would lead to moisture condensation in the insulation, we installed three humidity sensors in the insulation in each house.

Four sets of data of one week duration were taken. The first during the week of October 25-29, 1976 was under normal air conditioning load. The second set of data taken January 17-21, 1977 was under some heating load. In both cases, loads were very light since the average diurnal temperature was very close to the indoor temperature. A third set of measurements was made during the week of March 14, 1977. The outdoor temperatures were in the 35°-40°F range, which increased the load substantially. Some rain occurred also which helped to reduce the diurnal temperature range. The last set of data, during nominal cooling conditions, was taken the week of September 12, 1977. Four significant results were obtained:

1. The overall thermal resistance of the MED structure is twice that of conventional (El Jardin) construction.

2. Infiltration through the MED structure is less than 1/4 that of the El Jardin. However, the dampers in the ventilation system of the MED leak. This, coupled with apparent leakage through the ducts in the attic, increased the infiltration, when the fan is on recirculation, to 1.5 times that of the El Jardin.

3. No moisture condensation has been detected in the insulation of either MED. Dew points are high enough, however, to produce condensation in a more severe climate. Plastic probably should not be used as a support for the stucco.

4. The passive solar input was estimated and found to be about 6,000 BTU per hour.

STEADY STATE

Wall Conductance

Heat conduction through a composite wall, assuming steady state conditions, is given by:

$$q = U\Delta T = \frac{\Delta T}{R_W} \qquad (1)$$

where:
q = heat flow per unit area
U = overall heat transfer coefficient
ΔT = temperature difference across wall
R_W = $1/U$ = thermal resistance

or:

$$R_W = \frac{\Delta T}{q} \qquad (2)$$

Thus, to measure the thermal resistance, R_W, of a finished wall, it is necessary to measure the temperature difference across the wall and the heat flow through it under steady state conditions.

The thermocouples that were installed in the inside and outside surfaces of the walls and ceiling give the temperature difference across the wall. The inside surface thermocouples were located just under the seam tape in the joints between the plasterboard panels. The outside surface thermocouples were imbedded in the stucco just under the finish coat. Comparative measurements also were made by taping thermocouple junctions to the inside and outside wall surfaces in a few places.

The outputs of the thermocouples installed in the walls were measured with a 24-channel self-balancing potentiometer. All thermocouple leads were brought to a box located in the garage of each house. The location of the thermocouples and their identifying code and terminal numbers are presented in Table 1.

Heat flow was measured with heat flux sensors. These were 1/2 inch in diameter by about 0.050 inch thick disks of material of known thermal conductivity. A differential thermopile with alternate junctions imbedded in opposite sides of the disk senses the temperature difference through the disk. Thus, when the disk is attached to a wall with heat flowing normal to the wall, heat also flows through the disk. This produces a small temperature difference between the two sides of the disk, which causes the thermopile to generate a voltage proportional to the heat flow rate. The output is about 2.5 μv per BTU/hr-ft^2. A manually balanced potentiometer with a light-beam galvonometer was used to measure the output of the heat flow sensors. Use of potentiometers avoided pickup problems with the low-level dc signals.

Wall Moisture

Three humidity sensors were installed between the insulation and vapor barrier next to the plasterboard in each house. Thus, the sensor measured the relative humidity in the insulation at the inside surface. This was converted to dew point of the air in the insulation by also measuring the inside wall surface temperature and with the aid of a psychometric chart. One sensor was located in the kitchen ceiling, one in the north wall of the kitchen and one in the south wall of the master bedroom. A separate calibration curve was determined for each sensor. These are identified as follows:

TABLE 1
THERMOCOUPLE LOCATION

NO.	CODE	LOCATION
1	ROOF	Roof
2	LRFU	Under LR Slab
3	LRCI	LR ceiling unside drywall between rafters
4	1	Under BR slab, 2 ft. from foundation
5	LRI	LR ceiling inside drywall at rafter
6	2	BR slab under slab insulation
7	TNWO	North wall stucco, between studs
8	3	BR foundation insulation
9	TNSO	South wall stucco, between studs
10	4	Under foundation
11	TGWI	Bedroom drywall opposite garage
12	Gar Air	Garage Air
13	BFUS	Master bedroom, under slab
14	TSSO	South wall stucco, on stud
15	TGWO	Garage wall, garage side
16	TNSI	North wall inside, on stud
17	TNWI	North wall inside, between studs
18	HCI	Bedroom ceiling drywall
19	TSWI	South wall inside, between studs
20	AIO	Bedroom ceiling insulation, attic side
21	TSSI	South wall stucco, on stud
22	TEQO	East wall stucco, between studs
23	TSWO	South wall stucco, between studs
24	TEWI	East wall inside, between studs

Display Home (Lot 35):

Sensor No	Location
E6-57	Bedroom wall
E6-56	Kitchen wall
E6-51	Kitchen ceiling

Rented Home (Lot 34):

Sensor No.	Location
E6-45	Bedroom wall
E6-41	Kitchen wall
E6-49	Kitchen ceiling

The humidity sensor depends on ionic conduction. To avoid polarization and capacitance errors, a special ac instrument was used to measure the impedances. A sola transformer was used to standardize the line voltage at 118v. If the sola is not used, the impedance measurements are changed by the ratio of the actual line voltage to the standard 118v. Curves for converting meter reading to impedance are included in the appendix of this report.

Furnace Efficiency

The steady state furnace efficiency was computed from measurements of the flue oxygen concentration and the flue temperature during the burner cycle for both hi and lo fire.

Airflow

The return and ventilation air flow rates were measured by a methane tracer technique. The methane tracer was introduced at a measured flow rate at the outdoor inlet or a return air grill. The concentration was then measured at the air handler just ahead of the mixing damper. The air flow rate was then given by:

$$\dot{V}_a = \frac{\dot{V}_T}{C_T} \qquad (3)$$

$\dot{V}_a$ = air flow rate

$\dot{V}_T$ = tracer flow rate

$\dot{C}_T$ = tracer concentration

These measurements were used to calibrate the turbine flowmeters mounted in these ducts.

TRANSIENT MEASUREMENTS

Infiltration

Infiltration is most easily measured by a transient tracer technique. Methane was the trace gas employed. This is somewhat lighter than air so there is no tendency to be concentrated in low places. Chemically pure methane is non-toxic, odorless, and chemically inert in low concentrations at room temperature. There is a normal background concentration of around 1 PPM in the atmosphere. A nondispersive infrared analyzer with full scale sensitivity of 1000 PPM was employed to measure concentration.

The procedure was to feed a constant and measured flow rate of methane tracer into the inlet of the circulating air fan. The concentration in the return air duct just upstream of the fan was continuously monitored with the IR analyzer. Methane was added to the circulating air at a flow rate of 15.5 ℓ/m for a measured length of time - approximately 10 minutes - until the return air concentration reached about 600 - 700 PPM. This gave a safety factor of 60 - 70 below the lower flammability limit in the room air. The concentration in the supply duct at these flow rates was at last a factor of 10 below the lower flammability limit. Thus, there was no danger of explosion with these dilute concentrations.

After the return air reached the desired concentration of about 600 PPM, the methane tracer flow was stopped and the time rate of decay in concentration was observed. The infiltration flow rate is then given by:

$$V_i = V_h/\tau_i$$

where: V_i = infiltration flow rate (4)

V_h = internal volume of house

τ_i = time constant of decay

The time constant, τ_i of the decay was obtained by plotting on semi-log paper the concentration as a function of time after the methane flow was stopped. The plots appeared as follows:

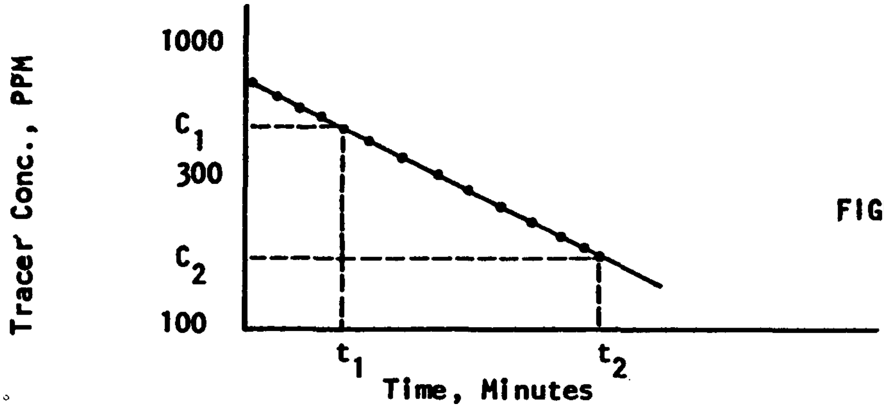


FIGURE 1. LOGARITHMIC TEMPERATURE DECAY

The best straight line was drawn through the points. The time constant then was the slope of the lines, i.e.:

$$\tau = \frac{t_2 - t_1}{\ln \frac{C_1}{C_2}} \qquad (5)$$

The flow rate of methane tracer was held constant during the charging period. This flow rate and the charging time were measured. The concentration of tracer in the return air sometimes departed from the straight line relationship in Figure 1 at the start of the decay period due to incomplete mixing in the room. Mixing was generally complete within 15 minutes, however. The straight line was extrapolated back to zero time to determine the equilibrium concentration of tracer, Co, at the beginning of the decay period. The house volume was then calculated from the relationship.

$$V_h = \frac{\dot{V}_T \, \tau (1-e^{-t/\tau})}{(C_o \times 10^{-6})\ (28.32)} \tag{6}$$

where: $\dot{V}_T$ = tracer flow, ℓ/m

C_o = tracer conc. at start of decay period, PPM

τ = time constant of decay, min.

t = charging time, min.

The house volume measured in this way was compared to the volume calculated from geometrical measurements to determine uniformity of tracer distribution. All closet doors, cupboard doors, and furniture drawers and doors were opened during infiltration tests to reduce dead volume in the house. The volume of the internal walls was calculated and subtracted from the geometrical volume.

Infiltration measurements are usually made with the continuous fan operation. However, this was found to increase infiltration (see Results Section). To avoid this, the fan was operated periodically to obtain samples for the IR analyzer.

Overall Heat Transfer

The overall heat transfer coefficient for the house can be computed from transient measurements also. It was shown in our proposal and in the Appendix of this report that the overall heat transfer coefficient can be computed from:

$$(UA)_h = \frac{Q_h(1-e^{-t/\tau})}{(T-T_o)-(T_r-T_o)e^{-t/\tau}} \tag{7}$$

where: $(UA)_h$ = product of the average wall heat transfer coefficient and the total area through which heat is lost or gained.

Q_h = heat input minus the infiltration loss.

t = time required to change house temperature from T_r to T with a heating or cooling rate Q_h.

τ = thermal time constant of structure

T = return air temp. at time, t.

T_o = outdoor temp.

T_r = return air temperature at start of on period.

Equation (5) can be solved for the time constant,

$$\tau = \frac{t}{\ln\left[\frac{Q_h-(UA)(T_r-T_o)}{Q_h-(UA)(T-T_o)}\right]} \qquad (8)$$

During the heating (or cooling) system off period, $Q_h = 0$ then:

$$= \frac{t}{\ln\left[\frac{T_r-T_o}{T-T_o}\right]} \qquad (9)$$

This transient method for measuring the total building heat transfer coefficient required measurements over a relatively long (2-3 hours) on and off period when the outdoor temperature was stable. This was done at night during the heating season. Night measurements had the advantage of eliminating any confusing solar effect. The thermal time constant, τ, was determined by plotting the natural logarithms of the temperature function $(T_t-T_o)/(T-T_o)$ versus elapsed time. The best straight line was drawn through the data points and equation (9) was used to compute the slope of the line which is the time constant, τ.

The time constant, τ, measured during the off period was then used along with the three temperatures, T, T_o, and T_r, the time interval t, and the heat input Q_h during an on period to evaluate equation (7). Equation (7) assumes the house responds as a first order system. In fact, it requires a fourth order system to adequately describe the transient. The shortest time constant is due to the thermal mass of the air in the house. When the first 40 to 60 minutes of a temperature transient was ignored, the effect of the thermal mass of the air was trivial. The thermal lag of the walls then dominated. The procedure was to look for linearity in the semi-log plot of the temperature transients after about 40 minutes of the transient had passed.

Passive Solar Input

Equation (7) was used also to estimate the passive solar input. The conduction coefficient $(UA)_h$ of the walls was measured during the heating season at night. In the day time, during the cooling season, the product of the conduction coefficient and temperature functions would account for the conduction heat gain. The passive solar gain would be added to this and appear as a heat flow input, Q_h, in equation (7). Thus,

$$Q_s = Q_{h,c} - Q_i \qquad (10)$$

where:

Q_s = solar input rate

$Q_{h,c}$ = apparent heating date during day time cooling season

Q_i = infiltration heat flow

Solving equation (7) for $Q_{h,c}$ and substituting into equation (10) gave:

$$Q_s = \frac{(UA)_h \left[(T-T)-(T_r-T_o)e^{-t/\tau}\right]}{(1-e^{-t/\tau})} - V_i \; C_p(T_o - \frac{(T_r+T)}{2})$$

where: $\dot{V}_i$ = infiltration flow rate in ft^3/hr. (11)

ρ = air density

C_p = specific heat of air

RESULTS AND DISCUSSION

THERMAL RESISTANCE

Twenty-four thermocouples were installed in the walls of the MED houses during construction. The plan was to use these, along with measurements of local heat flow, to determine overall wall conductivity. Figures 2, 3, 4 and 5 show the temperature gradients measured in the north and south walls of the display home. Since only the surface temperatures and heat flow rates could be measured, the internal temperature gradient must be deduced. Lines representing temperature gradients for wall thermal resistances of 15, 20 and 25 ft^2-hr - ^{o}F/BTU are shown. The actual temperature gradients must be tangent to the correct R line at the wall surface. We also knew that on these dates the outdoor temperature in the wall must have been greater than 50^{o}F. The R=20 line seems to fit the boundary conditions quite well, but this conclusion is not very precise. The long time constant of the walls and the diurnal variation of outdoor temperature did not permit the walls to even approach a steady state condition. Data taken in March, Figure 4, was under somewhat more favorable conditions, but even this was not very conclusive. Hence, it appeared the steady state measurements could not supply the results desired.

The transient heat flow measurements were more successful. Table 2 presents results of both infiltration and heat flow measurements using transient techniques. The overall average thermal resistance for the MED and El Jardin houses was calculated using ASHRAE Handbook values for the conductivity of the various components. All of the parallel heat flows were added together and the result was divided by the total heat transfer area to arrive at an average "R" for the structure. These calculations are included in the Appendix.

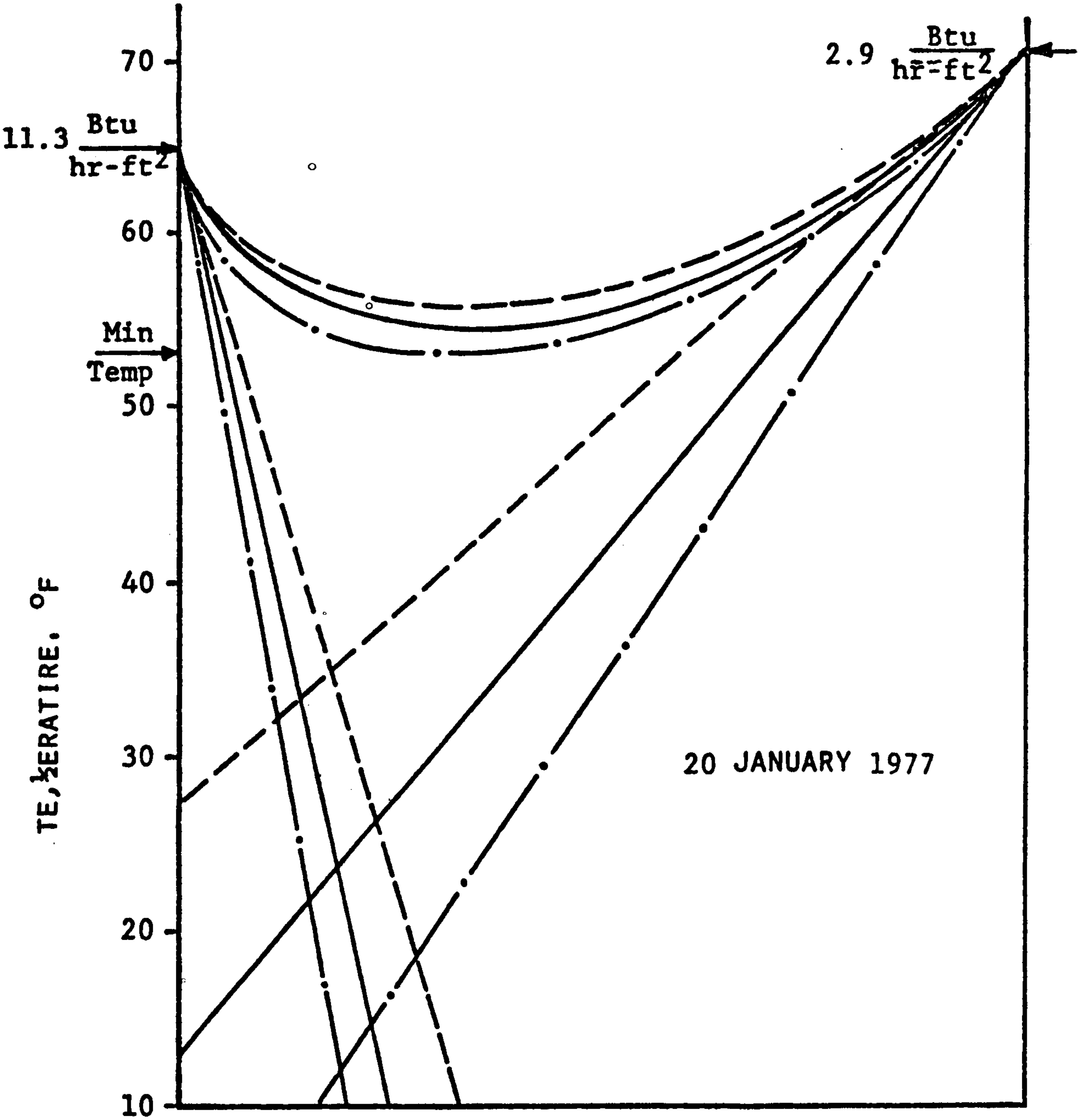


Figure 2. TEMPERATURE IN NORTH WALL OF MED

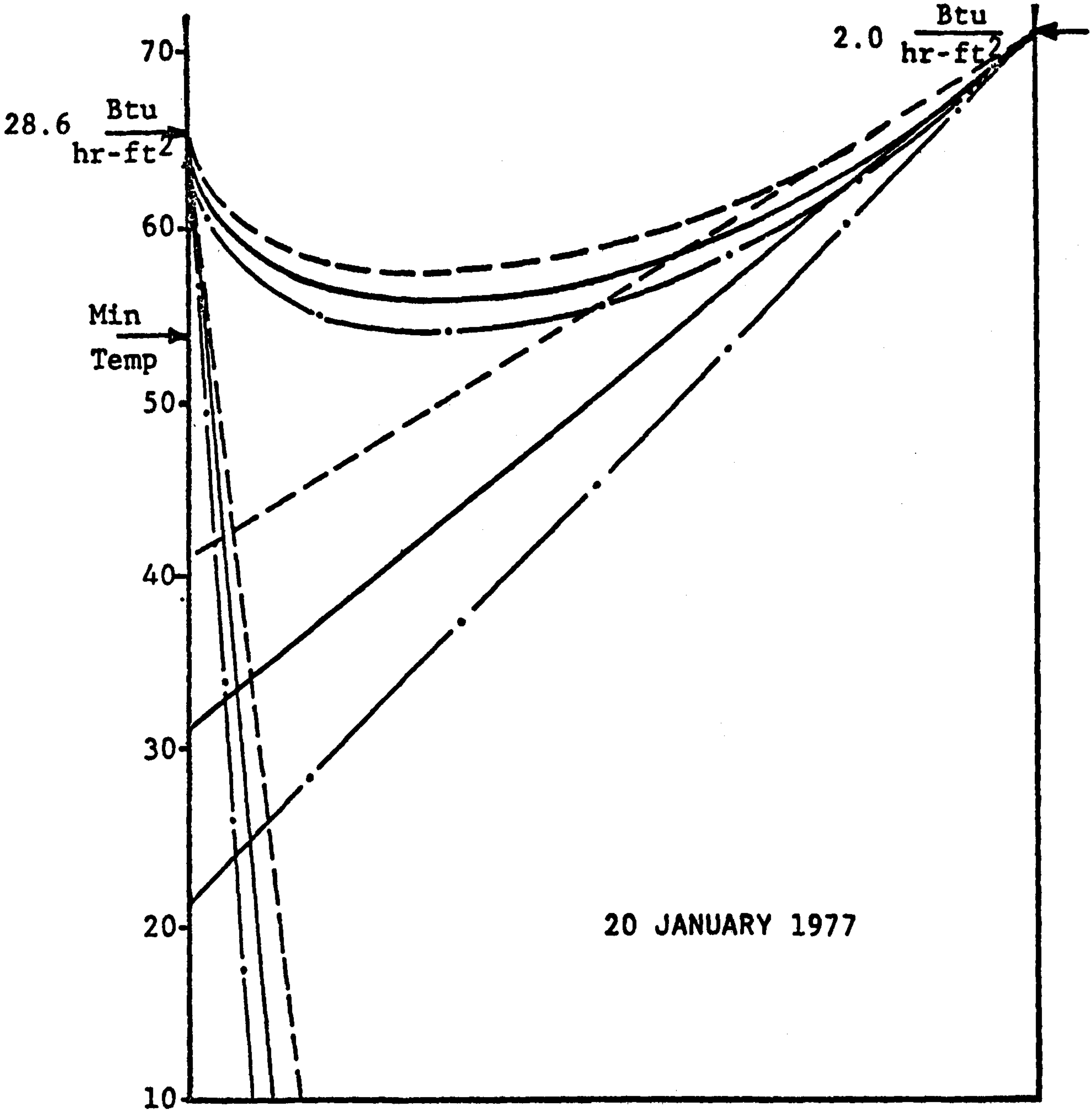


Figure 3. TEMPERATURE IN SOUTH WALL OF MED

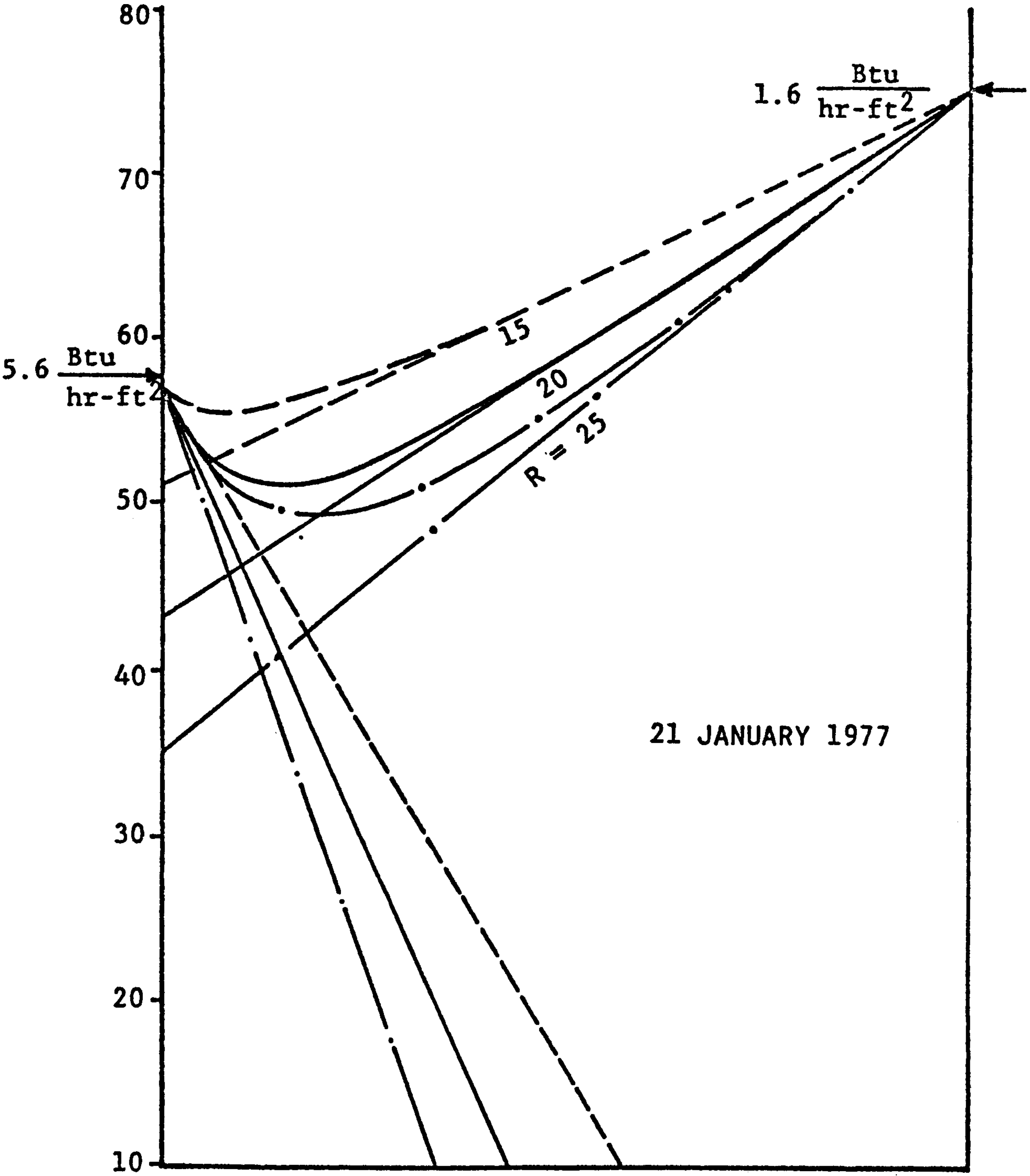


Figure 4. TEMPERATURE IN NORTH WALL OF MED

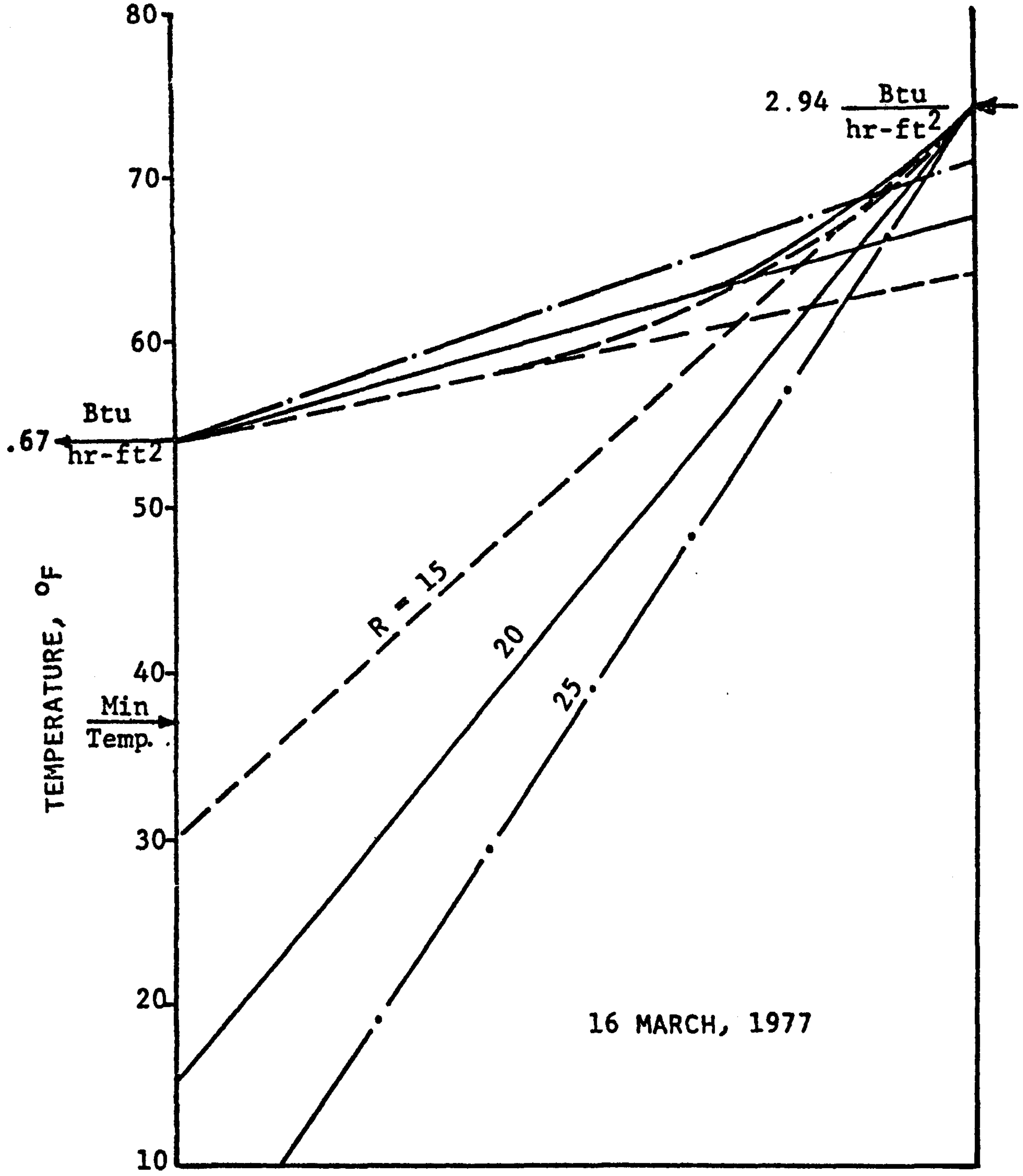


Figure 5. TEMPERATURE IN NORTH WALL OF MED

TABLE 2.

BUILDING THERMAL RESISTANCE (R_h)

NO.	HOUSE	DATE	SENSOR LOC.	SYSTEM	WEATHER			INFIL. LOAD BTU/HR.	HEAT SUPP. BTU/HR.	Q_{net} BTU/HR.	R_h	
					Cond.	Temp.	Wind				Meas.	Calc.
1.	MED I (D)	1-19-77	Return Air	Fan on Recirc.	Clear Night	55-68	5-10	1,642	20,894	19,285	18.2	16.2
2.	MED I (D)	3-17-77	Kitchen	Fan off during cool down	Rain Night	36-44	0-3	5,216	41,603	36,387	16.2	16.2
3.	El Jardin	1-20-77	Kitchen	Fan on	Clear Night	64	3-8	7,992	64,000	53,806	8.5	7.6

It was found that the MED structure did achieve its goal of a thermal resistance twice that of conventional construction. The MED had a calculated R=16.2 compared to R - 7.6 for the El Jardin. The transient measurements confirmed each of these calculations as shown in Table 2. In fact, the measurements indicated a slightly higher R value than the calculated. This was within experimental uncertainty, however.

The temperature transients for the MED are shown in Figures 6-10. Figure 11 shows the logarithm of the temperature function from which the thermal time constant was calculated. Temperature transients for the El Jardin are shown in Figures 12, 13 and 14. The January data produced a good correlation. However, the March data was not as good. There are several reasons for this.

The model used to calculate the time constant assumes the cool down is started from an equilibrium condition. However, in making the March measurements at night, we ran the warmup test first so that the cool down test could proceed during the remainder of the night. We expected that if the first hour of the cool down was ignored, equilibrium would have been established. This seemed to work in the El Jardin test, but not the MED.

Normally, the fan should be running during the cool down test to assure good mixing of the air in the house. However, because of the leakage problems in the MED air handling system, I decided to turn the fan off during the cool down in March, This may have led to some stratification, which would yield a poor average temperature for the inside air.

The cool down test in March was made with the thermocouple measuring kitchen air temperature. This gave good data in the El Jardin, but coupled with lack of circulation, gave poor data in the MED.

In summary, we believe the cool down data taken in January, which gave a thermal time constant of 1350 minutes, is accurate.

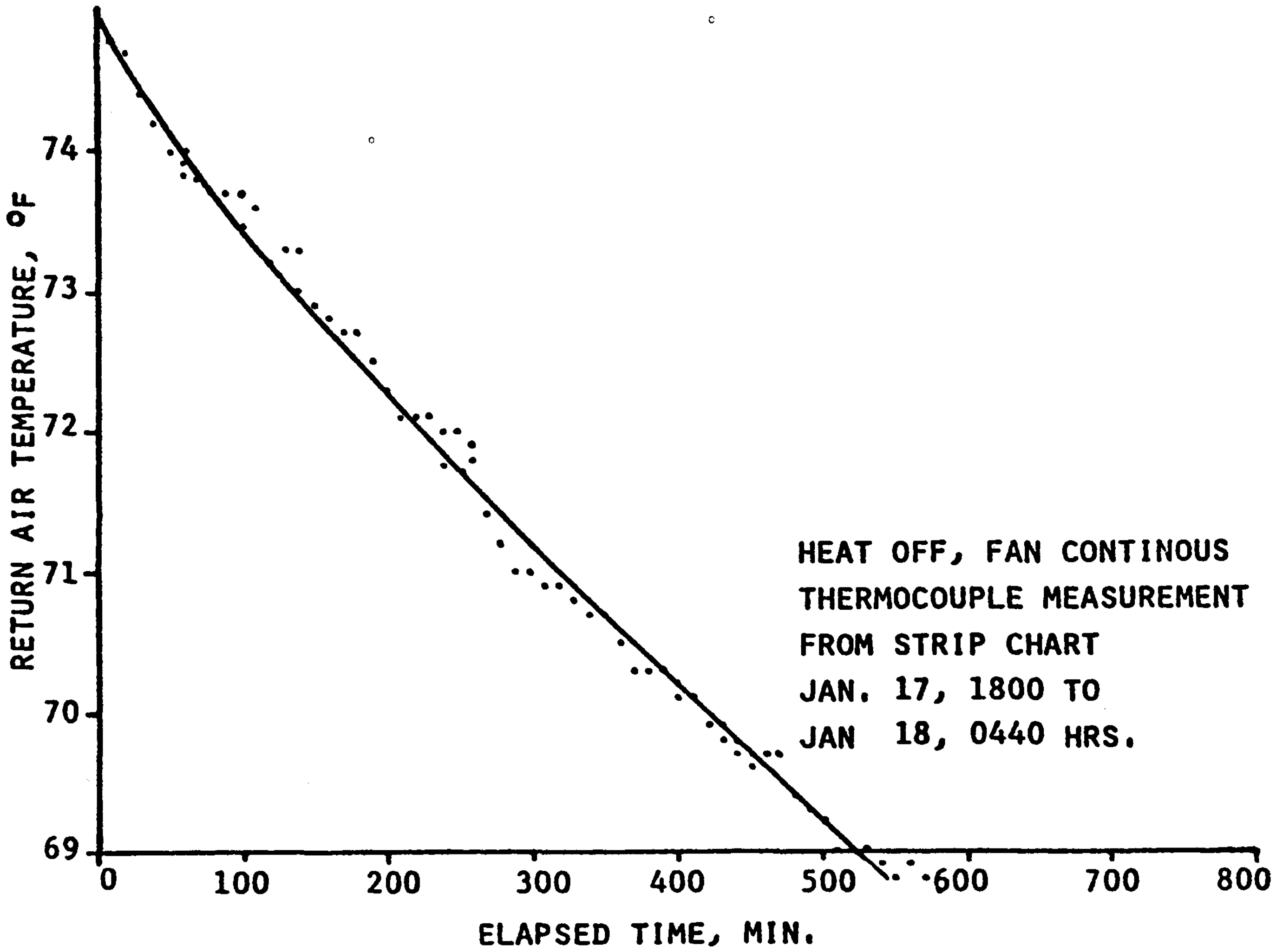


Figure 6. RETURN AIR TEMPERATURE DURING HEAT OFF PERIOD

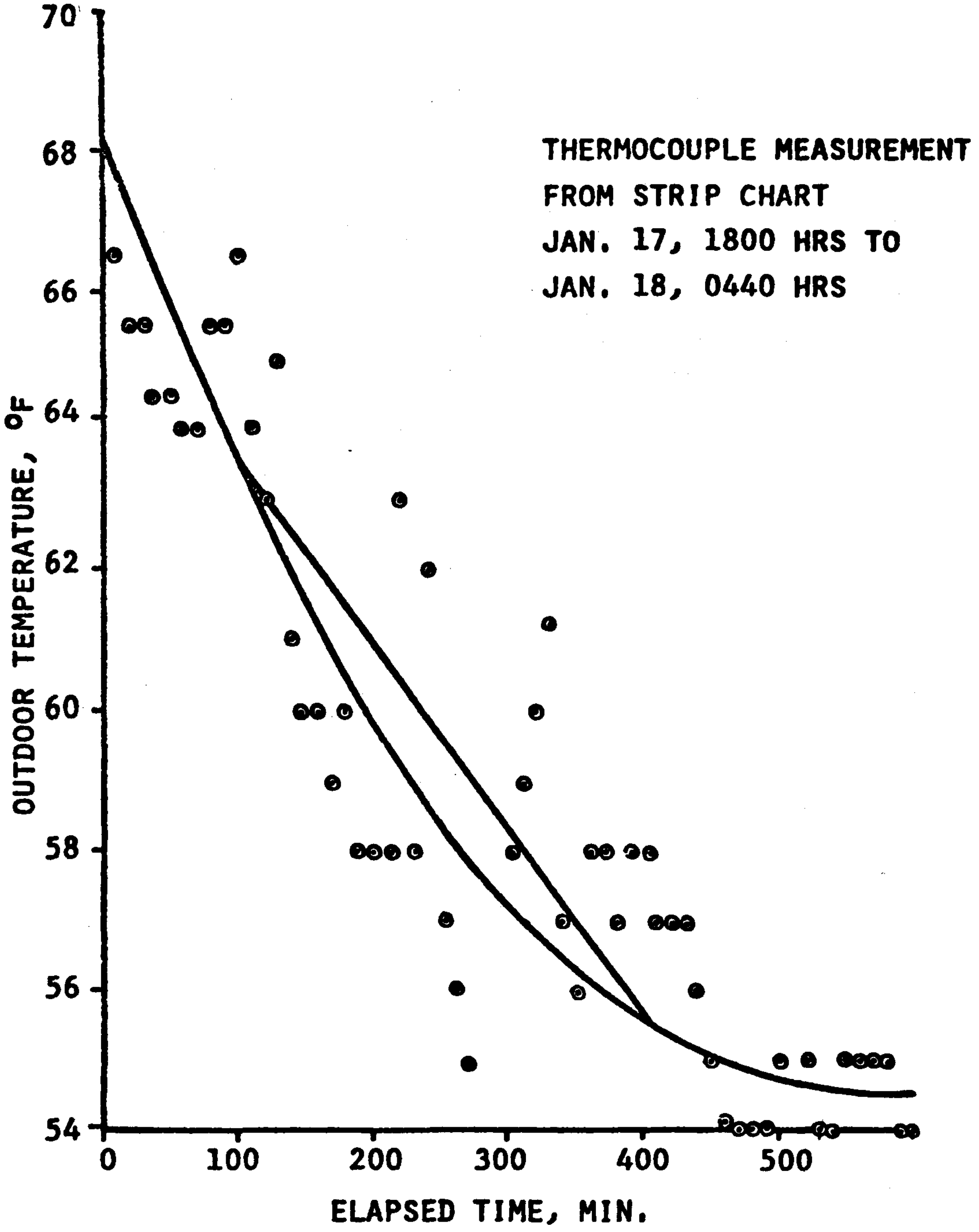


Figure 7. OUTDOOR TEMPERATURE AT GROUND LEVEL

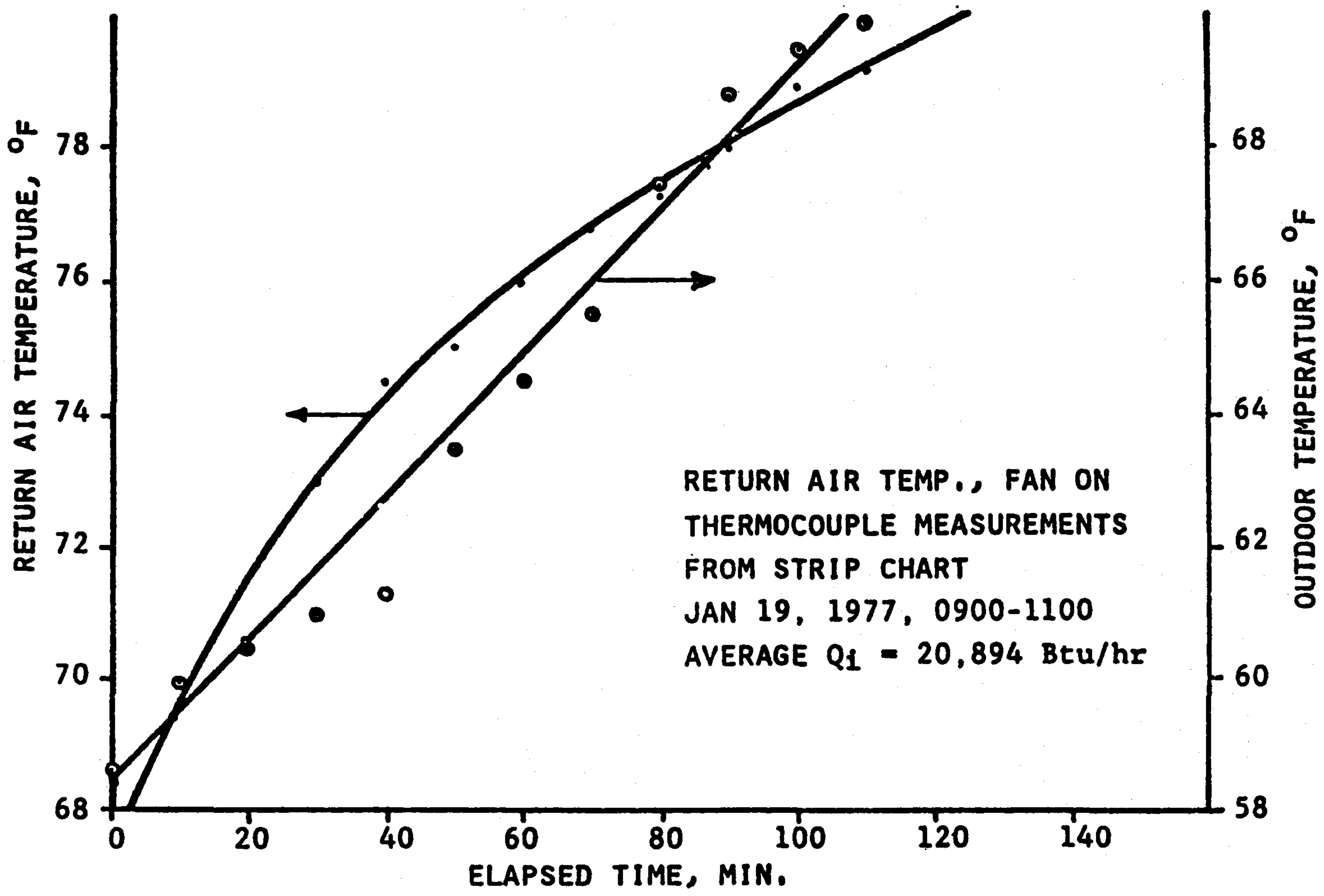


Figure 8. ON PERIOD TEMPERATURE RISE, MED

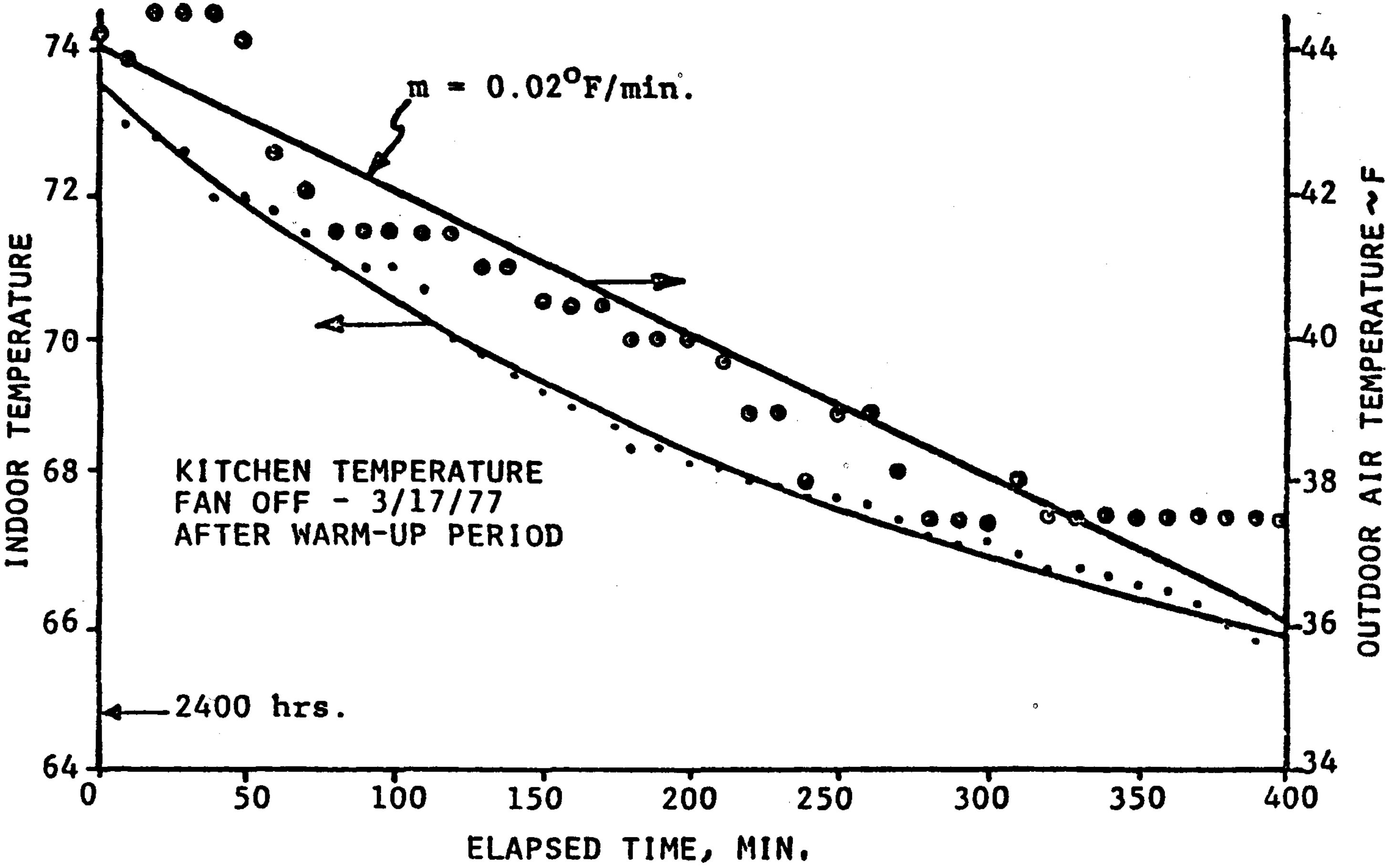


Figure 9. OFF PERIOD TEMPERATURE DECAY, MED I (D)

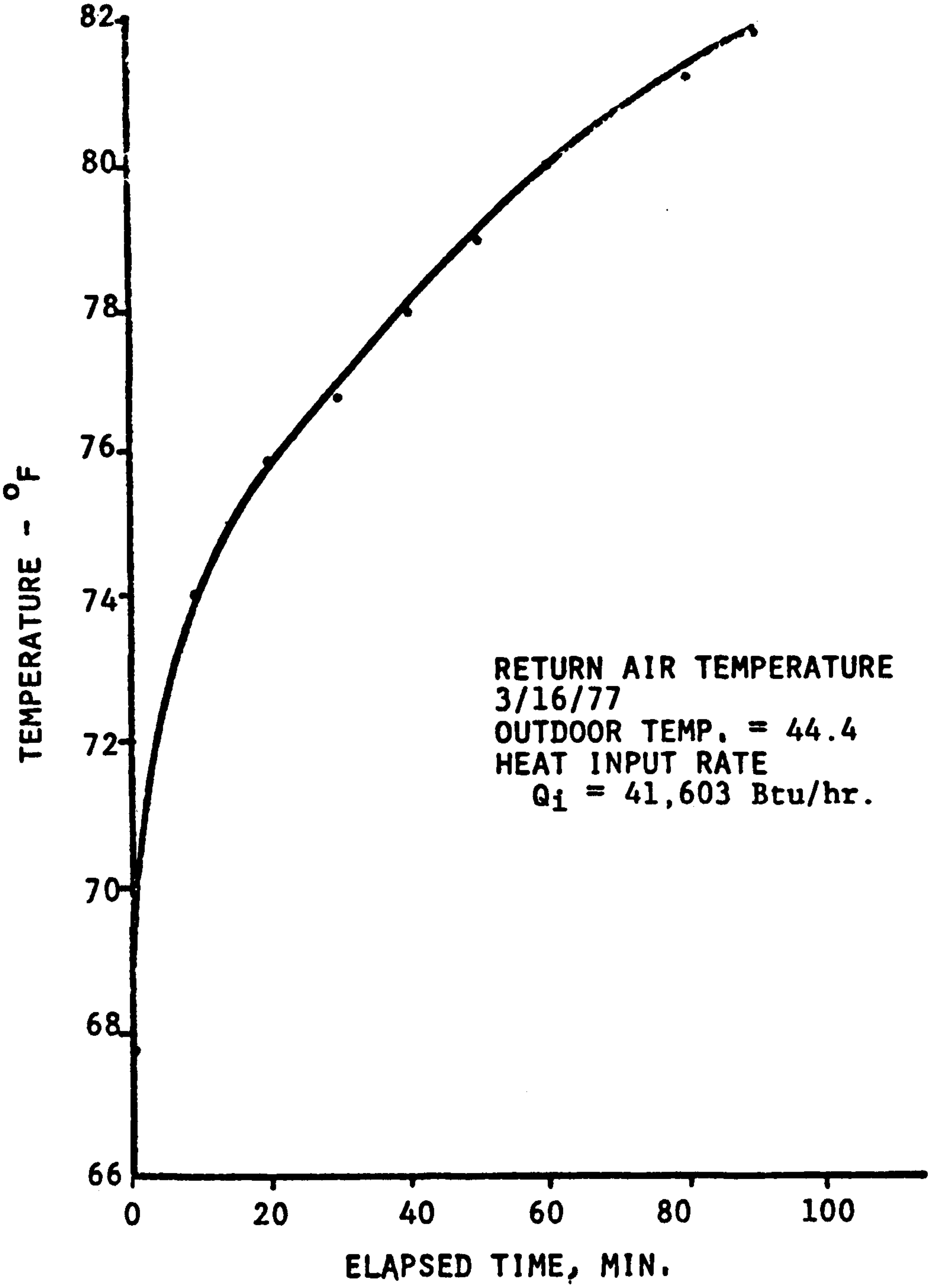


Figure 10. ON PERIOD TEMPERATURE RISE, MED (D)

Figure 11. RETURN AIR TEMPERATURE FUNCTION, MED

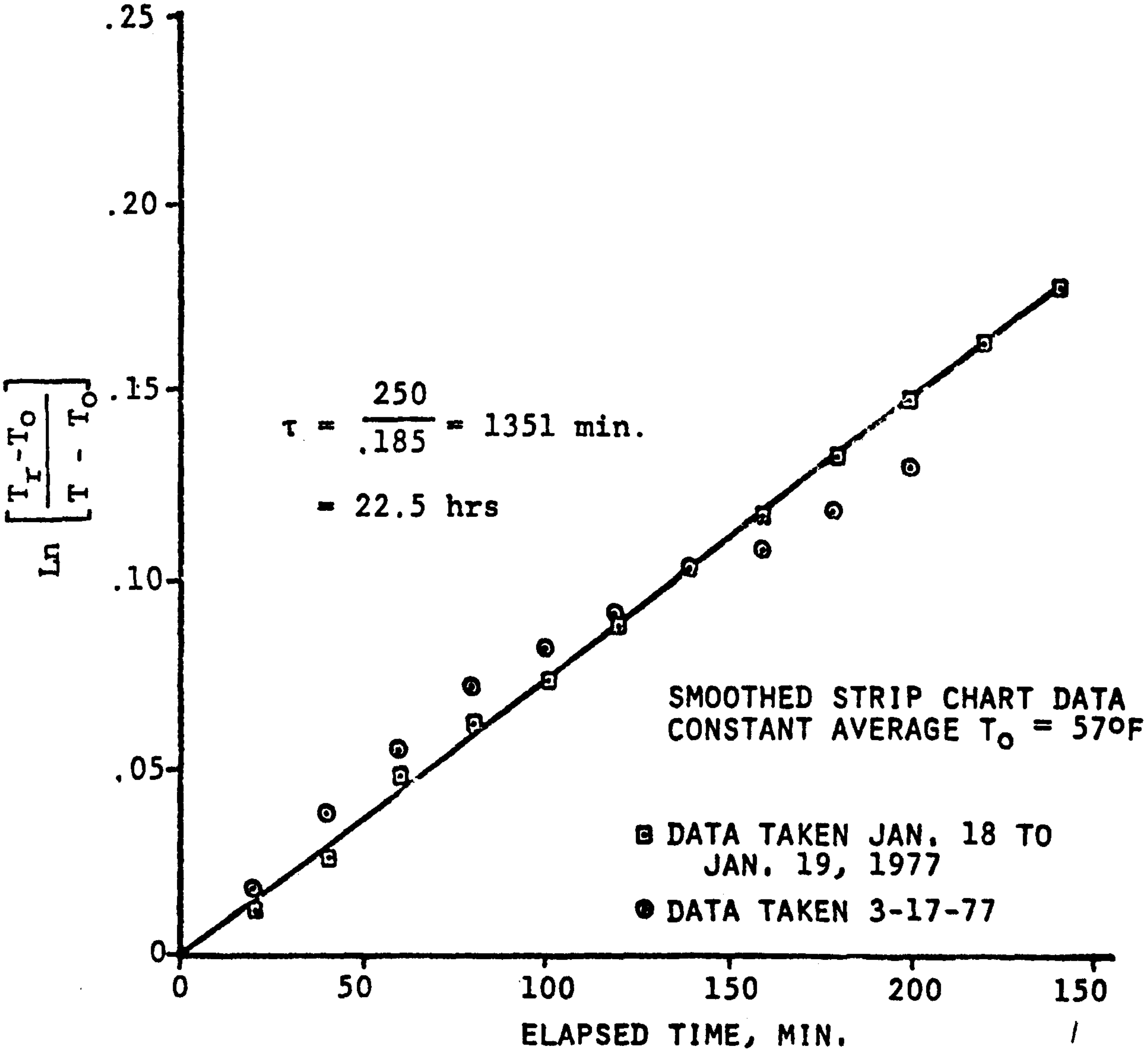
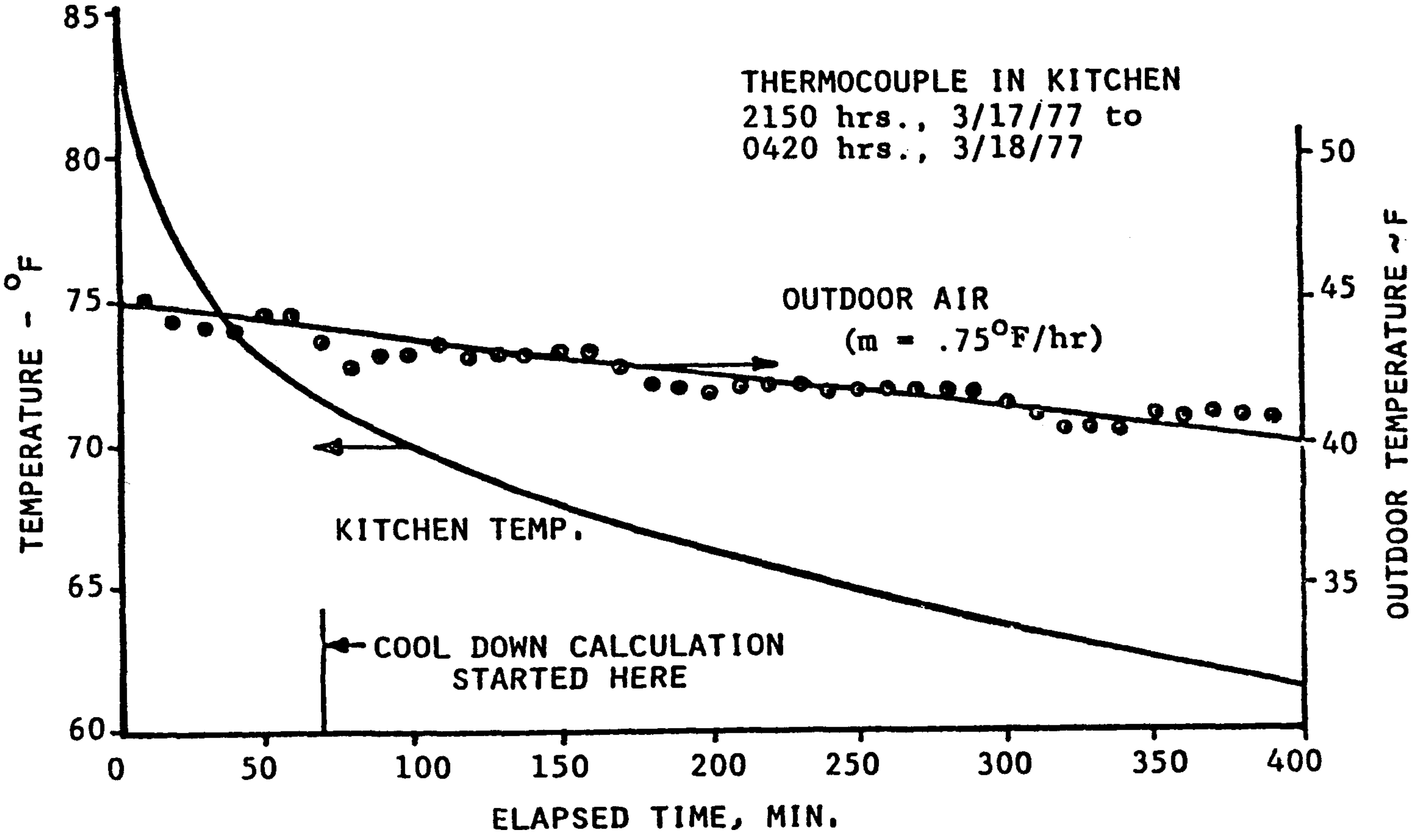


Figure 12. TEMPERATURE DECAY, HEAT OFF, El JARDIN



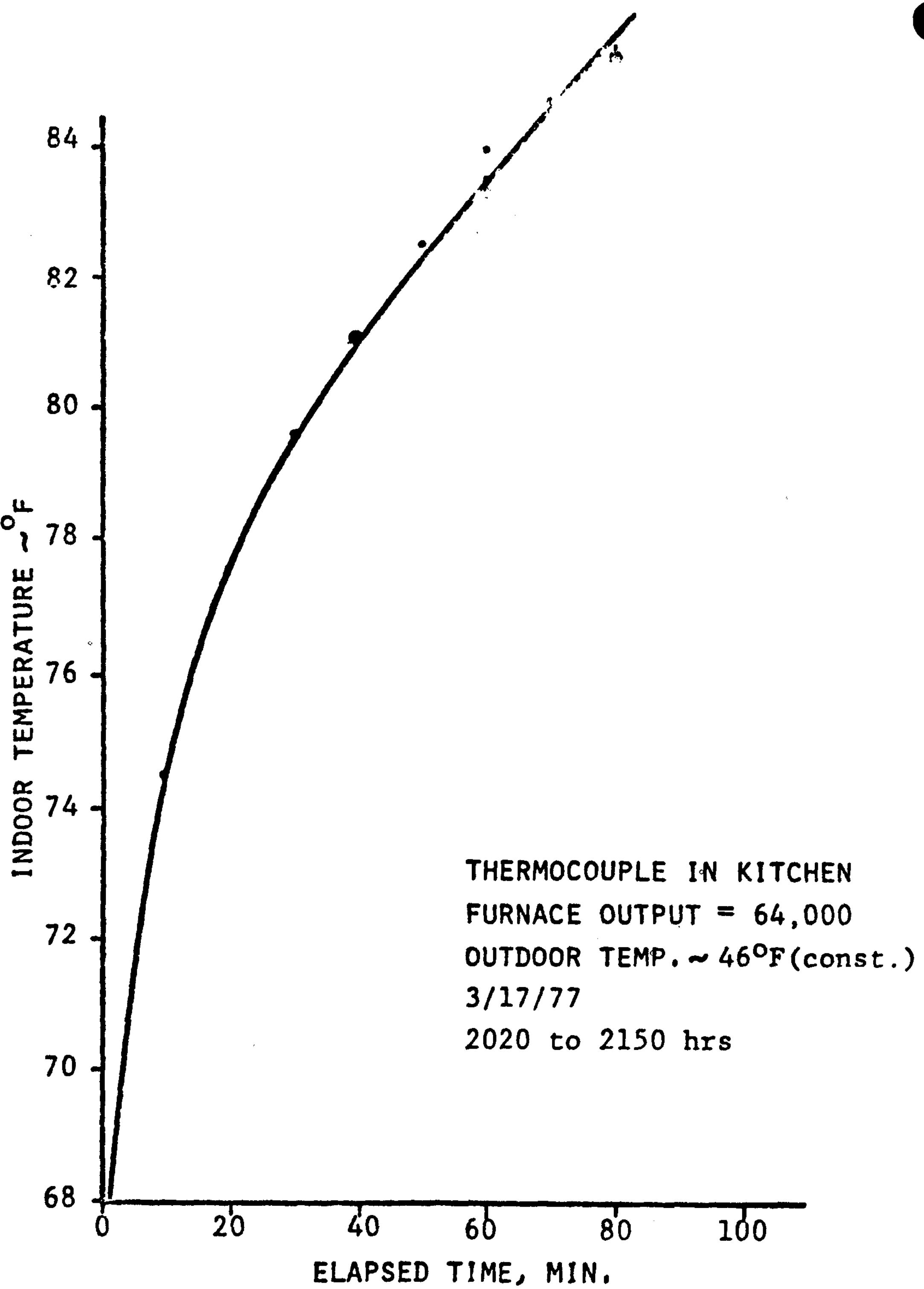
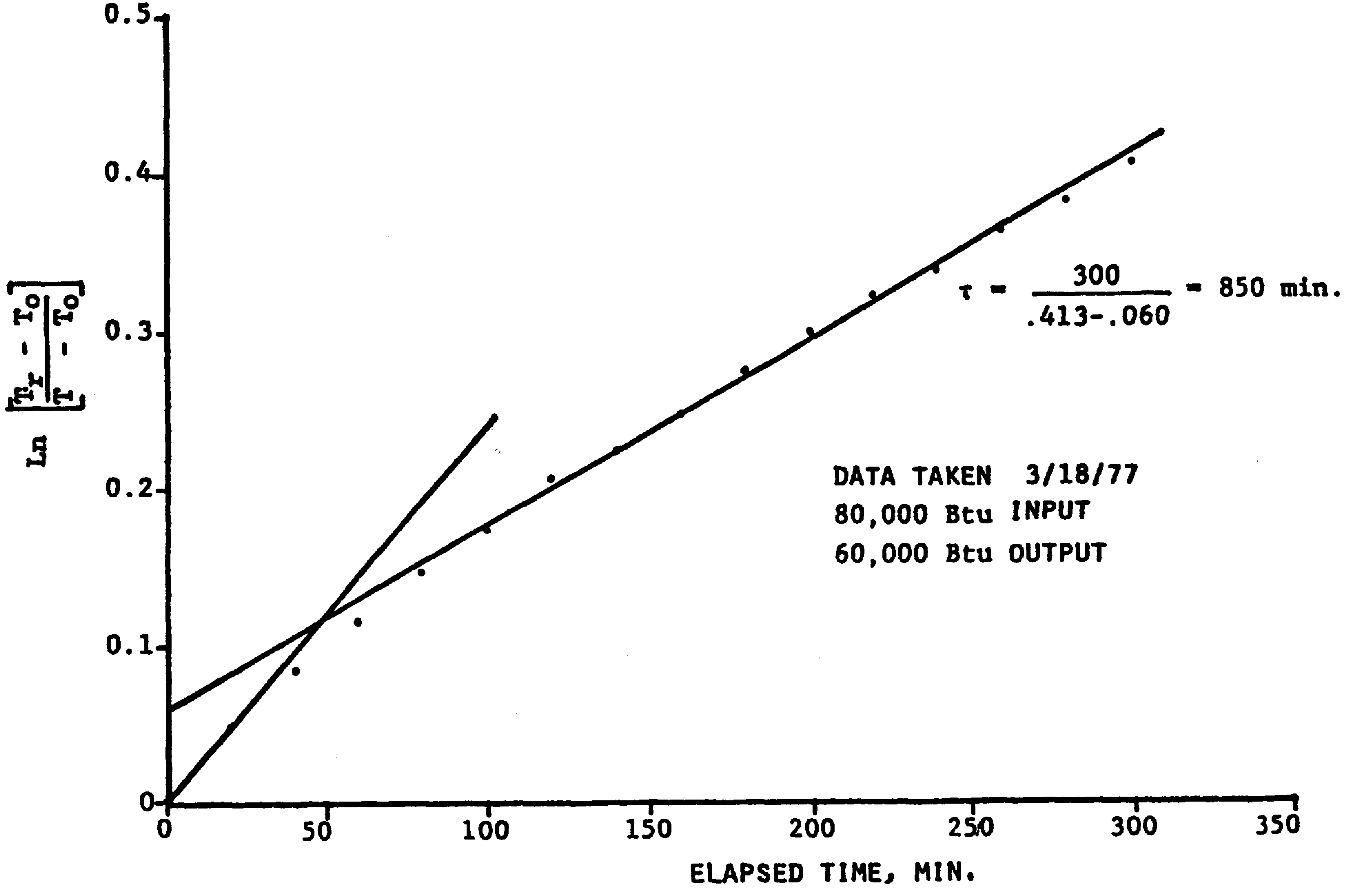


Figure 13. WARM-UP, El JARDIN

Figure 14. KITCHEN AIR TEMPERATURE FUNCTION, El JARDIN



$$\tau = \frac{300}{.413-.060} = 850 \text{ min.}$$

DATA TAKEN 3/18/77
80,000 Btu INPUT
60,000 Btu OUTPUT

PASSIVE SOLAR GAIN

The transient heat transfer measurements made at night in January and March established the overall conduction coefficient for the structure. Using 16.1 as the average R value for the structure, it was possible to employ equation (11) to estimate the passive solar input. Figure 15 shows the warmup transient due to solar effects for the display home. It was first cooled to a controlled temperature of 67.4°F on September 15, 1977. From 1230 to 1500 hours with bright sun and a stable outdoor temperature, the indoor temperature rose from 66.0°F to 1200 hours to 70.7°F at 1500 hours when the cooling system was turned off. The outdoor air temperature measured by a thermocouple on the north side of the house, was nearly constant at 73.3°F. The air temperature measured by the data logger on the south side seemed to be influenced by the solar heating of the south wall and is akin to a sol-air temperature.

The circulating fan was on during this test with outlet sealed. Thus, the infiltration rate was 159 cfm. Substituting these data into equation (11) gave:

$$Q_S = \frac{(UA)_h\left[(T-T_o)-(T_r-T_o)e^{-t/\tau}\right]}{(1-e^{-t/\tau}} - \dot{V}_i \rho c_p (T_o - \frac{T_r+T}{2})$$

$$= \frac{3655}{16.2}\,\frac{\left[\overset{-2.6}{(70.7-73.3)}\overset{+}{-}\overset{7.3}{(66.0-73.3)}e^{-180/1350}\right]}{(1-e^{-180/1350})} - (155x60)(.075)(.24)(73.3-\frac{66.0+70.7}{2} \tag{11}$$

$$= 6,850 - 829 = 6,031 \text{ BTU/hr}$$

Thus, the solar load coming through the windows and absorbed on the outside surfaces of the house is estimated to be 6,031 BTU/hr. This was the only data set we were able to get for this calculation. Weather conditions and the effect of visitors entering and leaving the house negated other measurements.

This level of passive solar input appears reasonable. It is hoped that MED II will offer more opportunity for working with this measurement technique. We believe it is a useful new approach to measurement of passive solar heat gain.

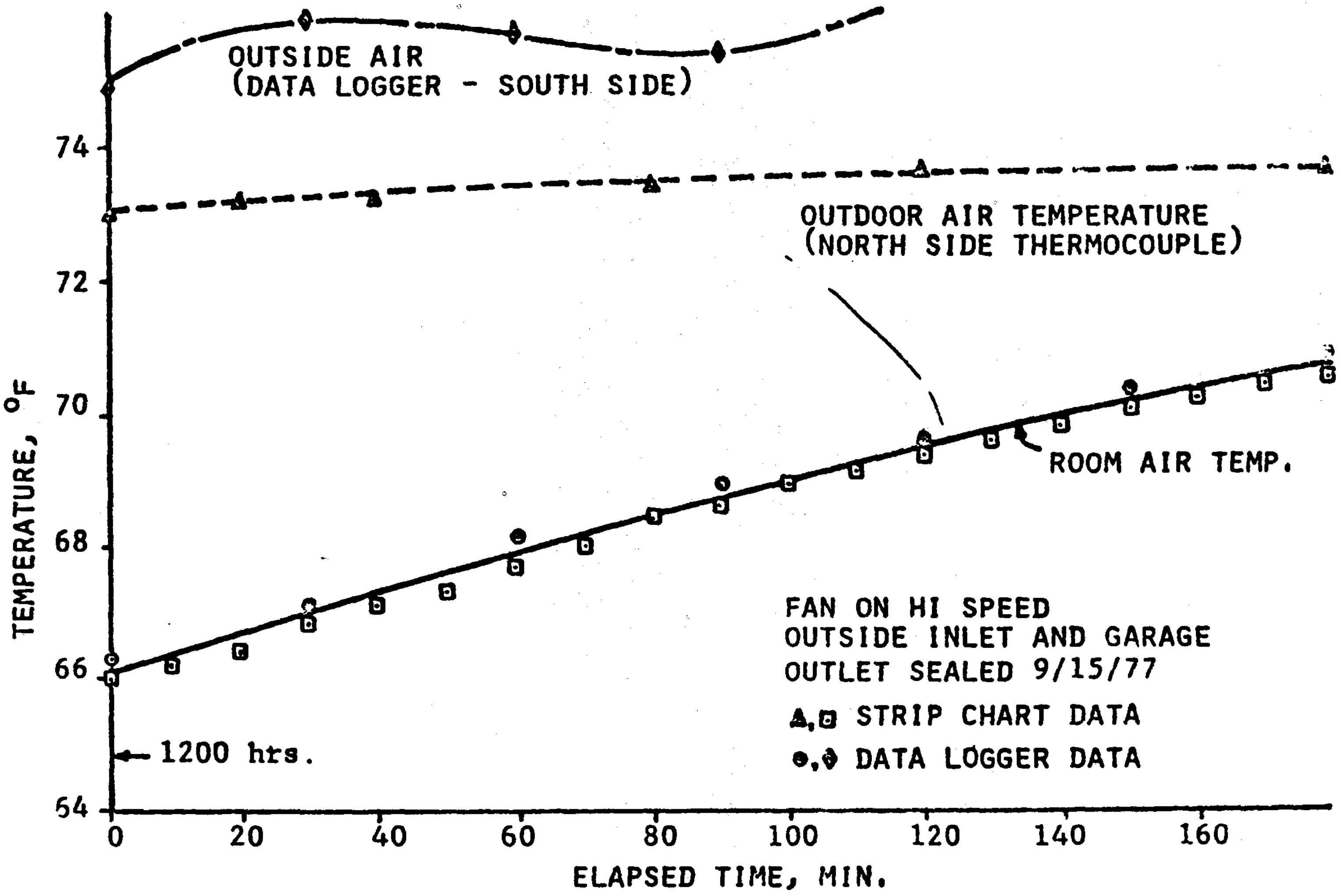


Figure 15. WARM-UP TRANSIENT DUE TO SOLAR GAIN, MED (D)

INFILTRATION

Special precautions were taken in the construction of the MED's to assure minimum infiltration. Figure 16 presents the data from one test. Additional results are presented in Table 3. Figure 16 shows the results of three different operating conditions. The line with the steepest slope was with the circulating fan on, fresh air dampers closed, and the garage registered sealed. The infiltration rate was 278 cfm or 1.7 air changes per hour. This is very high and we suspected leakage through the fresh air dampers. We, therefore, sealed the fresh air intake with plastic. This lowered the infiltration to 161 cfm or 0.99 air changes per hour as shown by the line with the intermediate slope in Figure 16. We then operated the fan intermittently turning it on for about 1.5 minutes out of 15 to be able to get an air sample in the return duct. This lowered the infiltration to 41 cfm or 0.25 air changes which represents a very tight structure.

When operating the fan intermittently we noted that when the fan was turned off the tracer concentration in the return duct decayed very rapidly. This meant that there apparently was leakage in the fiberglass ducts that go through the attic. This observation was confirmed in some of the thermal tests also. The structure itself appears to be very well sealed.

Figure 17 shows infiltration data for the El Jardin. The larger glass area with single glass and poorer weatherstripping contributed to the higher infiltration rate.

Following the October 1976 experiments, we derived equation (6) which enabled us to compute the house volume from the measured quantity of tracer added and the equilibrium concentration it produced at the end of the charging period. The house volume was then computed for all of those cases of the decay period immediately following a charging period. This gave a check on the uniformity of tracer mixing. The procedure could not be used; however, when a change was made, such as switching to intermittent fan operation midway through the decay period, that changed the infiltration flow rate.

The accuracy of measuring the house volume with the tracer depended upon the accuracy of measuring the amount of tracer added. The procedure was to try to maintain a constant tracer flow rate for a measured time interval. The calibration curves for the Matheson flowmeter used are shown in Figure 18. This was a variable area orifice meter with two floats, a pyrex ball, and a stainless steel ball. The nominal calibration curve supplied by Matheson gives a 2:1 scale reading for the pyrex versus the stainless steel balls. We checked the calibration of the pyrex ball against a bubbleometer in our laboratory and found a slight discrepancy as shown in Figure 18. For infiltration runs, we usually set the flow at a meter reading of 80 on the pyrex ball which gave a flow of 17.5 liters per minute (Honeywell calibration). This permitted a charging time of about 20 minutes which was slow enough to assure good mixing.

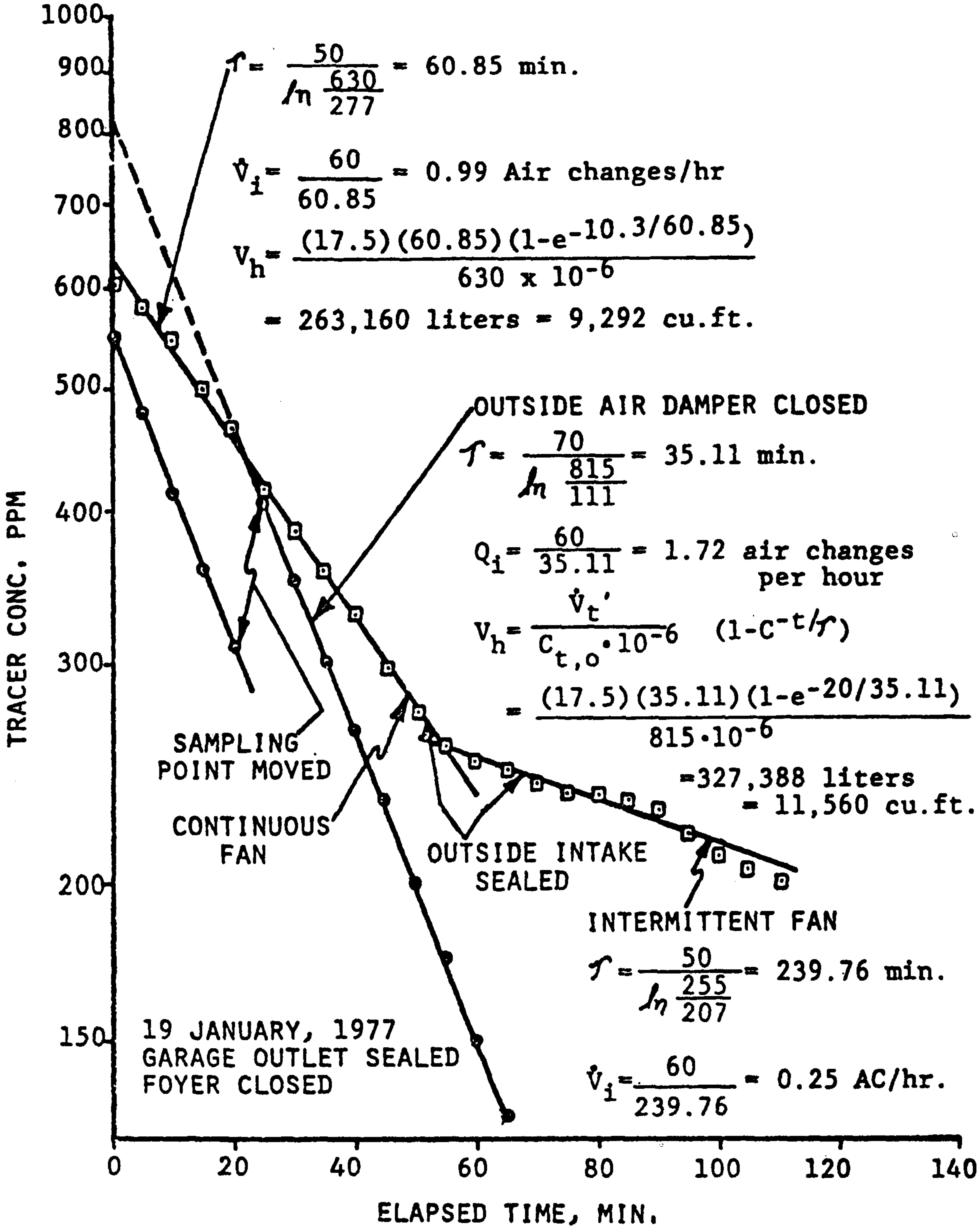
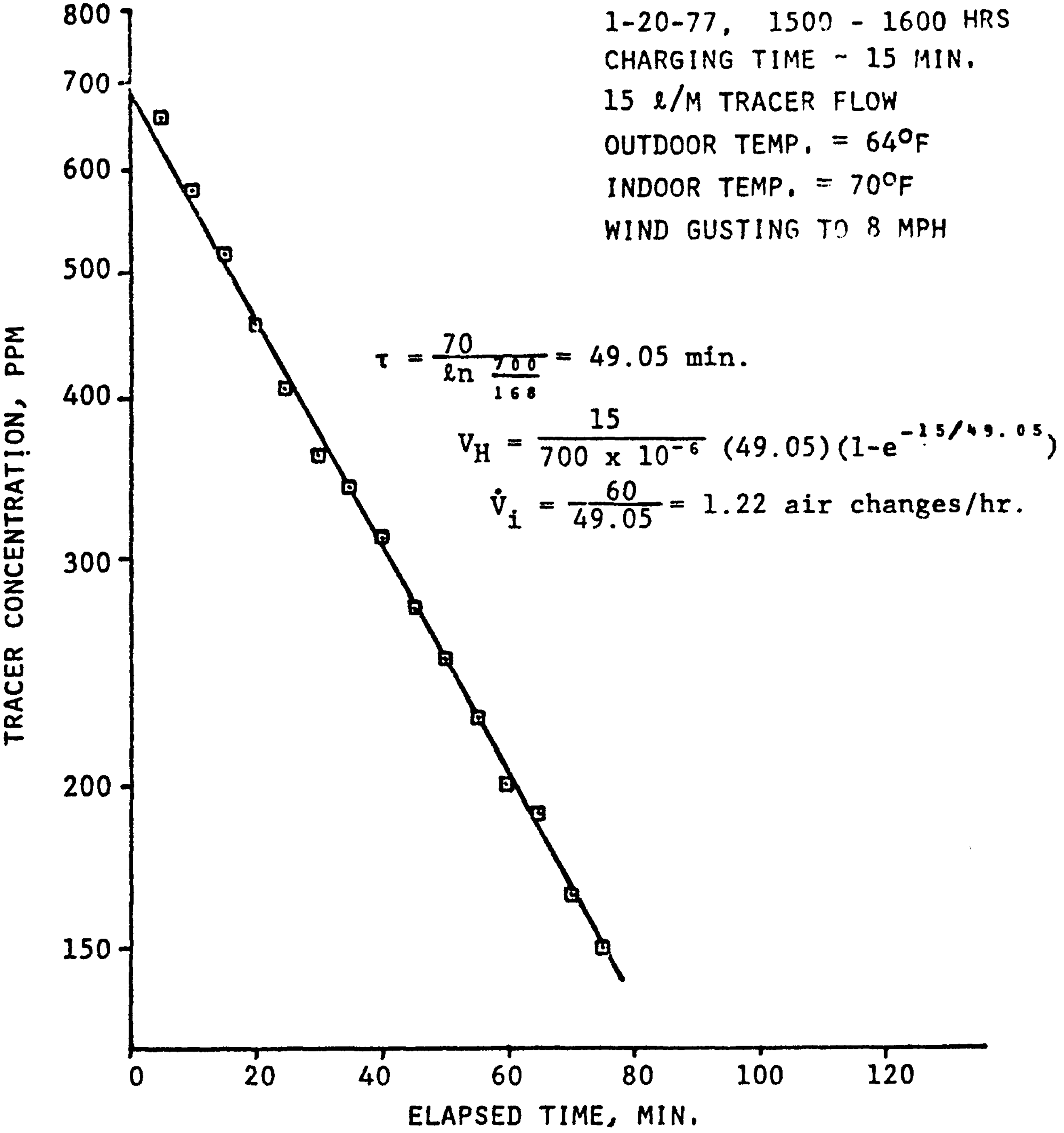


Figure 16. INFILTRATION IN MED (D)

TABLE 3.
INFILTRATION

NO.	HOUSE	DATE	CONDITIONS	TEMP °F	WIND mph	INFILTRATION		HOUSE CALC.	VOLUME MEASURED
						AC/Hr	Cfm		
1.	MED(R)	10-26-76	Fan on recirculation	80	30	1.82	295	9,739	
2.	MED(R)	10-26-76	Fan on recirculation Foyer doors closed Economizer intake sealed Refrig. louvers closed	80	18	1.33	216	9,739	
3.	MED(R)	10-27-76	Same as no. 2 except fan in vent position and attic scuttle sealed	70	14	.86	140	9,739	
4.	MED(R)	10-27-76	Same as no. 2 except attic scuttle sealed and kitchen pressure relief vent sealed	78	12	1.28	208	9,739	
5.	MED(R)	10-27-76	Same as no. 4 except intermittent fan - 1.5 min. on at 15 min. intervals to make reading	81	25	.36	58	9,739	
6.	MED(R)	10-27-76	Same as no. 5 except range vent sealed	81	15-20	.34	55	9,739	
7.	MED(D)	01-19-77	Fan on recirculation Foyer isolated Economizer damper closed Garage outlet sealed	72	1-2	1.72	278	9,739	11,560
8.	MED I(D)	01-19-77	Same as no. 7 except economizer intake sealed	79	3-4	.99	161	9,739	9,292
9.	MED I(D)	01-19-77	Same as no. 8 except intermittent fan	78	5-6	.25	41	9,739	
10.	MED I(D)	09-12-77	Fan on 100% recirculation Foyer isolated Economizer intake sealed Garage outlet sealed	72	3-5	1.48	240	9,739	10,834
11.	MED I(D)	09-12-77	Same as no. 10 except intermittent fan	72	3-5	.32	52	9,739	
12.	MED I(D)	09-13-77	Same as no. 10	76	3-5	1.45	235	9,739	9,691
13.	MED I(D)	09-13-77	Same as no. 9 except sample taken from living room; fan off	76	3-5	.28	45	9,739	
14.	MED I(D)	09-15-77	Same as no. 10	70	1-3	1.44	234	9,739	9,650
15.	El Jardin	10-28-76	As is; fan on recirculation	68	1	1.30	208	9,582	
16.	El Jardin	01-21-77	As is; people entering and leaving on 3 occasions; fan on	64	5-8	1.22	195	9,582	9,778



1-20-77, 1500 - 1600 HRS
CHARGING TIME ~ 15 MIN.
15 ℓ/M TRACER FLOW
OUTDOOR TEMP. = 64°F
INDOOR TEMP. = 70°F
WIND GUSTING TO 8 MPH

$$\tau = \frac{70}{\ell n \frac{700}{168}} = 49.05 \text{ min.}$$

$$V_H = \frac{15}{700 \text{ x } 10^{-6}} (49.05)(1-e^{-15/49.05})$$

$$\dot{V}_i = \frac{60}{49.05} = 1.22 \text{ air changes/hr.}$$

Figure 17. INFILTRATION IN E1 JARDIN

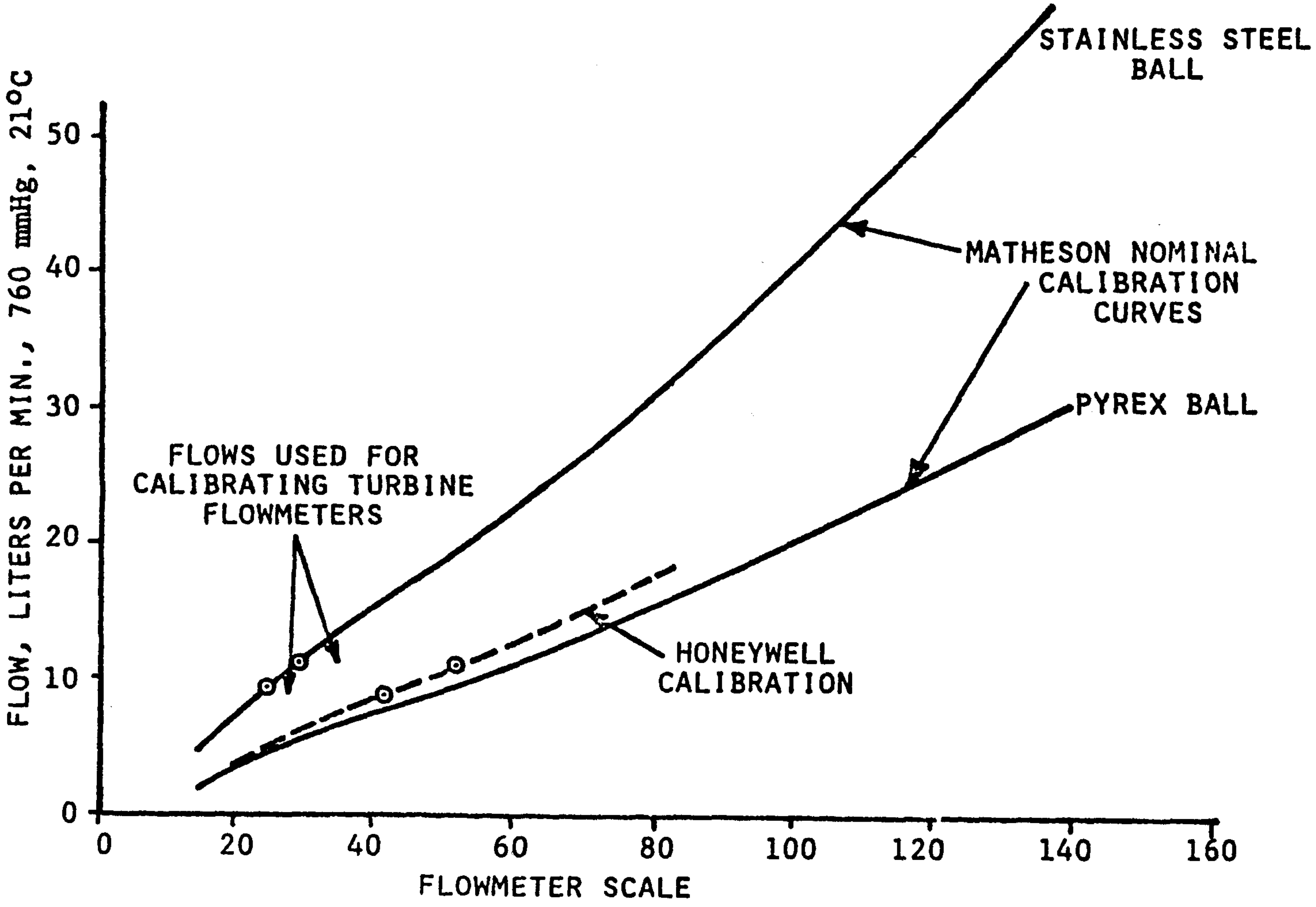


Figure 18. CALIBRATION CURVES FOR MATHESON NO. 605 FLOWMETER

The house volumes for MED and El Jardin were also computed from geometrical measurements. These calculations are presented in the Appendix and the results in Table 4.

TABLE 4
CALCULATED HOUSE VOLUME

MED	9,739 cu. ft.
El Jardin	9,582 cu. ft.

Table 3 shows generally good agreement except for two cases. The disagreement was attributed to unsteady tracer flow during the charging period. These errors have much less influence on the accuracy of the infiltration measurement.

WALL MOISTURE

Table 5 presents the results of humidity measurements in the insulation of each of the MED houses. The temperature of the drywall (inside wall temperature) was used to convert the relative humidities to dew points. The rh sensors were located between the inside surface of the insulation and the drywall. Thus, the drywall temperature should be very close to the dry-bulb temperature at the rh sensor. The outside wall temperature was that of the thermocouple buried in the stucco. If the outside wall temperature is lower than the insulation dew point temperature, there is danger of moisture condensation.

Table 5 shows that in all cases the dew point temperatures were lower than the outside wall temperatures indicating no condensation. The dew point in the master bedroom (MBR, i.e., south) wall of the occupied house was 50°F in March, however. This is high enough to lead to some condensation when the outdoor temperature drops rapidly. The total quantity of moisture in the sealed stud space is small and the rate of migration is slow. Thus, an extended cold period of, perhaps, a week or more would be needed to have any serious amount of condensation.

There was a definite seasonal variation in the dew point of the air trapped in the insulation. Although March is near the end of the rainy season, it is also near the end of the cold season. This produced the lowest dew points. The winter and spring of 1977 was exceptionally dry in southern California and this may have contributed to the low dew points in March.

The dew point of the air in the insulation increased substantially in September although this is a seasonally dry period. The outside air, being warmer at this time of year, undoubtedly picks up more moisture from the ocean, and, thus, has a higher dew point even though there is no rain.

The ceiling insulation of both houses was quite dry. This was to be expected since the roof is generally the warmest part of the house and there was no plastic vapor barrier outside of the ceiling insulation. The roof temperature thermocouple of the display home was suspect. The temperatures appeared to be unrealistically low.

TABLE 5.
INSULATION MOISTURE LEVEL

OCATION	DATE	DISPLAY HOME				OCCUPIED HOME				
		RH %	IWT °F	DP °F	OWT °F		RH %	IWT °F	DP °F	OWT °F
it Ceil	01-17-77	28	69	35	69 ?(1)		<5	70	<2	(2)
	01-20-77	15	72	24	57 ?					
	03-16-77	5	69	3	34 ?					
	03-17-77	5	63	0	73 ?		5	72	4	81
	03-18-77	>5	67	3	66 ?		~1	72	<0	74
	09-13-77	13	70	20	75	09-15-77	5			
it Wall	01-17-77	56	68	51	71		28	70	35	(2)
	01-20-77	49	72	52	54					
	03-16-77	41	59	35	49					
	03-17-77	40	62	37	55		30	70	36	60
	03-18-77	45	61	39	58		30	71	37	61
	09-13-77	70	70	59	68	09-15-77	43	76	51	74
BR	01-17-77	51	67	48	89		42	70	46	(2)
	01-20-77	48	71	43	53					
	03-16-77	40	60	35	49					
	03-17-77	47	61	41	50		50	69	50	60
	03-18-77	47	59	39	59					
	09-13-77	66	71	58	69	09-15-77	59	75	59	76

NOTE: IWT = Inside Wall Temperature

OWT = Outside Wall Temperature

DP = Dew Point Temperature

1. Roof temperature thermocouple in the display home must be incorrect. These temperatures were unreasonably low.
2. Thermocouples were not read in the occupied home in January.

Since the Mission Viejo climate is very mild and extended cold wet periods do not occur, the sealed stud space produced by using plastic rather than tar paper under the stucco does not appear to present a problem. This type of construction very probably would give condensation problems in a cooler and damper climate. The plastic infiltration barrier probably does not offer enough advantage to justify its use, however.

FURNACE EFFICIENCY

The steady state efficiency of the auxiliary furnace was measured at both high and low fire. This was done by measuring flue temperature, flue oxygen level, and gas flow rate during the burn cycle. The off-cycle losses were determined by measuring the flue and stack air flows and temperatures. Our computer model, based on the stack loss method, was then used to calculate steady state efficiency. The results are given in Table 6:

TABLE 6.
STEADY STATE EFFICIENCY OF AUXILIARY FURNACE

	FIRING RATE BTU/Hr.	FLUE TEMP. RISE ^{o}F	FLUE O_2 %	EFFICIENCY %
Lo Fire	52,700	486	7.7	73.1
Hi Fire	86,750	359	12.5	73.8

Off period stack flow 40 cfm

Since the auxiliary furnace is used only as backup for the solar collector, it is not feasible to use our HFLAME model to compute seasonal efficiency. The model uses weather input data to compute system load. Unfortunately, there is no provision for including solar data.

Table 6 shows that the furnace efficiency was the same at both hi and lo fire. Thus, it appears there is no advantage in using a two-stage furnace. A single-stage furnace could simplify the control system slightly.

The auxiliary furnace operates at very light load in the heating season. This increases the parasitic loss from the pilot. The pilot tends to keep the flue and stack warm, which increases flow. Direct spark ignition could reduce this off period loss.

TURBINE FLOWMETER CALIBRATION

The tracer technique was used to calibrate the turbine flowmeters in the ventilation duct and the return air duct. Methane was introduced at the inlet of the ventilation duct at a return air register in the house. The flow rate of the methane was measured. The concentration it produced was measured at the air handler just upstream of where the two ducts meet. The air velocity was then given by:

$$\dot{V}_a = \frac{\dot{V}_T}{C_T} \qquad (12)$$

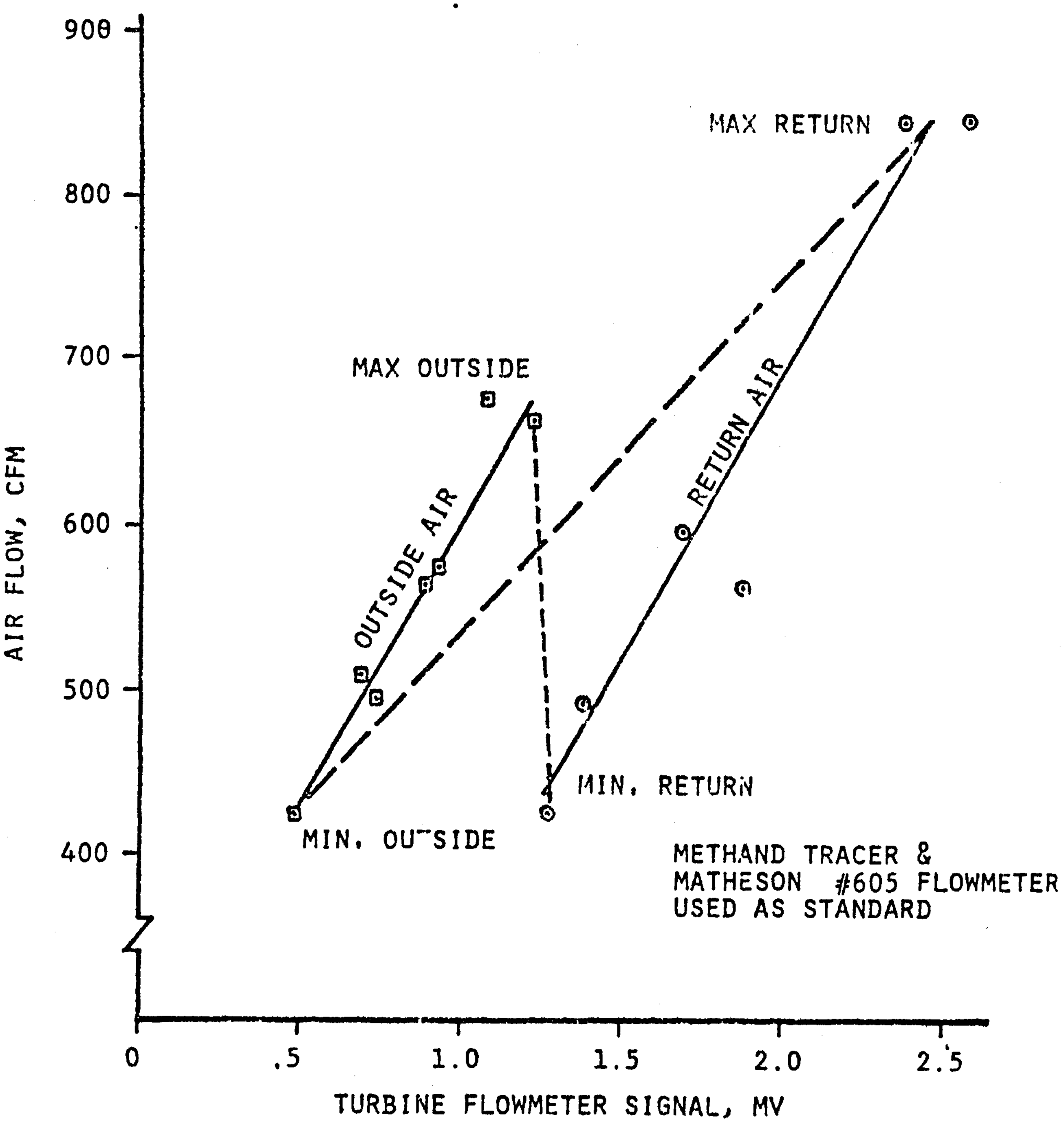


Figure 19. TURBINE FLOWMETER CALIBRATION

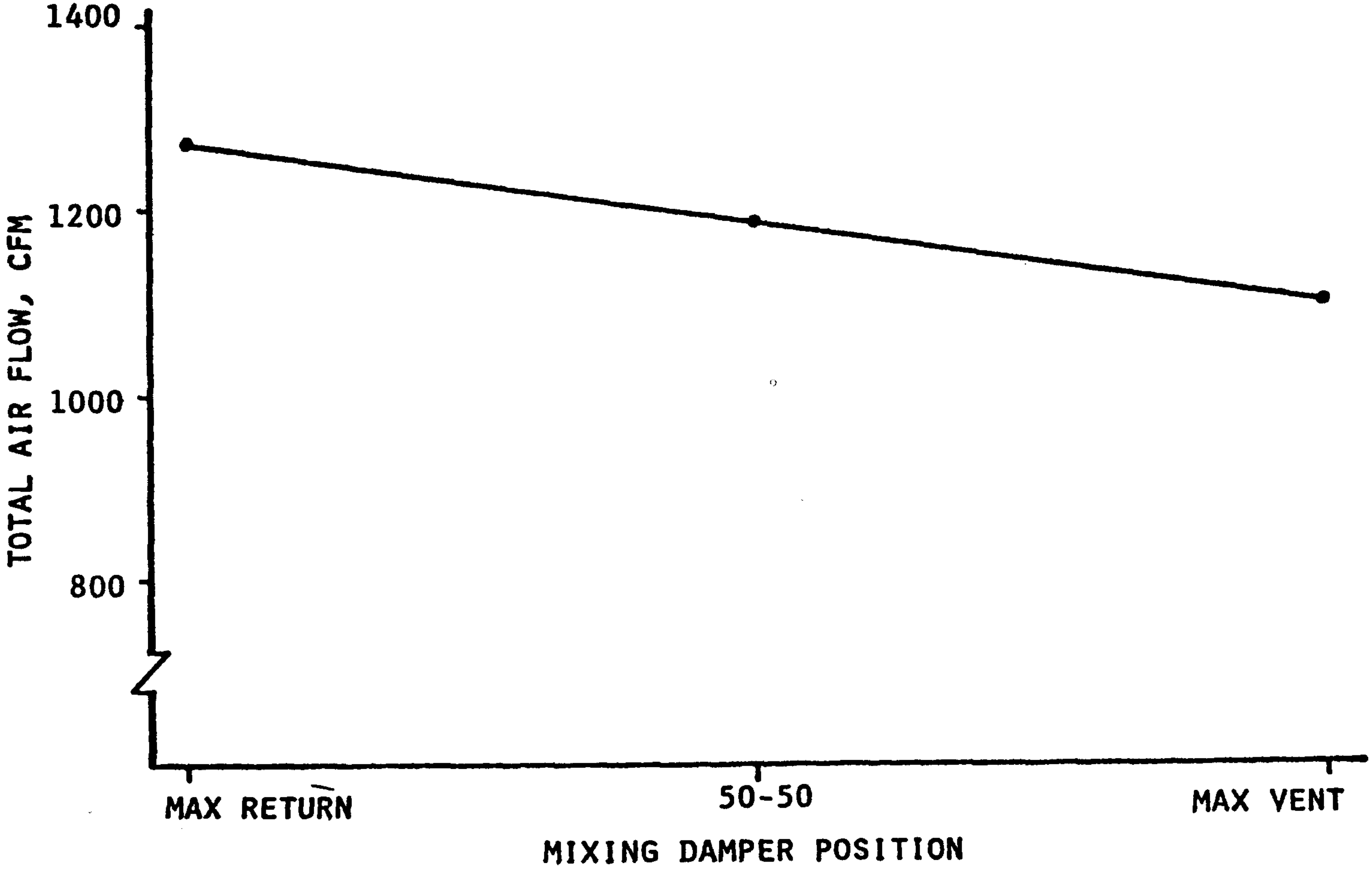


Figure 20. TOTAL AIR FLOW ACROSS COIL

where: $\dot{V}_a$ = air flow rate

$\dot{V}_T$ = tracer flow rate

C_T = tracer concentration

The results of these measurements are presented in Figures 19 and 20. The flow across the coil was relatively constant at 1200 cfm.

CONCLUSIONS AND RECOMMENDATIONS

The MED structure did meet its objective of a 50% reduction over conventional structures in heating energy needed to maintain indoor comfort.

The thermal transient measurement technique offers a means for estimating the passive solar input to a structure. The passive solar gain on a clear September day was found to be 5,986 BTU/hr.

Infiltration through the MED structure was only 1/5 that of conventional construction. However, the dampers in the fresh air vent have substantial leakage. The fiberglass ducts used in the attic appear to be porous and leak also. This leakage greatly increases the infiltration rate and negates the advantages of the very tight structure. It appears that a smaller air handling system with dampers that close tightly is needed. Metal ducts sealed with seam tape would eliminate the duct leakage in the attic.

The sealed stud space resulting from an inside vapor barrier and the outside plastic infiltration barrier do not appear to present a moisture problem. This construction in a more severe climate could present problems, however. Tar paper under the stucco probably is adequate and would relieve any danger of moisture condensation. Tar paper is probably preferable to plastic under the stucco.

There was no difference between hi and lo fire in the steady state efficiency of the furnace. A single-stage burner would simplify the control system slightly. Direct spark ignition would avoid some off period pilot losses.

The methane tracer technique was found to be useful for measuring the ventilation and return air flow rates. A relatively constant flow of 1200 cfm across the coil was measured.

APPENDIX

MED HEAT TRANSFER AREAS

Outside Walls:

[(Perimeter - garage wall) (8)]
+ gables - windows - door.

Walls - (34.67 + 32 + 34.67 + 10 + 5.5)(8)	934.7	
gables (32 x 5.17)	+165.4	
BR gable (8.17 x 4.42)(.5)	- 18.1	
gable above laundry: (9.83 x 2.75)	- 27.0	
(7.18 x 2.25 x .5)+(3.75 x .5 x 2.67)	- 13.1	
Windows + Door	-159.2	
		882.7

Window Area:

L. R. (2) (2.25 x 4.25)	19.13	
+ (3 x 4.25)	12.75	
Kitchen 3 x 4.25	12.75	
Door 6 x 6.67	40.02	
M. Bedroom 5 x 6.67	33.35	
Bedrooms (2) (2.75 x 4.25)	23.38	
		141.4
Door 2.67 x 6.67		17.8

Attic Wall:

Kitchen	(5.50 x 2.75)	15.13	
	(3.33 x 3.38)	11.26	
	(10.25 x 4.00)	41.00	
Living Rm	(17.83 x 4.50)	78.81	
	(6.00 x 4.67)	27.00	
M BR	(12.75 x 4.25)(.5)	27.09	
	(9.67 x 3.75)	36.26	
			236.6

Garage Wall:

	(12.5 + 5.5 + 9)(8)	+216.0	216.0

Vaulted Ceiling:

LR + Kit	(33.58 x 16.17)	+543.0	
	+(17.83 x 2.33)	+ 41.5	
	-(15.67 x 3.75)	- 58.8	
	-(5.50 x 3.63)	- 20.0	
		+505.7	
M BR	+(13.50 x 9.67)	+130.5	
			636.2

Horizontal Ceiling:

Bedrooms	(23.83 x 12.75)	+303.83	
Bathrooms	(15.0 x 5.67)	+ 85.05	
Laundry	(5.17 x 3.42)	+ 17.68	
Foyer	(8.25 x 5)	41.25	
			447.8

Floor:

	(33.58 x 30.83)	+1035.27	
	(8.25 x 5)	+ 41.25	
			1076.5

Floor Perimeter	(2) (34.67 + 32)	+ 133.3	
	-(9.0 + 5.5 + 12.25)	- 26.8	
			106.5

MED WALL HEAT TRANSFER

	THERMAL RESISTANCE	THERMAL CONDUCTANCE	TOTAL AREA	(UA)
Outside Walls:	"R"	U = 1/R	Sq. ft.	
Inside Air Film	.68			
0.5 in. Dry Wall	.45			
5.5 in. Fiberglass	19.00			
1 in. Stucco	.20			
Outside Air Film	.17			
	20.50	.0487	882.7	43.0
Vaulted Ceiling:				
Inside Air Film	.62			
0.5 in. Dry Wall	.45			
Insulation	28.00			
Roof Boards	.78			
Paper	.06			
Tile	.20			
Outside Air Film	.17			
	30.28	.0330	636.2	21.0
Horizontal Ceiling:				
Inside Air Film	.62			
0.5 in. Dry Wall	.45			
Insulation	28.00			
Attic Air Film	.40			
	29.47	.0339	447.8	15.2
Attic Wall:				
Inside Air Film	.68			
0.5 in. Dry Wall	.45			
Insulation	28.00			
Attic Air Film	.20			
	29.33	.0341	236.6	8.1

	THERMAL RESISTANCE "R"	THERMAL CONDUCTANCE U = 1/R	TOTAL AREA Sq. ft.	(UA)
Windows:				
Double - 1 in. Space	1.79	.560	141.4	79.2
Door: 1.25 in. wood	1.82	.550	17.8	9.8
Floor: (106.5 ft. perimeter x .40 BTU/ft-°F)		.40	1076.5	42.6
Garage Wall:				
Assume "R" is 1.5 times R of other walls due to effect of garage	30.0	.0333	216.0	7.2
Average Structure "R" value = 3655/226.1 = 16.2			3655.0	226.1

EL JARDIN HEAT TRANSFER AREAS

Outside Walls:

(Perimeter) x 8 + gables
-Windows - doors

Walls (34.67 + 32) (2) (8)		1066.7	
gables (32 x 5.17)	165.44		
den gable (8.17 x 4.42) (.5)	- 18.06		
gable above laundry:			
(7.00 x 2.75)	- 19.25		
(7.00 x 2.42) (.5)	- 8.47		
		+119.7	
Window & Door		-196.5	
			989.9

Window Area:

Kit, LR, BR			
(3) (3.5 x 4.5)	47.25		
(1) (4.5 x 5.5)	24.75		
Patio doors			
(2) (5 x 6.67)	66.70		
(1) (6 x 6.67)	40.02		
	178.72	178.7	178.7
Door (2.67 x 6.67)	17.8	17.8	17.8

Attic Wall:

Kitchen	(5.50 x 2.75)	15.13		
	+(3.33 x 3.38)	11.26		
	(10.25 x 4.00)	41.00		
LR	(17.83 x 4.42)	78.81		
	(6.00 x 4.50)	27.00		
M BR	(15.25 x 4.67) (.5)	35.61		
	(9.67 x 4.67)	45.16		
			254.0	254.0

Vaulted Ceiling:			
LR + Kitchen			
(33.58 x 16.17)	543.0		
+(17.83 x 2.33)	41.5		
-(15.67 x 3.75)	- 58.8		
-(5.50 x 3.63)	- 20.0		
		505.7	
M BR (16.17 x 9.67)		+156.4	
			662.1
Horizontal Ceiling:			
BR (23.83 x 12.75)	303.83		
Bath (9.67 x 2.83)	27.37		
+(6.00 x 5.33)	31.98		
Laundry (5.17 x 3.42)	17.68		380.9
Floor: (33.58 x 31.00)			1041.0
			3524.4
Floor Perimeter (2) (34.67 + 32.00)			133.3

EL JARDIN WALL HEAT TRANSFER

	THERMAL RESISTANCE "R"	THERMAL CONDUCTANCE U = 1/R	TOTAL AREA Sq. ft.	(UA)
Outside Walls:				
Inside Air Film	.68			
0.5 in. Dry Wall	.45			
3.5 in. Fiberglass	11.00			
1 in. Stucco	.20			
Outside Air Film	.17			
	12.50	.0800	989.9	79.19
Vaulted Ceiling:				
Inside Air Film	.62			
0.5 in. Dry Wall	.45			
Insulation	19.00			
Roof Boards	.78			
Paper	.06			
Tile	.20			
Outside Air Film	.17			
	21.28	.0472	662.1	31.25
Horizontal Ceiling:				
Inside Air Film	.62			
0.5 in. Dry Wall	.45			
Insulation	19.00			
Attic Air Film	.40			
	20.47	.0489	380.9	18.63
Attic Wall:				
Inside Air Film	.68			
0.5 in. Dry Wall	.45			
Insulation	19.00			
Attic Air Film	.20			
	20.33	.0493	254.0	12.52
Windows:				
Single glass	.88	1.13	178.7	201.9
Door 1.25 in. wood	1.82	.55	17.8	9.8
Floor (Perimeter X U)		.81	1041.0	108.0
$R_{ave} = \frac{3524.4}{461.3} = 7.6$			3524.4	461.3

INTERIOR VOLUME

	MED		El JARDIN	
Gross Volume:				
(33.58 x 30.8 x 8)	8274		8274	
+ LR + Kit. Vaulted ceil (33.58 x 15.5 x 5.17)(.5)	1346		1346	
(17.83 x 4.8 x 2.33)	199		199	
+MBR Vaulted Ceil (9.67 x 12.6 x 4.25)(.5)	260	(9.67x15.5x5.17)(.5)	387	
		10,079		10,252
-Laundry Rm Ceil (5.5 x 7.25 x 4.17)	166			
-Kit Ceil (10.33 x 2.83 x 4.5)	132			
-Plumb. Chase (15.42 x 1 x 8)	123			
-Internal Walls (17 + 28 + 26) (8) (.375)	213			
-Refrig	36			
		-670		,670
				9,582
+Vestibule: (8.25 x 5 x 8)	330	330		
		9,739		
Net Volume El Jardin		9,582		
MED		9,739		

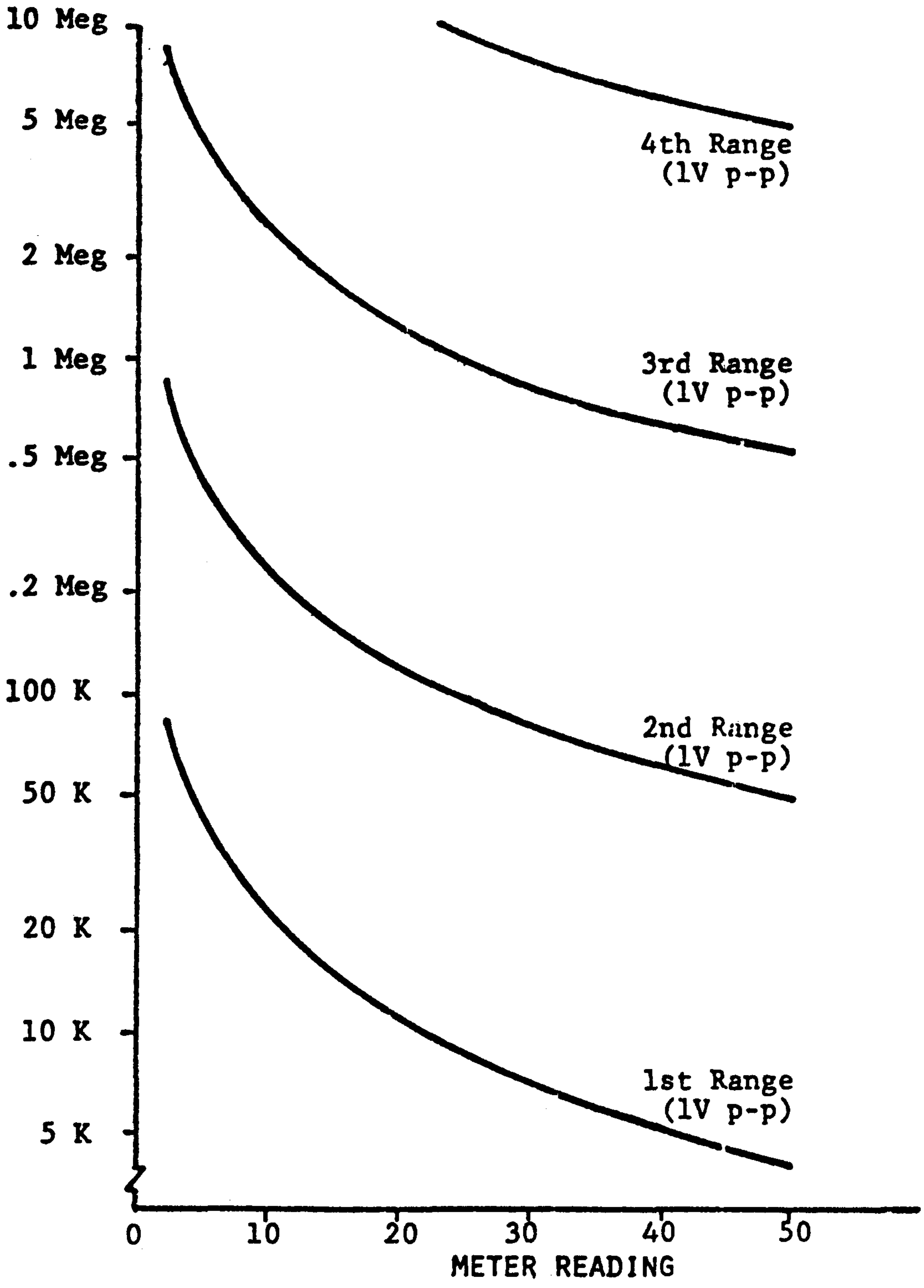


Figure 21. IMPEDANCE METER CALIBRATION

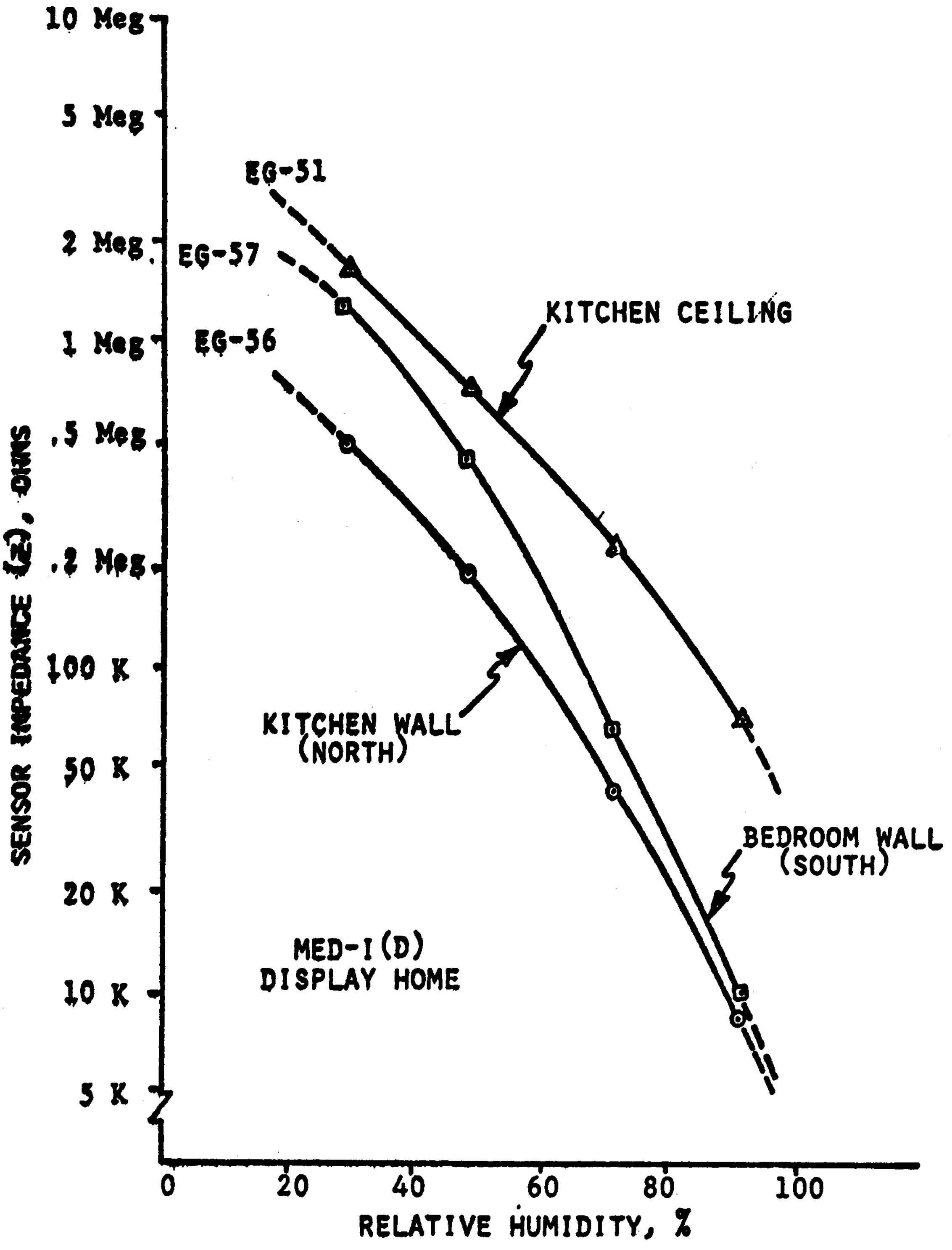


Figure 22. CALIBRATION FOR HUMIDITY ELEMENTS

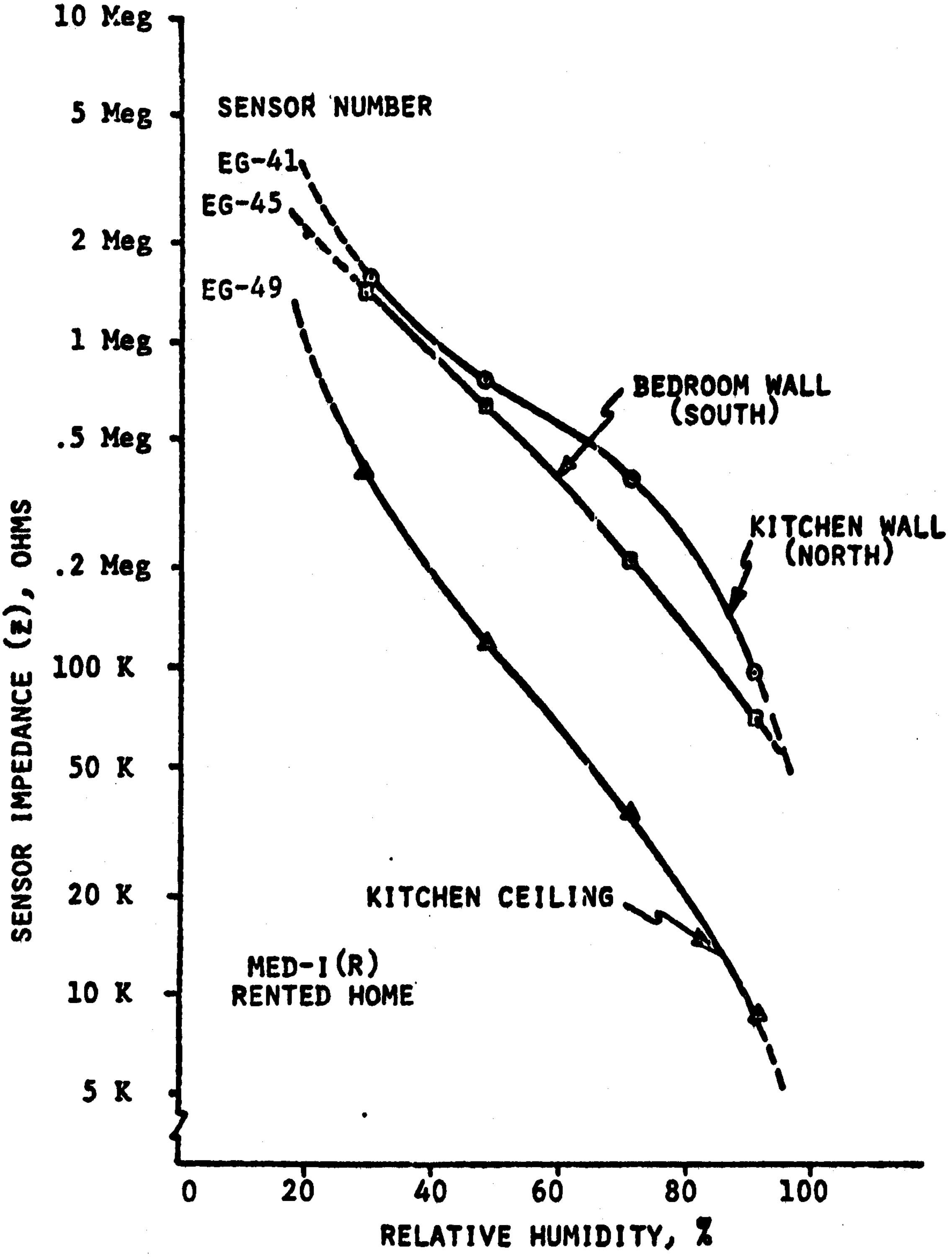


Figure 23. CALIBRATION FOR HUMIDITY ELEMENTS

APPENDIX III

LAWRENCE BERKELEY LABORATORIES
ODOR AND MOISTURE EXPERIMENTS

The complete report of the MED infiltration and indoor pollution studies made by the Lawrence Berkeley Laboratory will not be available until early 1980. However, we do have access to the preliminary results of the infiltration tests conducted on both MED houes. These tests resulted in infiltration rates of 1.5 air changes per hour - fan on and .2 air changes per hour - fan off. The Honeywell results were very similar with 1.7 ach - fan on and .25 ach-fans off. The Lawrence Berkeley Laboratory tests then confirm the Honeywell conclusions about leakage in the economizer ductwork as well as tightness of the MED building shell. The following is a summary of the Lawrence Berkeley Laboratory experiments.

PRELIMINARY RESULTS - MED INFILTRATION - AIR LEAKAGE TESTS

The Lawrence Berkeley Laboratory has a long term goal of recommending standards for air leakage in residential construction in the United States. Therefore, we seek to measure properties of energy efficient homes such as the MED-I structure as well as more traditional houses. In addition, we seek to determine if fan pressurization measurements can be used to predict air infiltration rates.

Air Leakage with Fan Pressurization

Several pressurization and depressurization measurements were made with different house openings covered with plastic and taped. The results are:

	PRESSURE (inches H_2O)	LEAKAGE (cfm)	HOUSE CONDITION
(1)	+0.20	2710	Normal operating condition
(2)	-0.20	1755	Normal operating condition
(3)	+0.20	1720	Tape duct openings and attic trap door in bedroom
(4)	-0.20	930	Same as (3)
(5)	+0.20	910	Tape large vent on kitchen wall
(6)	-0.20	770	Same as (5)

The plus and minus signs before the pressures that are listed distinguish between pressurization (+) of the house (interior pressure of house greater than exterior or depresurization)(-) (interior of house at a lower pressure than the exterior).

We measured leakages at many pressures: we listed the results for 0.20 inches H_2O (50 Pascals) in order to compare the results of our measurements with the Swedish standard for air leakage. This states that at an overpressure of 50 Pascals (created by a fan system similar to the one we used) the house shall have a leakage rate which does not exceed 3.0 air changes per hour (ACH). The measurement shall be made when all design ventilation openings are taped closed. We calculated the volume of the MED-I house to be 10,300 ft^3.

Dividing the average air leakage at plus and minus 0.20 inches H_2O pressure when openings are taped by this volume yields an average air leakage value for the MED-I house of 4.9 air changes per hour at 50 Pascals.

The major leakage of the house, the ducts and the kitchen vent, is eliminated by the time the measurement referred to above was made. The leakage which yielded the 4.9 ACH figure is residual structural leakage.

Natural Infiltration

Infiltration rates were measured using ethane as the tracer gas. The concentation decay technique was used for these measurements. When the ducts were unsealed and the fan was operating, ethane was injected slowly into the return duct. After the concentration in the house reached 80 ppm, the injection was stopped. The concentration was then measured as a function of time to determine the infiltration rate. When the ducts were sealed, injection was made directly into the house and mixing was done manually. The measurement results are shown below:

DATE	TIME	INFILTRATION RATE hr-1	WIND SPEED	TEMPERATURE DIFFERENCE	NOTE
11/29	16:25 - 18:17	0.19	1.0 m/s	7°C	(1)
11/30	9:16 - 11:00	1.12	1.5 m/s	5°C	(2)
11/30	11:35 - 12:17	0.22	1.7 m/s	4°C	(3)
11/30	12:17 - 12:27	1.81	1.4 m/s	3°C	(4)
11/30	13:00 - 13:48	1.48	2.4 m/s	3°C	(5)

NOTES: (1) Ducts taped, fan off

(2) Ducts open, fan on

(3) Ducts open, fan off

(4) Ducts open, fan on

(5) Ducts open, fan on, economizer vent taped closed, kitchen vent taped closed.

The data show that the infiltration depends strongly on the fan condition. We assume that excess infiltration is the result of duct leakage and excess pressures that exist in the house when the fan is operating. Infiltration rates are weather dependent but as a rough estimate we suggest that the infiltration rate in this house is 0.2 air changes per hour when the fan is off and 1.5 air changes per hour when it is operating.

The preliminary results of the Lawrence Berkeley Laboratory indoor air quality studies of the MED houses have been published in a related study:

Indoor Air Quality Measurements in Energy-Efficient Houses by James V. Berk, Craig D. Hollowell and Chin-I Lin of the Energy Efficient Buildings Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California 94720.

The MED test results as presented in this report have been included in this Appendix. The complete report on both infiltration and indoor air quality will be available in early 1980.

PRELIMINARY RESULTS - MED AIR QUALITY TESTS

Experimental Methods

The EEB Mobile Laboratory is a facility designed for field studies of ventilation requirements and energy utilization in buildings. It is equipped with the instrumentation listed in Table II in order to monitor the contaminants shown in the same table. The mobile laboratory, containing sampling, calibration, and monitoring systems was positioned outside each of the houses studied. For inorganic gaseous pollutants, air was sampled through teflon sampling lines from three rooms within the structure and from an outdoor site. The four lines were sampled for ten-minute intervals in sequence to allow monitoring of the gas concentrations in all four locations; consequently, ten-minute samples were taken from each site every forty minutes.

Infiltration rates were monitored continuously at the latter two homes using an H_2O tracer gas system. This system, developed at LBL, continuously injects controlled amounts of N_2O while monitoring the indoor concentrations.[5] The data is recorded and processed to yield continuous infiltration rates. Infiltration at the MED house was measured with a simple exponential decay-rate method using ethane as the tracer gas. At all three locations, outdoor weather parameters were monitored in order to see if they could be correlated with changes in ventilation rates.

The particulate matter in the air was monitored at the sampling points using four dichotomous air samplers[6] (DAS), developed at LBL specifically for indoor monitoring. These devices separate the particulate matter above and below 2.5 microns and collect the samples on teflon filters; these samples are subsequently analyzed for total mass concentration (by beta gauge techniques) and chemical content (by x-ray flourescence).

The MBTH method is used for measuring total aliphatic aldehydes in indoor studies. An accurate flow control system developed at LBL is used to collect samples from indoor and outdoor air. The aldehydes, sampled in individual bubbler tubes containing MBTH solution, are refrigerated and brought back to LBL for analysis. There, the sample solution containing aldehydes is oxidized to yield a blue-green dye. The concentration of aldehydes is measured and calibrated (as formaldeyde) spectrophotometrically at 628 nm. Simultaneously with the MBTH method, the chromotropic acid and pararosaniline methods are used for measuring the formaldehyde fraction of the total aldehydes.

Results and Discussion

Methods of measuring air change rates in which the tracer gas concentration varies, such as simple expotential decay, utilize the "effective volume" of the structure. This represents the volume of air involved in the mixing process. Methods which maintain a constant concentration by continuously injecting tracer gas yield air flow rates (rates at which outdoor or "fresh" air enters the building). The LBL continuous tracer gas system measures air flow rates; however, concentrations vary somewhat and the "effective volume" can be calculated. The flow of fresh air divided by the "effective volume" represents the air exchange in air changes per hour. Air change rates measured at the MED house using a simple ethane decay curve yielded values of approximately 0.2 air changes per hour (ach). Flow rates measured at the ISUERH using the N20 continuous tracer gas system varied from about 2000 ft^3/hr to 7000 ft^3/hr as shown in Figure 3. Figure 4 illustrates the variation of flow observed over a 24-hour period. It should be emphasized that these rates routinely varied over wider ranges than shown for this day. The air exchange rate varied at the ISUERH from about 0.15 ach to 0.75 ach with an average of approximately 0.3 ach. The average value is in good agreement with results determined by simple exponential decay-rate methods.

Preliminary results from these field monitoring sites show that the pollutants studied fall into two major classes; those for which the primary sources are indoors and those for which the primary sources are outdoors. As houses are tightened and ventilation rates are reduced, substances in the former class show higher concentrations indoors than outdoors, while substances in the latter class tend to be shielded from the indoor environment.

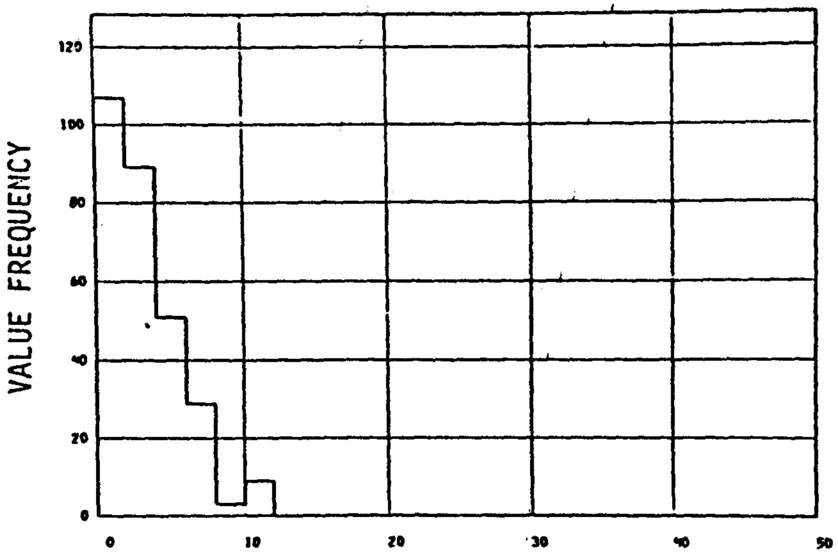
Figures 5 and 6 show historgrams of 10-minute carbon monoxide and nitrogen dioxide concentrations both indoors and outdoors at the occupied MED house. In the occupied MED house, CO and NO_2 concentrations are higher indoors; presumably, their source is natural gas combustion from cooking activities. These are to be compared with the National Ambient Primary Standards of 9 ppm (CO for one hour) and 50 ppb (NO_2 annual average), which are considered to be levels of air quality necessary, with an adequate margin of safety, to protect the public health.

Figure 7 shows histograms of the ozone concentrations indoors and outdoors at the occupied MED house. In the case of this pollutant, the house serves to shield the occupants from ozone in the outdoor environment. The short-term (1 hour) air quality standard for O_3 is 120 ppb. Carbon dioxide, shown in Figure 8, is of considerable interest because it is produced both by the combustion processes within the house and by the occupants themselves. The CO_2 levels observed in these energy efficient houses are well below the recommended standards.[8] In buildings such as educational institutions, which have high occupant densities, carbon dioxide may be the most important parameter in determining ventilation rates.[8,9]

6. B.W. Loo, R.S. Adachi, C.P. Cork, F.S. Goulding, J.M. Jaklevic, D.A. Landis, and W.L. Searles, "A second generation dichotomous sampler for large-scale monitoring of airborne particular matter," Lawrence Berkeley Laboratory Report LBL-8725, to be presented at the 86th Annual Meeting of the American Institute of Chemical Engineers, Houston, Texas, April 1-5, 1979.
7. Code of Federal Regulations, 40 C.F.R. 50

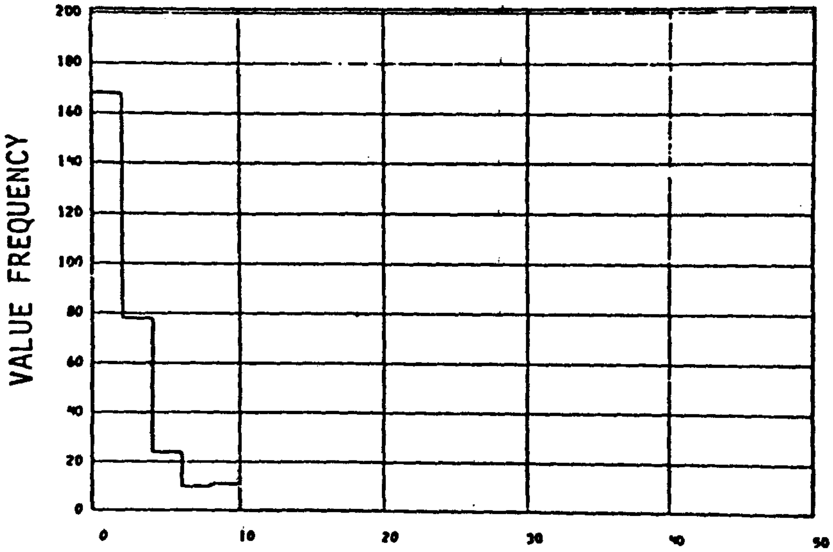
8. I. Turiel, C.D. Hollowell and B.E. THurston, "Automatic variable ventilation control systems based on air quality detection, "Lawrence Berkeley Laboraotry Report LBL-8893, to be published in Proceedings of the Second International CIB Symposium on Energy Conservation in the Built Environment (June 1979).

9. J.V. Berk, C.D. Hollowell, C. Lin, and I. Turiel, "A report on the results of energy conservation and indoor air quality measurements in an air conditioned California high school," to be published as a Lawrence Berkeley Laboratory Report.



MED-I HOUSE CO KITCHEN

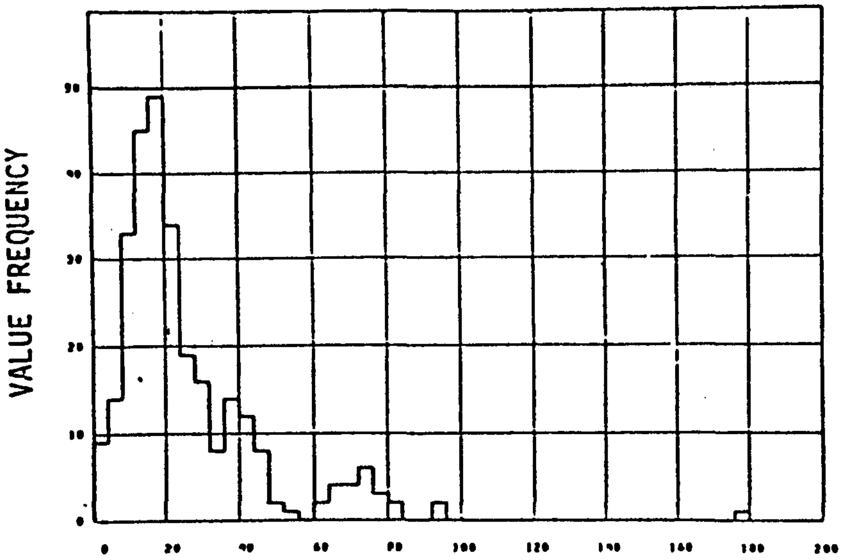
9/1/78 TO 9/9/78 BIN SIZE = 2 PPM



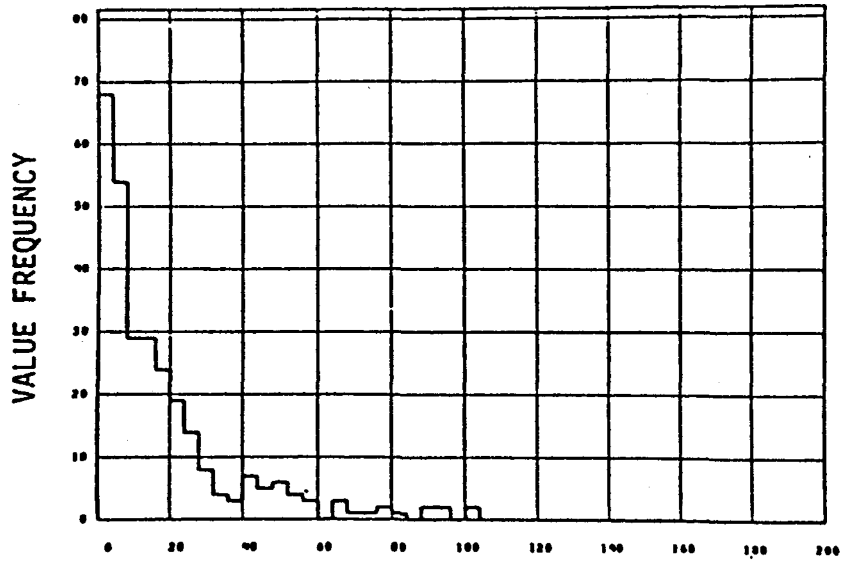
MED-I HOUSE CO OUTDOORS

9/1/78 TO 9/9/78 BIN SIZE = 2 PPM

Figure 5. Summary of indoor/outdoor carbon monoxide measurements at the MED house

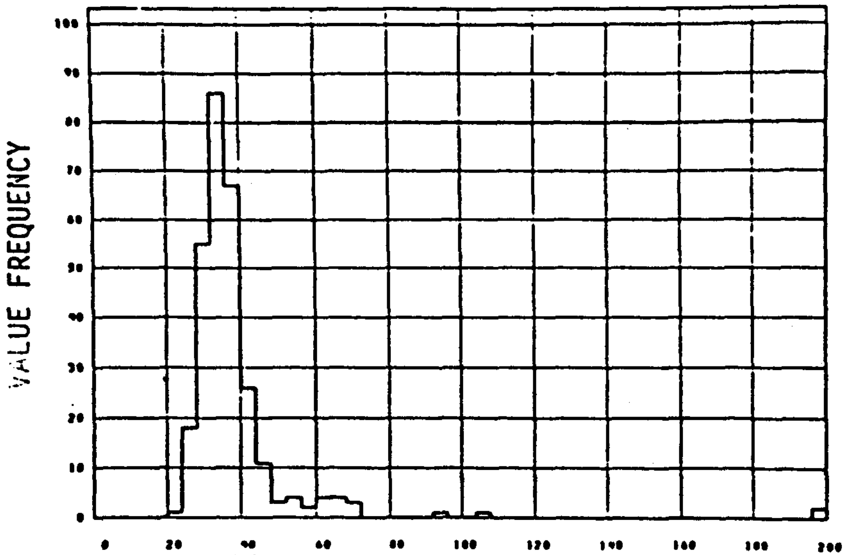


MED-I HOUSE NO_2 KITCHEN
9/1/78 TO 9/9/78 BIN SIZE = 4 PPB

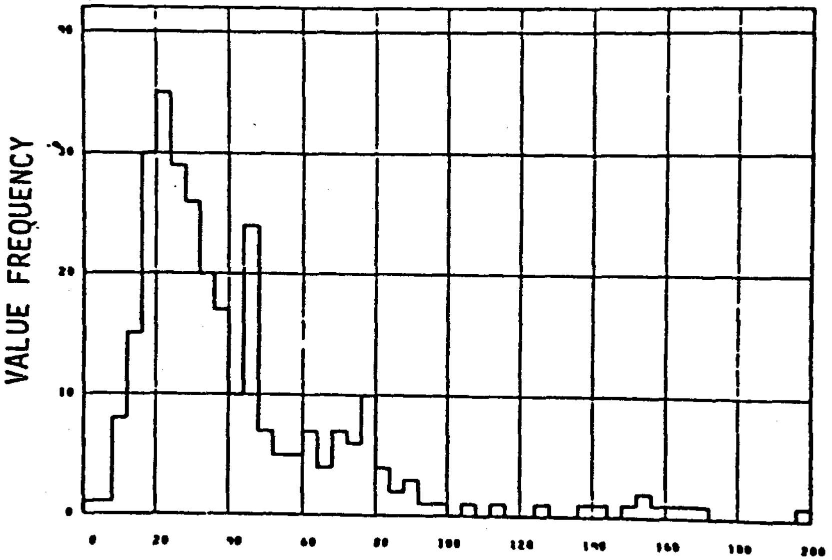


MED-I HOUSE NO_2 OUTDOORS
9/1/78 TO 9/9/78 BIN SIZE = 4 PPB

Figure 6. Summary of indoor/outdoor nitrogen dioxide measurements at the MED house.

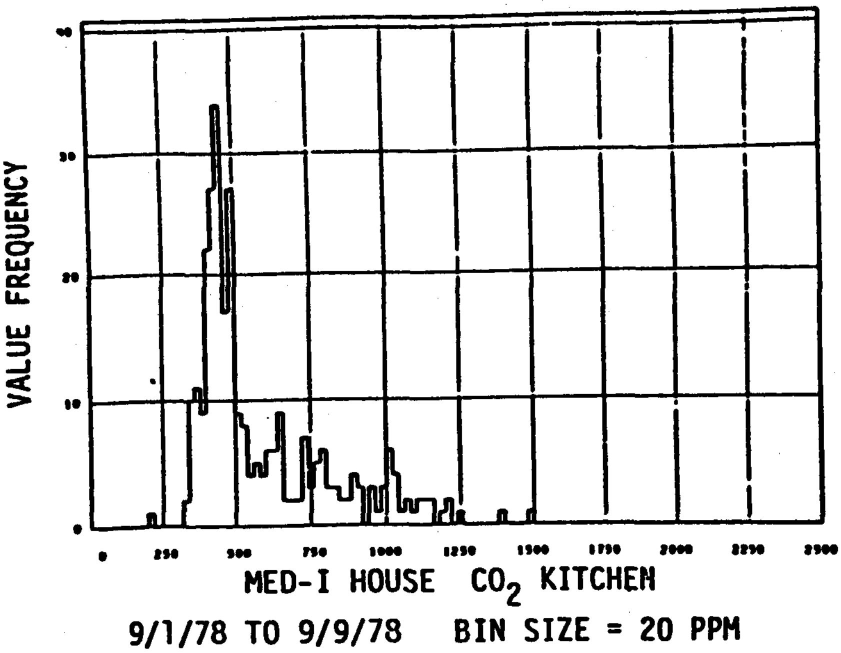


MED-I HOUSE O_3 KITCHEN
9/1/78 TO 9/9/78 BIN SIZE = 4 PPB



MED-I HOUSE O_3 OUTDOORS
9/1/78 TO 9/9/78 BIN SIZE = 4 PPB

Figure 7. Summary of indoor/outdoor ozone measurements at the MED house.



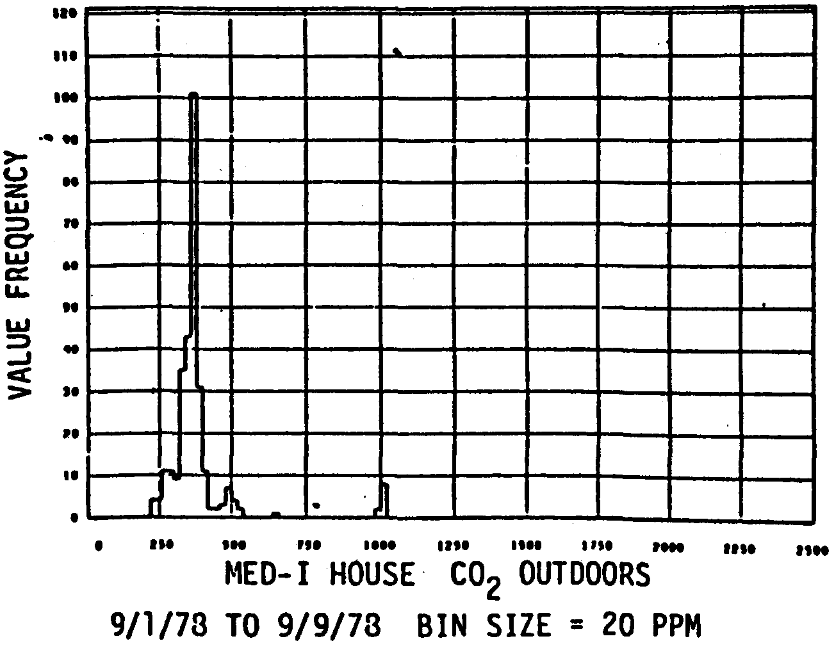


Figure 8. Summary of indoor/outdoor carbon dioxide measurements at the MED house.

APPENDIX IV

CARNEGIE-MELLON UNIVERSITY
DATA STUDIES

TABLE OF CONTENTS

A PRELIMINARY ANALYSIS OF THE MINIMUM ENERGY DWELLING (MED)

Prepared For

Burt Hill Kosar Rittelmann Associates

Butler, Pennsylvania

By

Dr. Alton J. Penz

Carnegie-Mellon University

February, 1979

INTRODUCTION 1

This report contains a discussion of some preliminary analyses performed on instrument data collected from two houses in Southern California. The houses, referred to as the Minimum Energy Dwelling Project (MED), were the product of a research effort executed jointly by Southern California Gas Company, The Mission Viejo Company, and Burt Hill Kosar Rittelmann Associates, Architects. The project, which was supported by both Southern California Gas and DOE, basically involved construction of two Mission Viejo model homes with some special considerations given to them in construction, and fitted with elaborate mechanical systems. The mechanical systems included solar collectors, a hot water driven absorption chiller, and back-up, gas-fired boiler. Domestic hot water was to be preheated via a solar storage tank. Finally, both houses were instrumented, primarily for weather conditions and mechanical system operation. This report presents an analysis of the data and the derived findings on MED house thermal performance. Some results based on energy load simulations of the MED houses is presented as well.

The contents of this report are organized into several sections. In the section immediately following this introduction, a summary of the results is presented. The intent of this summary is to identify the major results found in the analysis. Since this report is a preliminary analysis, the results can most frequently be interpreted as hypotheses or tentative conclusions. Sufficient study and re-examination of house performance (necessitating on-site visits) have not been done to confirm situations or conditions implied by the data.

The Sections 3 - 8 of the report focus on individual aspects of the MED houses. The emphasis in these sections is to provide a thorough review of the data analysis for, e.g., solar collectors, heating and cooling performance, domestic hot water preheating, and house thermal characteristics. The discussion presumes an understanding of very basic statistics; for the uninitiated, Appendix A contains a discussion of how statistics were used in the analysis.

Finally, Appendixes B and C contains the summary data on which analysis was performed. A list of variables with their definitions is included, as well as identification of the underlying assumptions contained in their use.

SUMMARY OF RESULTS 2

General

The Southern California climate is quite mild, and the MED houses are constructed with special consideration given to insulation, effective use of sunlight, and the application of active solar energy collection for space heating/cooling and domestic water heating. As a result, the houses required little heating or cooling if managed properly. Nevertheless the alternative operating conditions that occurred or were imposed on the houses, coupled with elaborate mechanical systems and extensive data collection have created an extraordinary opportunity for evaluating energy use and conservation potential for homes in Southern California.

Figure 2.1 presents a first pass perspective on how well the rental home performed for the months of January - August, 1978. The demonstration unit cannot be shown because of poor data. The dashed lines represent alternative houses, based on electric and gas meter readings. For the MED home, the lower line represents the electric and gas consumption (including solar collector pump - 15,000 BTU/day) as indicated by meter readings. The top line adds solar energy used, supplied by the collectors to derive a total energy consumption curve.

One can argue that the MED houses outperform all of the other units, although the results do not imply that all systems in the MED houses are economically feasible. For example, heating in the demonstration unit permitted too great a variation in interior temperature, apparently as a result of control problems. Whereas the demo also performed better than the comparable unit that employed conventional air conditioning in summer, its good performance is attributable to a well constructed house rather than an efficient air conditioning system.

Finally, this illustration should be treated gingerly because much of the variation may be attributable to differences among households rather than houses. Research at Princeton for a similar situation (i.e., "identical" housing) indicates that 2/3's of the variation in household energy consumption is attributable to household behavior.

Space Heating/Cooling

1) The space heating/cooling analysis is constrained to examination of heating in the rental unit in January-February, 1978, and cooling in the demo unit for May-August, 1978 for the following reasons:

   a) Heating in the demo unit occurred only in the afternoons occasionally, as if it operated only when someone forced it on. Temperatures in the demo floated between 41 degrees F and 75 degrees F in January-February, 1978.

   b) The data indicates only a few observations of air conditioning in the rental house in July-October, 1978.

c) Economizer cycle data is limited. In the demo, the economizer was intentionally prevented from operating. In the rental unit, fan times but not air flow data is available so that analysis is constrained.

Figures 2.1 through 2.4 illustrate heating/cooling performance in the two houses.

2) In the rental unit, heating occurred mostly in the morning at a rate of 29,000 BTU's per day and 3,000 BTU/Hr. The thermostat was not set back at night and temperatures seldom dropped below 68 degrees F. The demo unit, when it did demand heating, operated at a maximum rate of 4,500 BTU/Hr, based on 30 minute observations.

3) Eighty percent of the heat supplied in the demo unit came from solar storage. In the rental unit, 100% of the heat came from the boiler, even though solar storage had acceptable temperature levels. A control problem is suspected.

4) The air conditioning load in the demo unit was very heavy in comparison with the rental unit. In July - August, 1978, the demo required 270,000 (150,000) BTU's per day at a maximum rate of 24,000 BTU's per hour. The number in parenthesis is the energy removed from the house, versus thermal energy expended in the air conditioning system. The economizer was not allowed to operate, and presumably windows were closed. The rental unit required almost no air conditioning: 500 BTU's per hour average, only between 8:00 PM and 10:30 PM, totaling 9,000 (3,000) BTU's on the average day.

5) Solar Storage provided 30 - 50% of the air conditioning energy required in the demo unit. It was never used in the rental, possibly because storage temperatures might have been too low, but lending strength to the conclusion expressed in #3.

6) The temperature sensors on the coil were not calibrated, so energy added (heating) or removed (cooling) is reported according to temperature sensors located further from the coil.

7) In conjuction with #6, and other analysis, a mixing of cold coil water with hot chiller water may occur during air conditioning.

8) The boiler sometimes operates so that it is heating water returning to solar storage during air conditioning mode in the demo.

Domestic Hot Water

1) The demo unit was not examined for domestic hot water preheating and consumption. The volume of use was very low because it was not occupied by a family and the demo hot water heater was turned off.

2) In the rental unit, the total amount of water use, and the amount of hot water use, are roughly in agreement with MED Handbook projections. The distribution of use varies somewhat, apparently attributable to the occupant's lifestyle: usage is essentially shifted 3-4 hours later throughout the day. Some seasonal shifting of use is evident; more water is consumed in early afternoon during winter months, and this use shifts to late afternoon in the summer.

3) Evidently the flow meter for the hot water heater failed in May-August 1978, and September-October, 1977; thus identifying the amount of energy supplied via solar storage preheating versus the heater is difficult. Nevertheless the evidence suggests that preheating supplies 50-60% of hot water energy needs in winter (November-February) and of 100% of energy needs in the summer months. Figure 2.5 illustrates these findings.

Solar Collectors

1) The solar collectors performed with an overall efficiency rate of 40 - 50% in terms of energy stored versus incident insolation energy, on the basis of observations when the collectors were operating. This rate was achieved consistently throughout the year, except for the rental unit in June - August, 1978.

2) The solar collectors performed with an overall efficiency rate of 30 - 40% in terms of energy stored versus incident insolation, on the basis of all observations, i.e., including days when the weather was bad or start-up/shut-down difficulties occurred. This rate was consistent for both units throughout the year. Except for the rental unit in June - August 1978, collection rates ranged from 300 BTU/SF-day to 800 BTU/SF-day (January versus July, expected performance).

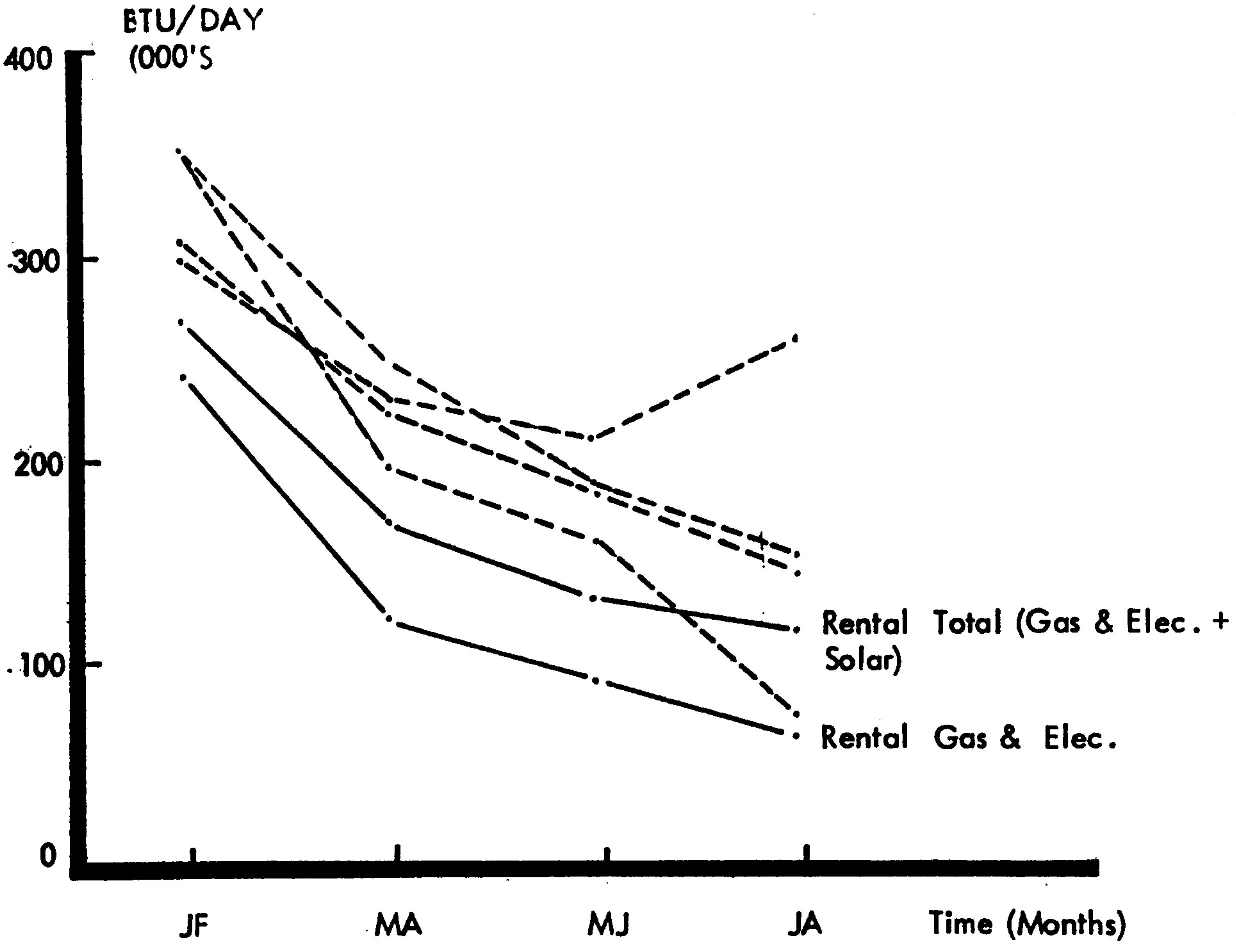
3) Both units experienced highly variant behavior in early morning and late evening, presumably associated with start-up/shut-down controls. Sometimes the units operated all night.

4) The data on the reject loop is too noisy to permit any detailed study, but some very tentative conclusions are that its use is too unstable. Either too much or too little energy is dumped, and the control system probably leads to cycling (off-on) with high frequency.

5) The rental unit apparently experienced difficulties operating in June-August, 1978. The tentative conclusion is that the internal use did not draw off much energy from storage in mid-afternoon, storage temperatures became excessively high, and as a result the reject loop was often needed.

6) Both units experienced a significant loss rate in the lines between the collector and storage, on the order of 5-10% of energy collected. The rental unit consistently lost twice the amount of energy as the demo unit. Losses appear to be related to collector water temperature. They could be explained by a 0.5 degree F drop in temperature over the lines, or by leakage in the rejection loop valve V3.

FIGURE 2.1



------ OTHER MISSION VIEJO HOMES

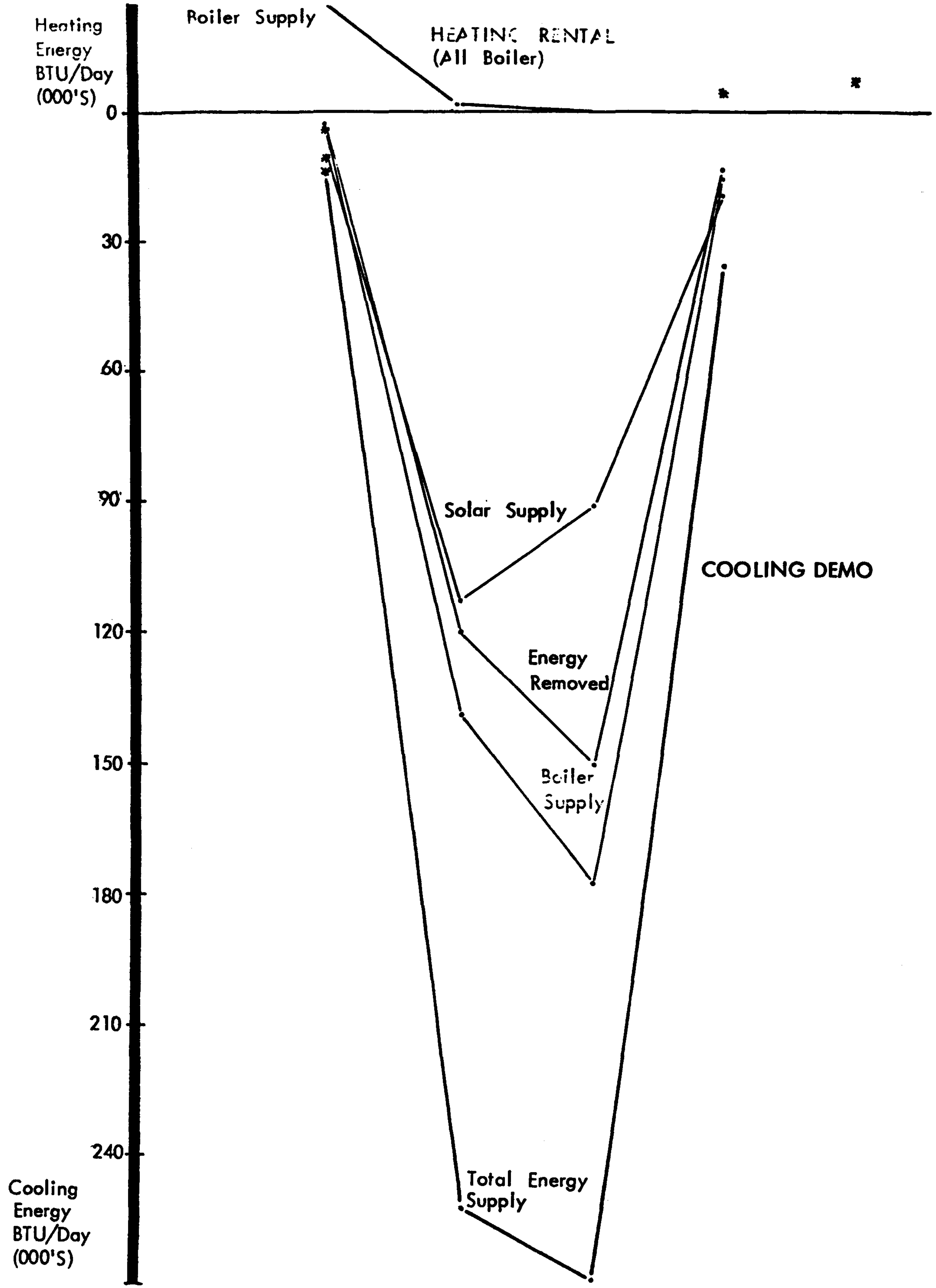

Heating Energy BTU/Day (000'S)
Boiler Supply
HEATING RENTAL
(All Boiler)
0
30
60
90
120
150
180
210
240
Solar Supply
COOLING DEMO
Energy Removed
Boiler Supply
Total Energy Supply
Cooling Energy BTU/Day (000'S)

FIGURE 2.2

FIGURE 2.3

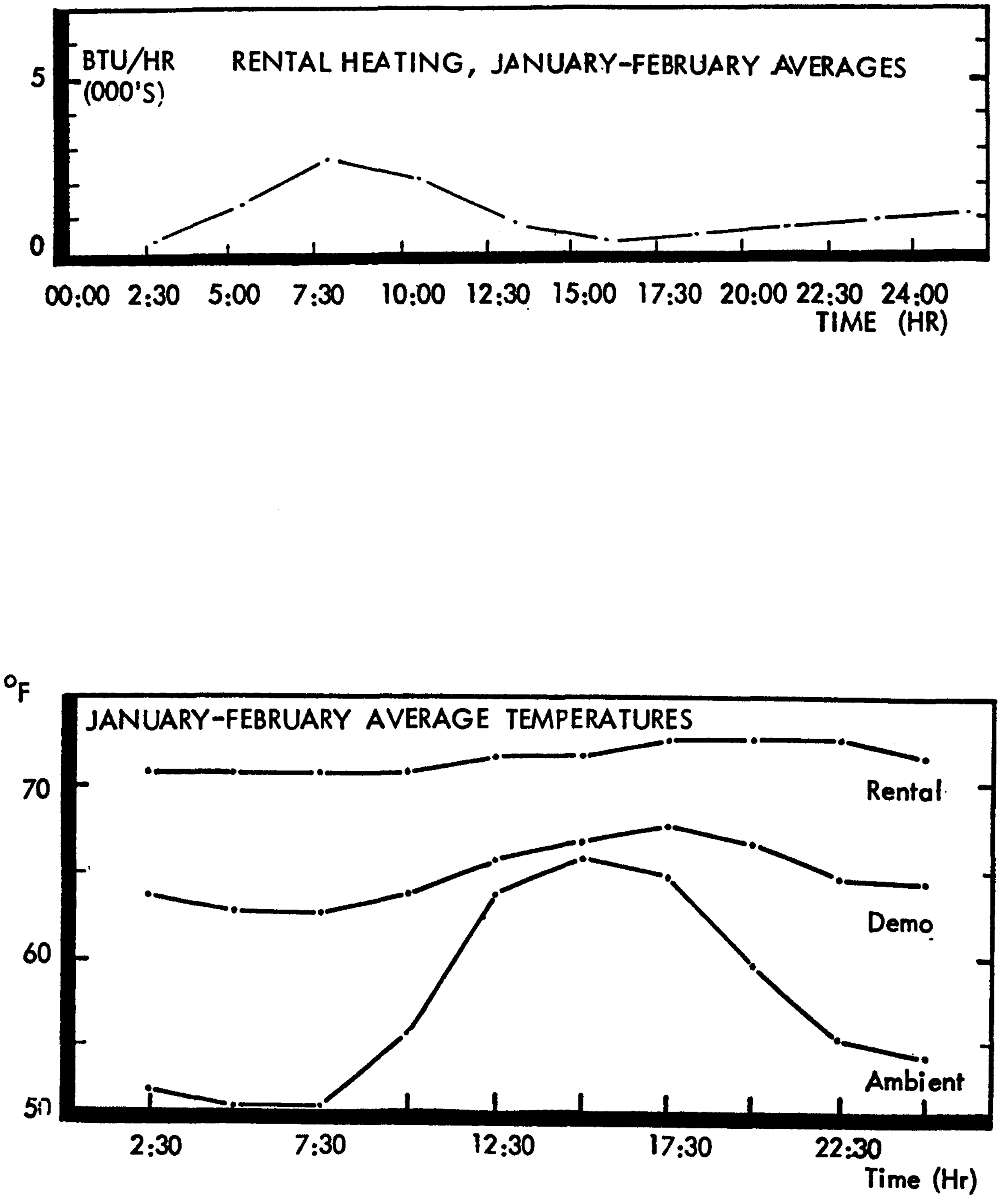
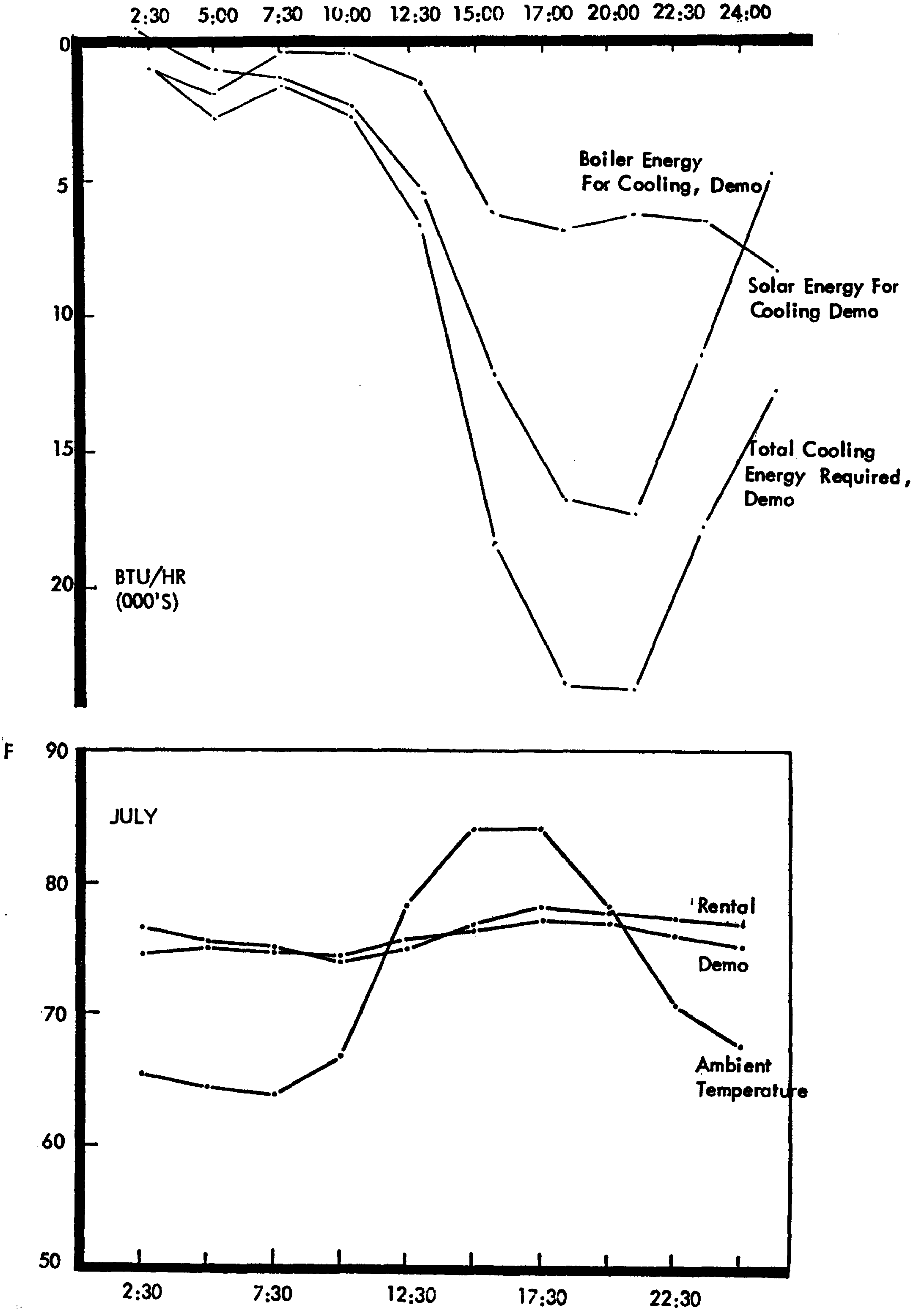

BTU/HR
(000'S)
RENTAL HEATING, JANUARY-FEBRUARY AVERAGES
5
0
00:00
2:30
5:00
7:30
10:00
12:30
15:00
17:30
20:00
22:30
24:00
TIME (HR)
°F
JANUARY-FEBRUARY AVERAGE TEMPERATURES
70
60
50
Rental
Demo
Ambient
2:30
7:30
12:30
17:30
22:30
Time (Hr)

FIGURE 2.4


2:30
5:00
7:30
10:00
12:30
15:00
17:00
20:00
22:30
24:00
0
5
10
15
20
BTU/HR (000'S)
Boiler Energy For Cooling, Demo
Solar Energy For Cooling Demo
Total Cooling Energy Required, Demo
F
90
80
70
60
50
JULY
Rental
Demo
Ambient Temperature
2:30
7:30
12:30
17:30
22:30

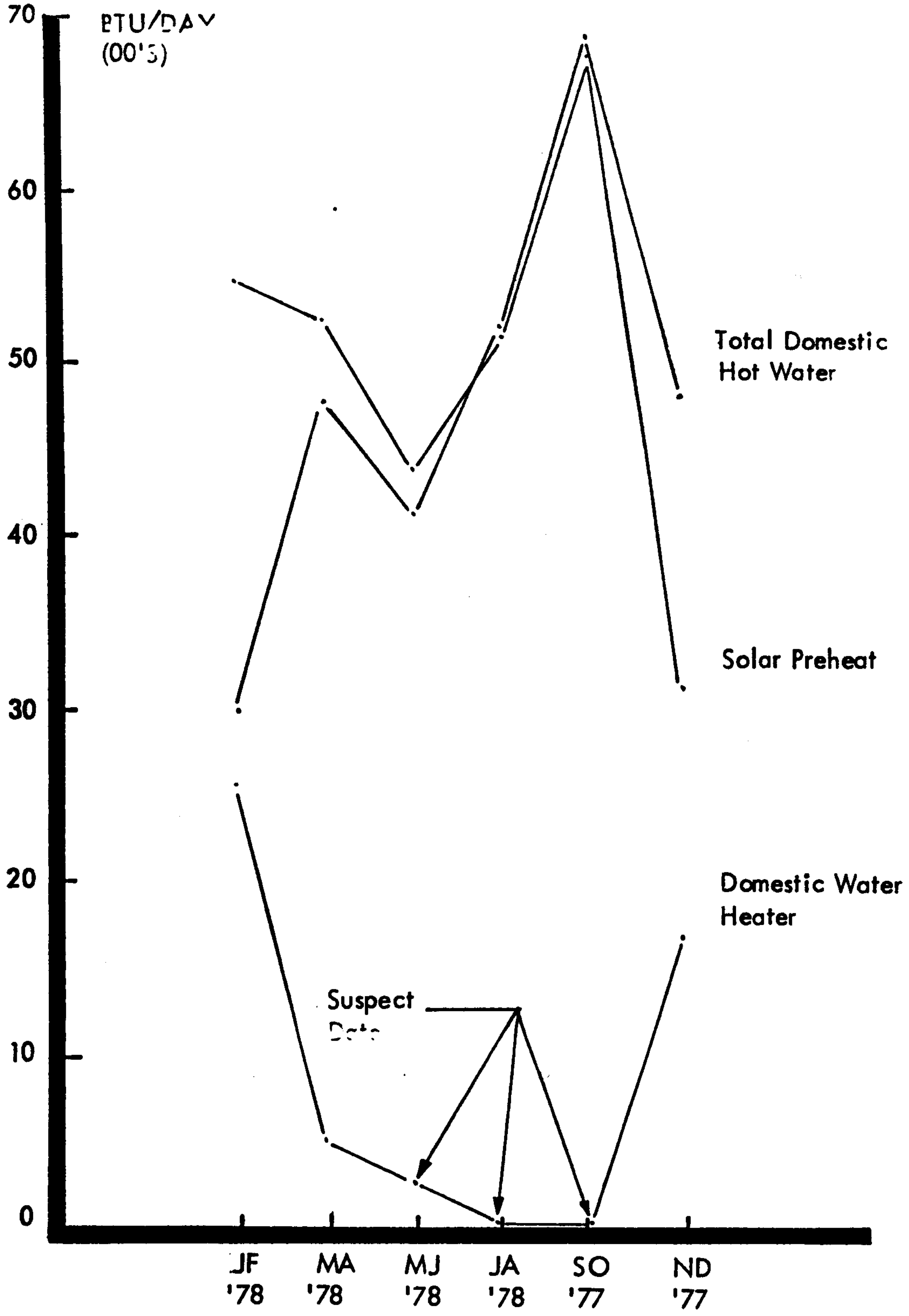

BTU/DAY
(00'S)
70
60
50
40
30
20
10
0
Total Domestic Hot Water
Solar Preheat
Domestic Water Heater
Suspect Data
JF '78
MA '78
MJ '78
JA '78
SO '77
ND '77

FIGURE 2.5

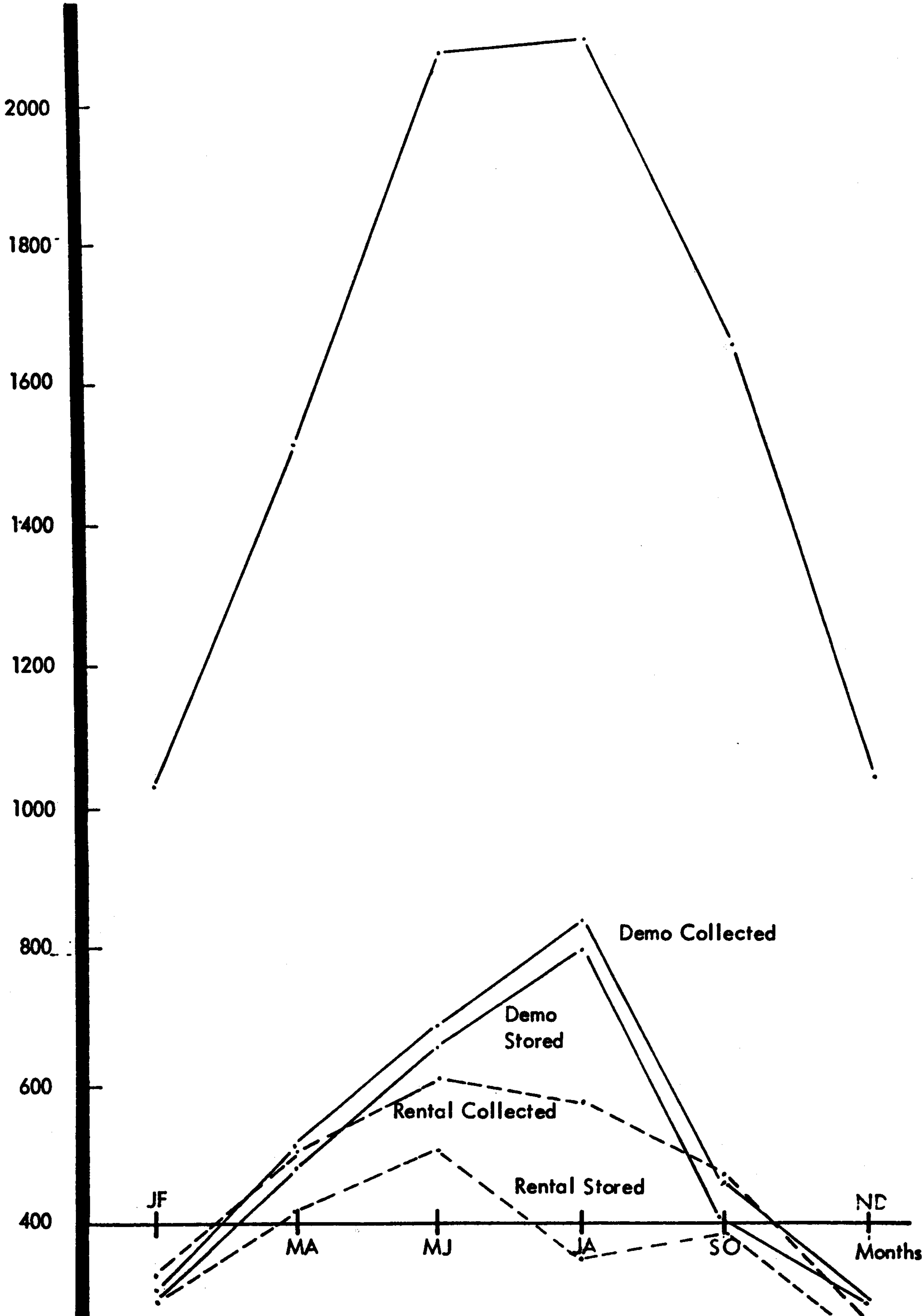

2000
1800
1600
1400
1200
1000
800
600
400
Demo Collected
Demo Stored
Rental Collected
Rental Stored
JF
MA
MJ
JA
SO
ND
Months

FIGURE 2. 6

7) An appreciable amount (50-90%) of the energy calculated as being stored cannot be accounted for in terms of measured use. While a more detailed study should be helpful, the tentative conclusion is that this energy is lost from storage via conduction and thermosiphoning. The "U" factors for the tank and the vault walls could account for 100% of the loss if no insulation existed in the vault. The more likely explanation is that a 6-12 gallon per hour flow from storage through the coil generated by thermosiphoning and undetectable with the flow meters used, can account for 100% of the loss.

System Performance: Cost/Benefit Projections

The following comments constitute a rough estimate of operating performance for the two houses. They are based on a synthesis of the material presented here.

Winter Operation

In January-February, the rental house requires approximately 30,000 BTU/day in space heating and 55,000 BTU/day for hot water consumption. The solar storage provides 30,000 BTU/day for domestic water heating, and it could provide more with an altered pre-heating coil design. The tank temperatures are not high enough and the domestic water is not stored long enough for greater transfer to occur. The pre-heating coil is 8" in diameter and extends horizontally through the center of the tank. An improved design might be larger in diameter having greater surface area and take advantage of high temperatures located near the top of a stratified tank.

The rental unit requires an average maximum rate of heating of 5,000 BTU/hr. Based on experience in the demo unit, the current design can supply at least 45,000 BTU/hr. The solar collectors as configured store 80,000 BTU/day in the winter. If the tank loss rate can be reduced, this amount is adequate to cover both domestic water and space heating needs. In addition to system capital costs, the operation requires a solar collector pump, a fan coil pump, and a fan. According to operating times in the rental unit, 30,000-50,000 BTU/day can be supplied for hot water heating at a (pro-rated) cost of 7,600 "electrical" BTUs/day for operation of circulating pumps to transfer solar energy + system amortization. Space heating (30,000 BTU/day) can be supplied at a cost of 10,480 "electrical" BTUs/day for operation of circulating pumps and air handling equipment to transfer solar energy + system amortization. This efficient use of solar energy would yeild coefficients of performance of 3.9 for domestic hot water heating and 2.9 for winter space heating.

Summer Operation

In summer, the ideal situation is 100% of hot water supplied from solar storage and use of an economizer cycle. The domestic hot water can be supplied at the rate of 50,000 BTU/day at a cost of 15,245 BTU/day + amortization. Since the collector stores 216,000 BTU/day, gross excess capacity exists. Initial computer modeling during the design of the MED house indicated that 8 modules at 256 sq.ft. would provide adequate heat production with a conservative safety factor.

However, due to the experimental nature of the project, the use of an unusual collector that had not been modeled before and the general feeling that overproduction is better than underproduction in a system equipped with a heat rejection loop. The gross excess capacity would indicate that the initial computer modeling was correct.

The economizer is used very little, according to our (somewhat suspect) data. This is because the residents often exercised the option to open the windows to maintain comfort. Nevertheless, economizer use can cost an average of approximately 391 BTU/day in electrical consumption with the use of natural ventilation for cooling when appropriate.

In contrast, an absorption chiller method of cooling is quite expensive. According to the demo unit performance, the chiller would require 260,000 BTU/day in thermal energy to remove 130,000 BTU/day from the house. Of this 260,000 BTU, approximately 100,000 comes from solar collection (MED system - capacity, storage tank size, etc.) at a cost of 15,000 electrical BTU/day, and 160,000 BTUs come from the gas fired boiler at a cost of 200,000 BTU/day in gas consumption. In addition, 3 pumps and two fans consume 80,000 BTU/day. The net result is 265,000 BTU of gas and electricity consumed plus equipment amortization, to remove 130,000 BTU from a house which could have been cooled alternatively with the economizer at a cost of approximately 400 electrical BTU/day averaged including the opening of windows when appropriate to maintain comfort. The coefficient of performance for the chiller/solar/blower system is approximately 0.5. These numbers, while derived from results of system analysis, check reasonably well against electric meter measurements.

Additional Research

The MED data collected to date has proven to be invaluable for studying energy use in Southern California housing. Nevertheless, much work can be done as a contribution to energy use/conservation in housing. For example, we have not really probed in depth as to how certain systems have operated; the analysis presented here is more of a summation of aggregate performance rather than an explanation of why performance occurred. In the solar collector analysis, we cannot at this time predict how much energy would be collected or stored even if we knew the supposedly important parameters such as isolation levels, air temperatures, flow rates, water temperatures, tube sizes, etc.

Much of the additional analysis can be performed with data that has been collected already. This situation is true with respect to the solar collectors, for instance. But the temperature sensors at the air handler coil were not calibrated until September, 1978. As a result, we have not been able to calculate the exact amount of energy provided to the house via the coil; instead, our calculations must include line losses, because energy is measured at the source rather than the destination. Data collected since September would provide some insight into the seriousness of line losses, which evidently are significant in the solar collectors.

Another major concern is that we do not know why or how the solar storage tank is losing so much energy. If it is attributable to thermosiphoning , a site study may identify this behavior. Otherwise, more extensive analysis of collector data should provide some insight.

ANALYSIS PROCEDURE 3

Data Collection And Quality

The data collected on the MED homes is described in Appendix B. Approximately 95 instrument readings were monitored every two seconds, averaged or cumulated over a 30 minute or 1 hour period, and recorded on cassette tape. A Hewlett Packard 98-25 computer performed this task. Later, the cassettes were transferred to a seven inch, nine track tape and shipped to CMU. Here, the data was analyzed on a DEC 20 with heavy use of the SPSS statistical analysis program.

The data appears to be in good condition from September, 1977, to August, 1978. A few earlier months, and to some degree September-October of 1977, contain suspect data. The main difficulty is that when the data was recorded, the interval which it represented was not recorded. The assumption must therefore be made that a recording of, e.g., 25 gallons of flow (cumulative) must have occurred since the previous data record (times were indicated). In the earlier months (July-August, 1977) record times were somewhat sporadic and flow data was not consistent, so this information was not used. Although most graphs presenting data by month show the sequence January, February... December, in fact the September-December data is for 1977, and January-August data is for 1978.

The data also contains several calibration measurements. Since most sensing devices provided electrical responses to phenomena, e.g. current as a function of temperature, and the devices were connected in series, each observation included line voltage readings. If the absolute voltage differed by more than ± 10,000 mv from 100,000 mv or the voltage differential in either house across the sensors in series exceeded ± 1.0 mv, the observations were discarded. With the exception of October 1977, few observations were rejected for calibration reasons.

All data was checked during preliminary analysis, as best as possible, to identify inconsistencies in data definitions and instrument calibrations. One concern is that a number defined as representing, e.g. temperature of water out of the solar collector, was exactly that, and not, e.g. temperature of water into the storage tank. Secondly, the data was checked for individual instrument calibration. The only observations that appeared out of line in this respect were the temperature sensors for the solar rejection loop and the water coil in the air handler. The rejection loop sensors may be acceptable for one or two month's of data in late summer, 1978. Otherwise, Mike Forster reported difficulties in sealing them from inclement weather, and their measurements are erroneous. The coil temperature sensors were not calibrated until September, 1978.

Generally, however, the data appears to be in excellent condition with respect to representing how the system performed. The MED houses represent an extraordinary opportunity to examine how a house and its mechanical equipment perform under normal practice, i.e. non-laboratory, conditions.

Data Analysis

The data on which much of this report is based included approximately 1,000,000 recorded instrument measurements. The bulk of these measurements were zeros, reflecting that most of the time few systems were in operation. The MED houses are located in a mild climate so that the only mechanical subsystem that operated frequently was the solar collector. Nevertheless, when subsystems operated, sufficient data was collected to reach conclusions on their performance.

Ideally, individual subsystems performance should be studied by examining the data on an observation by observation basis. One could then check for consistency in system operating conditions, e.g., the temperature maintained during nights in winter. This depth of study was beyond the scope of this effort; recommendations are made elsewhere regarding potentially valuable additional analysis.

In this study, most of the analyses were performed by blocking the data into two and one-half hour intervals over two month time periods. For example, the ambient temperature is reported as the average of all observations recorded between 12:00 Noon and 14:30, say, during the months of January and February. This approach assures that most numbers reported as averages are reasonably reliable, yet one can still observe changes in performance over a daily cycle and throughout a year. The only area where this approach did not work very well was domestic hot water use in the rental unit (it was not studied at all in the demo unit). Evidently, over any two month period the consumption of hot water, while essentially consistent for a day, occurred in large amounts during a few events each day. Further, the events were scattered throughout the day.

Data Extrapolation

In the following analyses of subsystems the problem arises as to how to extrapolate the observations to imply aggregate or cumulative performance. Suppose, for example, that we are examining the energy collected from the solar collectors between 6:00 AM and 8:30 AM. Over this time interval, if the data acquisition system is operating, five observations of the instruments are scheduled: 6:00, 7:00, 7:30, 8:00, and 8:30. The 6:00 observation represents performance between 5:00:01 and 6:00:00 and is discarded. Therefore, each two month block of this time interval could contain approximately (4)(60) = 240 observations. Typically, the data acquisition system would record roughly 140 observations, of which 40 would indicate that the solar system was operating. The 140 observations tended to be distributed uniformly throughout two months. The 40 solar collector observations, on the other hand, tended to be bunched; it is possible that the solar collector operated only 10 days in two months in this time interval (40 observations/4 observations possible each day). The more likely situation is that the collector operated 40/140 of the time that it was observed.

Unfortunately, the 40/140 of the time that the collector was observed to operate could have reflected that it either came on each day around 8:00 (40/140 of the observations possible in the 6:00 - 8:30 interval) or that the sun was stronger on some mornings than others, and the collector started earlier some days than others. Without more detailed studies, assumptions must be made.

Usually, the convention adopted was to describe collector performance both as observed in operation and extrapolated. Extrapolated results assume that the collector performed (e.g.) 40/140 of the time, and this performance was reported on a bi-monthly basis. The averages for each time interval in a day, summed over a day, provides a daily profile of how the collectors performed as observed (as if they had operated continuously for a day) and extrapolated (adjusted for non-performance).

As observed performance more closely approximates collector performance under "ideal" conditions, i.e. eliminating maintenance shutdowns, system failures, and in the case of the collectors, poor weather. Extrapolated performance more accurately represents actual or expected performance.

In the case of other systems, slightly different conclusions might be reached. When heating the houses, for example, typical water coil pump times tended to be short, e.g. five minutes per 30 minute observation. It is quite possible that the heating system was "on" and functioning properly in a 30 minute period without the pump operating. The observation data would report no performance so that "as observed" calculations would be inflated estimates of actual house heating performance.

WEATHER AND SOLAR COLLECTORS 4

Weather

The observations of insolation conditions are quite complete and provide one of the strongest indications that the data acquisition system was operating satisfactorily. The diffuse radiation measure, HHD, is suspect, however, because the metal band designed to block direct sunlight from the meter was not always positioned properly. Some efforts were made to extrapolate diffuse conditions, based on measurements of direct and diffuse insolation together, but these have not proven successful. One difficulty is that the band sometimes may block the sun partially, rather than all or none.

Figure 4.1 presents the insolation measured and adjusted to a standard rate of BTU/SF-HR. Each point represents the average of the observations recorded during that time interval. The time intervals were:

Interval	Duration
5:00 - 9:30	4.5 hr.
9:31 - 12:00	2.5
12:01 - 14:30	2.5
14:31 - 17:00	2.5
17:01 - 22:00	5.0

Thus Figure 4.1 does not indicate cumulative insolation for an interval, but rather a rate. In fact, the first and last intervals are of varying length, depending upon the season. Furthermore, the data is as observed; since the insolation measurements are quite complete, especially for 9:31 - 17:00, this data could be interpreted as extrapolated as well for this time interval.

Finally, the lines connecting the points are intended to visually demonstrate trends; since no data is shown between the points, curve fitting in more detail is not possible.

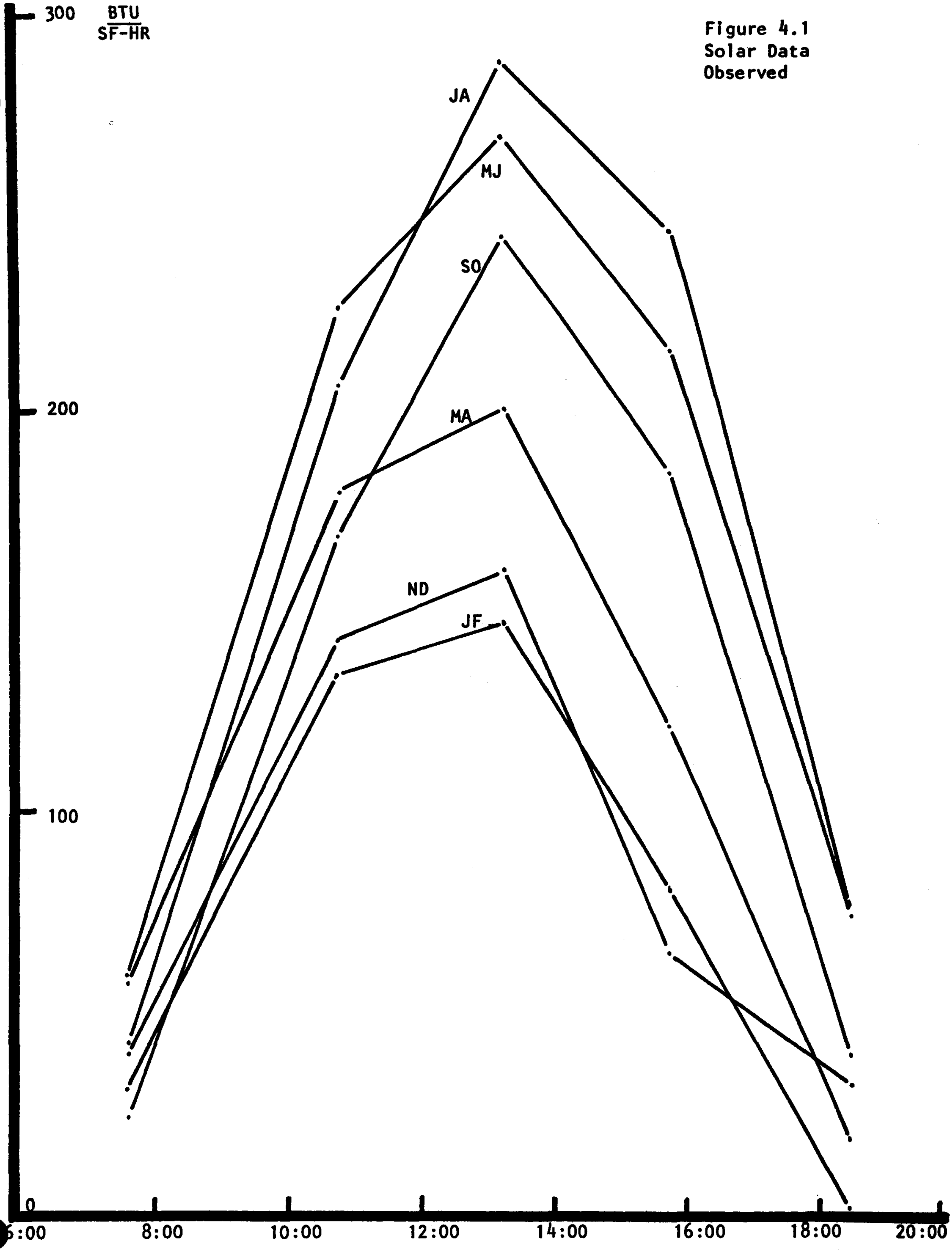
The month key, used throughout the report is:

JF	January - February, 1978
MA	March - April, 1978
MJ	May - June, 1978
JA	July - August, 1978
SO	September - October, 1977
ND	November - December, 1977

No unexpected weather data conditions arose, and the measurements agree with projections in the MED Workbook. The weather did of course fluctuate from hour to hour, and these variations are apparent in the data (Appendix B). These variations are worth exploring further because collector performance varied according to actual insolation levels. In some regions, shutting down the collectors when heavy cloud cover occurs may be worthwhile.

Finally, throughout all of the graphs, a "*" will denote a data point for which the standard error exceeded ± 10% of the average value (Appendix A). Translating, each data point represented by a "." is, statistically speaking,

Figure 4.1
Solar Data
Observed



Solar Incidence on Collector Surface (HPC), Average over 2 months for five intervals
*Denotes statistically unreliable calculation

calculated to be within ± 10% of the true average (mean) value. This condition does not hold for data points indicated with an "*". (In some graphs, a "+" indicates data that is borderline, i.e. roughly ± 10% of the mean. This conversion was dropped in latter analysis.)

Measuring Collector Energy

In the following analyses the energy measured will be either energy collected at the collector or energy placed in storage. The calculations are:

$$E \text{ collected} = \frac{(\text{FSC gal/observation})(\text{TS4-TS3 }^{\circ}\text{F})(8.333 \text{ BTU/gal-}^{\circ}\text{F})(60 \text{ minutes/hr})}{(\text{DUR minutes/observation})(270 \text{ sq.ft.})}$$

$$E \text{ stored} = (\text{FSC})(\text{TS1-TS2})(8.333)(60)/((\text{DUR})(270)),$$

each measurement thus being in BTU/sf-hr, where 270 sq.ft. of collector are assumed. The E stored is presumably net of rejection loop behavior; the temperature sensors TS1 and TS2 are indicated to be near the storage tank.

The flow meter values were typically based on a full 30 minutes of pump operation, with flow rates varying between 1.5 and 9.0 gal/min. According to Mike Forster, the meters are accurate to ± 10% for flow rates above 1.0 gal/minute. The temperature sensors are accurate within ± 0.25°F each. With temperature differentials averaging (roughly) 10°F, the potential error from the calculation is (10%)(.5°F/10°F) = 15%.

Unfortunately, the flow meter is located (according to sensor diagram, Appendix B) near the storage tank outlet (to the collector). Any leaks or boiloffs in the collector, resulting in loss of water returned to storage, will inflate the reporting of energy collected and stored.

No means is available for monitoring leakage, because the volume of make-up water added to the collector system is not recorded. A check was made to identify observations in which the water leaving the collector exceeded 215°F or, more strongly, 220°F. The amount of energy reported as collected under these conditions was negligible (e.g., less than 3% error in daily extrapolated totals). Furthermore, although 220°F was used here as a boundary value for possible boiloffs, boiloffs probably did not occur until temperatures exceeded 140°F (communication with Dick Rittelmann). This condition occurred very rarely. Most interestingly, observations of $TS4 > 215^{\circ}F$ were relatively frequent throughout the year from September '77 until May - June, 1978. Zero incidences occurred in July - August, 1978, suggesting a significant change in system performance. No changes were reported in the site maintenance logs except changes in pumps and therefore flow rates. The effect of these changes is not discernible (if it is non-zero) with the blocked data, however.

Collection Performance

Figure 4.2 illustrates the performance of the collectors as observed throughout the day for the months of (January - February, and May - June). These were typical winter and summer months. In January - February (1978), the collectors performed consistently the same throughout the day, and averaged 52% and 48% efficiency (demo and rental, respectively): i.e., 52% of incident insolation was captured during the time intervals observed.

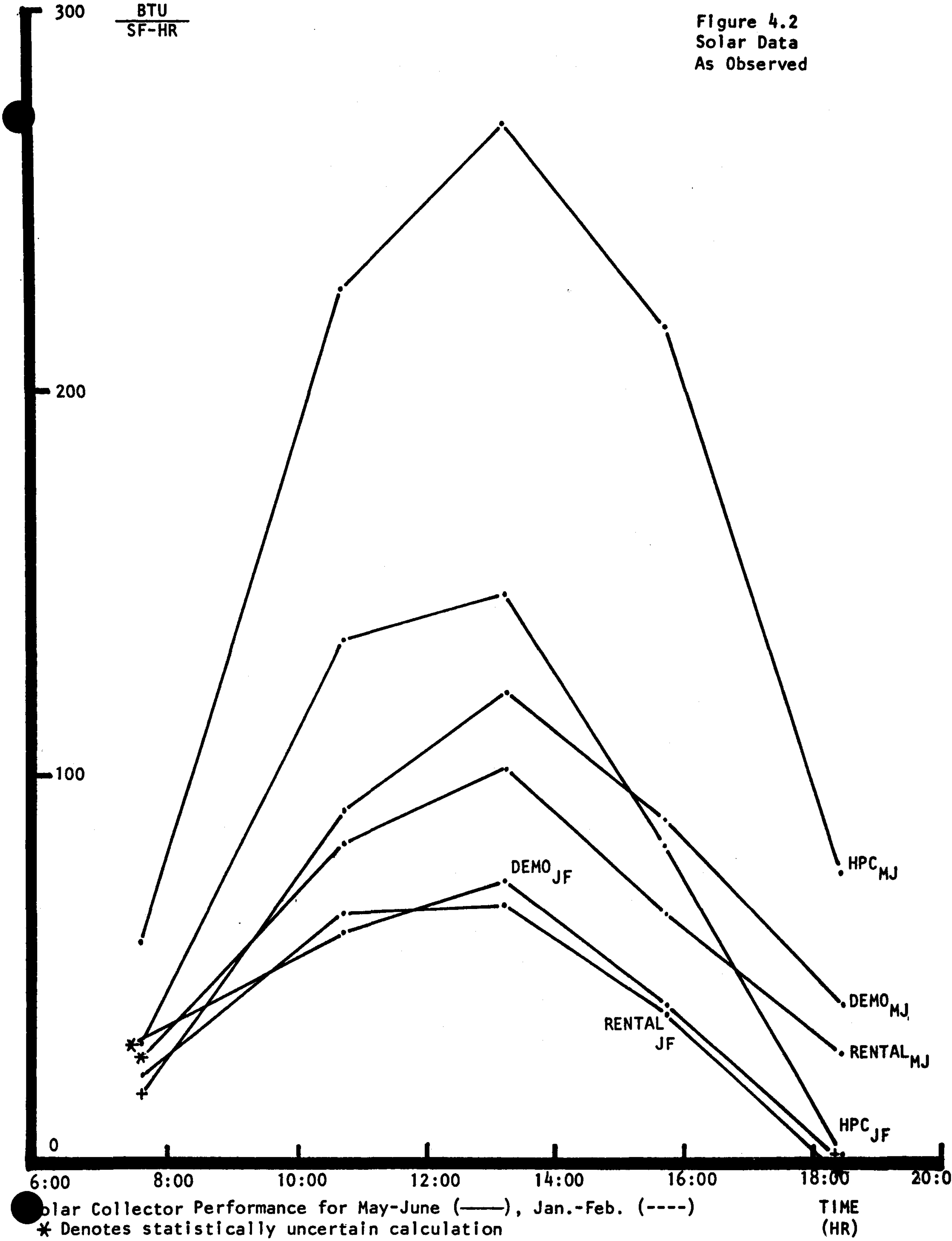


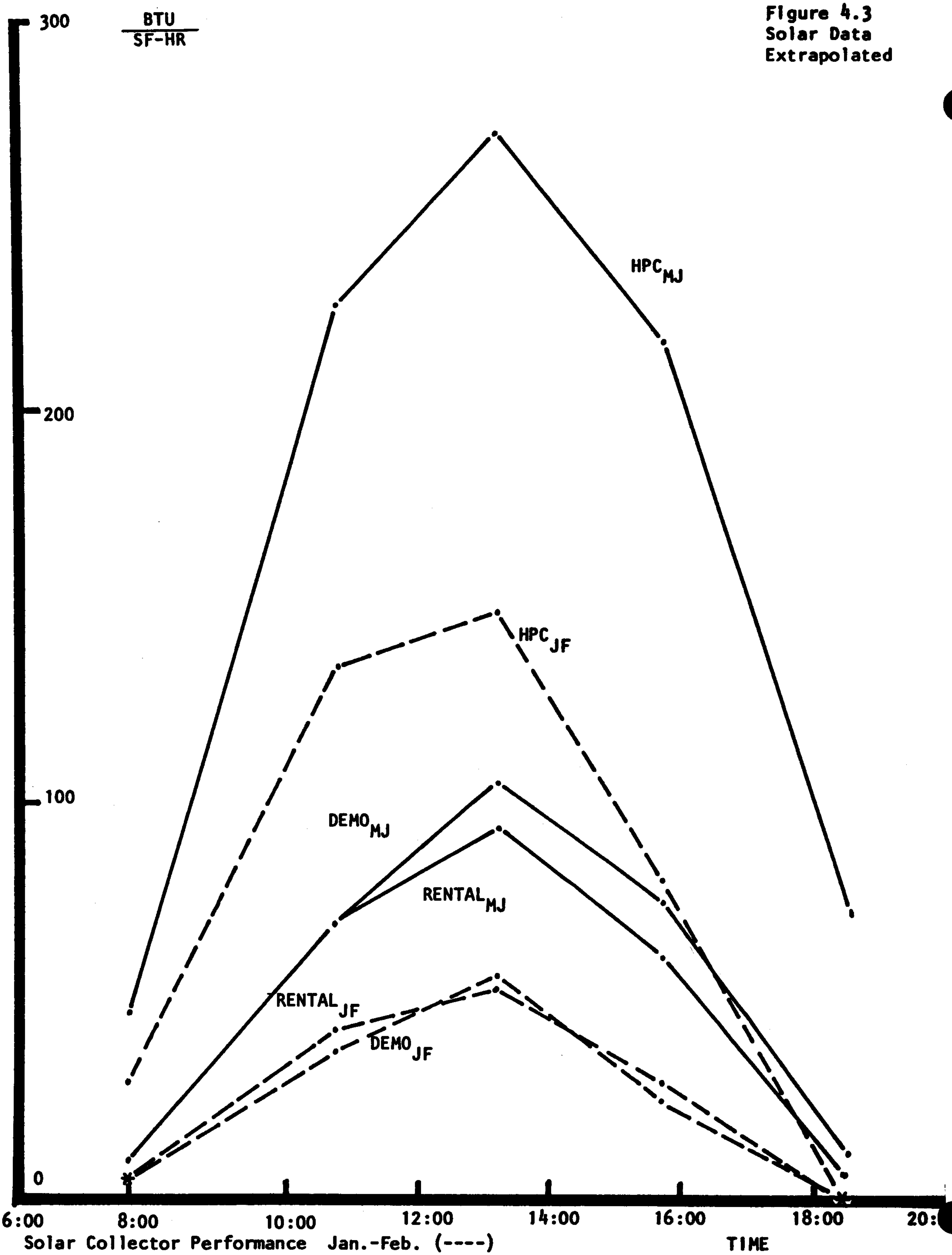
Figure 4.2
Solar Data
As Observed

olar Collector Performance for May-June (——), Jan.-Feb. (----)

* Denotes statistically uncertain calculation

\+ Denotes statistically suspect calculation

Figure 4.3
Solar Data
Extrapolated



Solar Collector Performance Jan.-Feb. (----)
May-June (____)

* Denotes statistically uncertain calculation

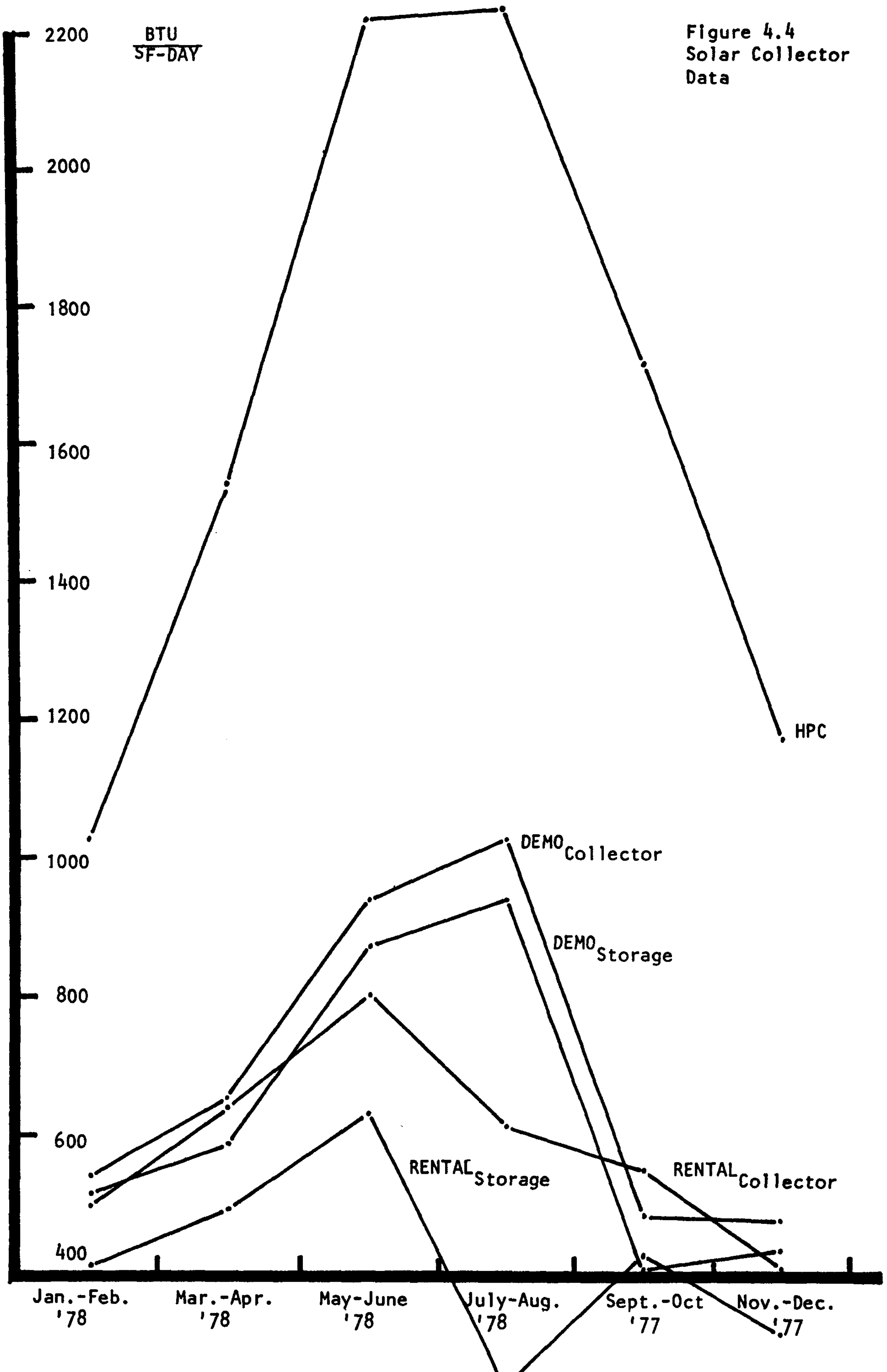


Figure 4.4
Solar Collector Data

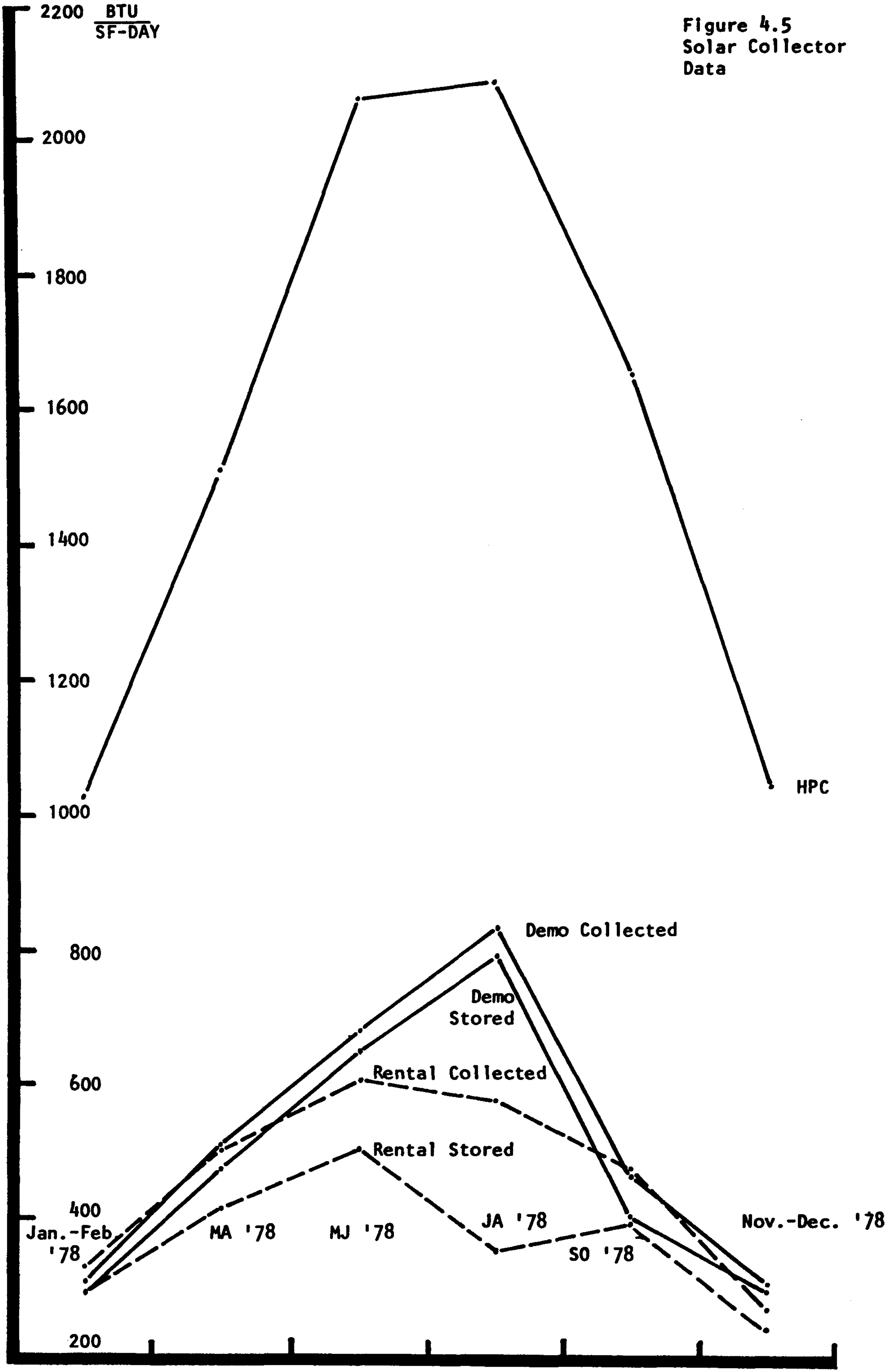


Figure 4.5
Solar Collector
Data

In the early morning and late evening hours performance varied substantially with losses actually realized on some days, especially evenings in January - February in the rental house.

The May - June data reports a greater discrepancy between the two houses, especially in the afternoon. Whereas collector efficiency in the demo dropped to 42%, the rental realized only 36% efficiency. The cause of this discrepancy is not known, but is suspected to be extremely high collector temperatures reached in the rental unit. This issue is discussed in more detail later.

Figure 4.3 repeats the Figure 4.2 analysis but with extrapolated data. The major change is that early morning performance is reduced, one argument being that the weather is not always as good in the early morning so that average morning performance is reduced. The efficiencies thus drop, as summarized in Table 4.1. Significantly, the efficiencies drop more in January - February than in May - June; in fact the extrapolated data indicates that the demo unit performed better in May - June. In January - February, the rental unit performed better.

Table 4.1

Collector Efficiencies (%)

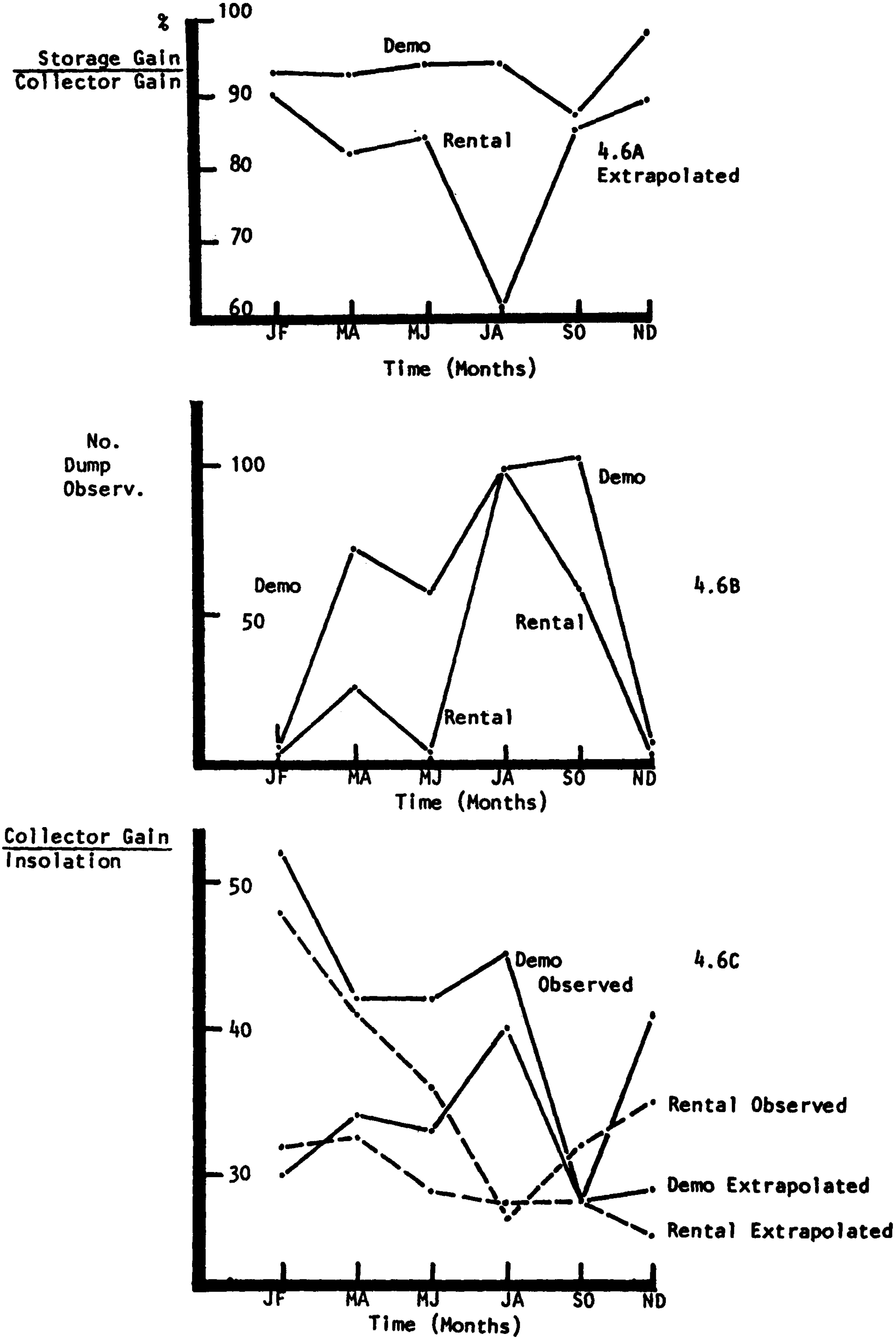
		As Observed		Extrapolated	
		JF	MJ	JF	MJ
Demo	Collection	52	42	30	33
	Stored	95	93		
Rental	Collection	48	36	32	29
	Stored	81	78		

Annual Collector Performance And Storage Issues

Figures 4.4 and 4.5 illustrate collector performance throughout the year on a daily basis as observed and extrapolated, respectively. Both graphs emphasize several general trends which one expects: total collection rises with increases in insolation levels, for example. This study does not identify whether the increase in energy collected is attributed to a longer duration for sunlight (in summer) or an increase in its intensity. It is probably attributable to both, up to a maximum intensity.

In general, the collectors realized a 30 - 40% efficiency rate with respect to energy collected versus incident energy, based on extrapolated data. According to observed data, the rates were approximately 40 - 50%. (Figure 4.6C). Which situation is the more accurate cannot be determined without further study. The number of observations showing collector operation in the early morning and late afternoon is a major source of the discrepancy between extrapolated and as observed data. If the fewer observations can be attributable to weather

Figure 4.6 A, B, C
Solar Collector
Data



variations, then the extrapolated data represents the expected efficiency, considering weather. If the difficulty is, say start-up/shut-down control problems (known to exist-personal communication with Mike Forster), then the observed data may better represent "good" system performance.

Both Figures 4.4 and 4.5 emphasize operational difficulties experienced by the rental collector. The major anomaly is the drop in collection and storage efficiency in the rental unit in July-August and (less severely) in May-June. First, the collector realized a considerably lower rate of collection across the collector, consistently throughout the day. The cause of this change has not been identified, although one suspected source is some alterations to collector tube diameters and/or pump speeds. As Figure 4.6B indicates, the rental collectors experienced an unusually high rate of rejection loop use in July-August, relative to the rate in other months (number of observations in which the reject loop was utilized). Still, the rate is not abnormal relative to the demonstration unit; furthermore, it is low in May-June, but rental performance in May-June was also low relative to trends in both rental and demo units.

What is equally peculiar but probably related is that the storage rate in the rental unit was dramatically down in July-August. An initial reaction is that the high use of the reject loop caused the system to lose too much energy which could not be made up at the collector. Perhaps this reason partially explains what happened, but it isn't the full answer. Large losses in the reject loop would lower the temperature of the water entering the collector and marginally improve the collector efficiency. This condition did not occur.

Another suspected cause, mentioned earlier and discussed later, is that the rental unit achieved extremely high operating temperatures in the afternoon. These high temperatures reduce collection rate efficiency and, through higher temperature differentials between collector water and ambient conditions, increase losses.

In general, we see from Figure 4.6A that the collectors performed consistently (barring July-August in the rental unit) with respect to returning energy from the collector to storage. The interesting point is that the loss rate (energy collected - energy stored) for the rental unit was consistently twice the loss rate for the demonstration unit. This loss rate, in May-June, for example, contributed a 10% efficiency difference (92% versus 82%) between the demo and rental units. This difference corresponds to a 0.3°F additional temperature drop between the storage tank and the collector (round trip, excluding collector) assuming a 4.5 gal/min flow rate. The loss rate is highest in summer months (ignoring July-August) and lowest in January-February. Since the loss cycles rather than increases monotonically over a year as well as daily, it appears to be related to temperature differentials between solar collector water and ambient conditions. Probably the rental unit has a piece of pipe insulation either missing or wet, an extra exposed pipe strap, a leaky dump valve, or some other perturbation which can cause an additional energy loss. Without identifying the exact cause no definite answer can be given, but the smallness of the necessary temperature drop, 0.3°F, contrasted with the magnitude of the loss, emphasizes the seriousness of very small and seemingly inconsequential design details on performance. This argument will occur frequently in subsequent analysis.

Control Problems, Projection, and Stability

The data indicates that serious control problems existed in the collector systems as far as turning the pumps on and off was concerned. In fact, the pumps never shut off some nights. The result is that the collectors actually performed somewhat more poorly than was indicated in the earlier figures. Since the collectors were designed to minimize energy re-radiation, and the number of overnight operations were few, the losses were negligible.

The crux of the start-up/shut-down problem is identifying the proper condition for collecting energy. In fact a few observations scattered throughout the day indicated net loss of energy (presumably) if insolation levels dropped too low. This problem should be studied in more detail.

The rejection loop data is inadequate to generate any firm conclusions without a very detailed examination of the data, observation by observation. With the exception of July-August, the rental unit operated with consistantly lower temperatures throughout the day (Due to house loads on solar storage - Section 8). Because the reject loop temperature sensors were unreliable, it is difficult to state more than tentative hypotheses, based on casual observation of reject data. What appears to happen is that the reject loop ejects a significant amount of heat. The signal to employ it, however, is the water temperature at the collector outlet. As a result, the system may cycle between reject loop on, outlet temperature low (turn loop off) to outlet temperature high (with loop off) so loop is turned on. Table 4.2 indicates the percentage of observations in which the reject loop was on at least part of the time. The time periods here are slightly different; periods 1 - 9 account for the first 22.5 hours of each day, in 2.5 hour intervals. Period 10 is 1.5 hours long; 22:31 - 24:00.

Figure 4.7 provides a scatter plot of the percentage of observed reject loop observations as a function of storage tank temperature for time periods 5 - 7. The concept is that periods 6 and 7 cover the most intense insolation levels and are most likely to incur reject loop use. Period 8, while experiencing high storage temperatures, is a time interval well past peak sunlight hours. This graph suggests that a rule for regulating reject loop activity might include the time of year, time of day, and storage tank temperatures. Since these figures represent averages, however, more detailed studies would be helpful.

Regressions

In the beginning an attempt was made to identify (statistically) a relationship between collector performance and such conditions as insolation levels (direct and diffuse), collector inlet temperatures, water flow rates, and other such variables. Such a relationship might be linear (or long-linear), such as

$$E \text{ collected} = a + (b)(HPC) + c(TS2-TAD) + d(FSC/DUR),$$

where a, b, c and d are derived coefficients for the parameters. The relationships found to date have not been significant, however, and shed little insight on the problem. The only statistically strong relationships found were that collection rates are quite dependent upon insolation levels, and losses (energy collected-energy stored) is related (weakly) to temperature differentials.(TS2-TAD).

Several reasons can be given for the poor results which suggest that additional study would be rewarding. First, much confusion existed among Mike Forster, Luanne and Bob Kobet, and Alton Penz as to what the insolation measurements HPC, HH, and HHD represented (i.e., perpendicular direct insolation, direct and diffuse insolation, the perpendicular component of direct plus diffuse, etc.). That confusion has been eliminated. Secondly, the data used was for May-August of 1978, under the premise that this data was the most complete. As Figure 4.5 indicates, however, the average insolation levels were relatively constant, yet average collector performance (in the demo unit - the rental unit was ignored) changed substantially. The cause(s) of this behavior have not been identified and provoke questions of two forms: a) What information is necessary to account for system performance (how much data, what kind, what are minimum intervals of observation) and b) what conditions actually affect system behavior?

MED Analysis
January 14, 1979
Alton Penz

TABLE 4.2
SOLAR STORAGE TEMPERATURES, REJECT EVENTS

Months	D/R	T/RE	Periods						Possible Boiloffs	Totals, Avg
			1-4	5	6	7	8	9-10		
Jan-Feb '78	D	T		131	136	144	146		3	
		RE	0/0.0	0/0.0	4/2.2	1/0.5	0/0.0	0/0.6		5
	R	T		111	115	122	127		4	
		RE	0/0.0	0/0.0	0/0.0	2/1.1	0/0.0	0/0.0		2
Mar-Apr '78	D	T		151	160	173	169		8	
		RE	0/0.0	6/2.4	36/16.3	30/13.9	0/0.0	0/0.0		72
	R	T		139	148	159	165		0	
		RE	0/0.0	1/0.4	14/5.8	9/3.8	1/0.4	0/0.0		25
May-Jne '78	D	T		160	166	175	174		26	
		RE	0/0.0	2/1.4	14/9.0	26/18.6	15/4.5	0/0.0		57
	R	T		150	163	175	185		12	
		RE	0/0.0	2/1.4	1/0.6	0/0.0	0/0.0	0/0.0		3
Jly-Aug '78	D	T		169	183	193	197		0	
		RE	0/0.0	0/0.0	28/13.7	61/34.1	9/1.9	0/0.0		98
	R	T		176	188	197	202		0	
		RE	0	1/0.5	17/7.9	75/45.4	6/1.3	0/0.0		99
Sep-Oct '77	D	T		168	172	185	188		16	
		RE	0	1/0.6	42/33.1	47/37.9	3/1.2	0/0.0		102
	R	T		155	164	178	185		57	
		RE	0	0	20/13.4	33/23.9	5/2.1	0/0.0		58
Nov-Dec '77	D	T		139	146	156	158		1	
		RE	0	0	5/1.9	1/0.4	0	0/0.0		6
	R	T		120	125	132	127		1	
		RE	0	0	2/0.7	0	0	0		2

Key for RE: n/r n = # positive observations
r = percentage of total observations

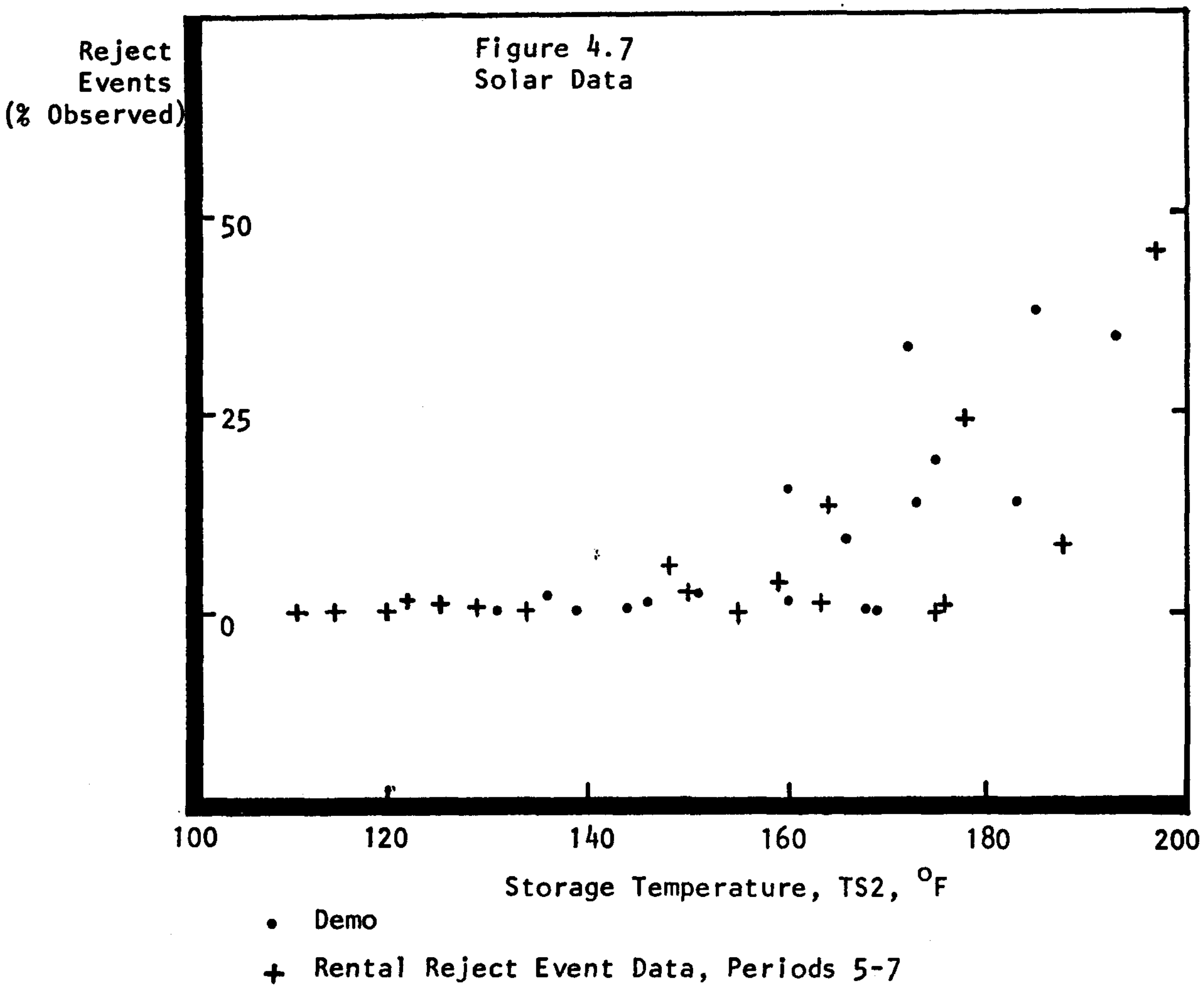


Figure 4.7
Solar Data

SPACE HEATING AND COOLING 5.

The data accounting for space heating and cooling is very much a case of "good news and bad news" in terms of supporting conclusions. In terms of substantive results, some very interesting relationships were revealed. The basic approach adopted for analyzing the space heating/cooling loads via the recorded observations was the blocking method described in Section 3. Unlike the solar data, however, the entire day was examined so that the intervals examined were:

Number										
Interval	00;01- 2:30	2:31- 5:00	5:01- 7:30	7:31- 10:00	10:31- 13:00	13:01- 15:30	15:31- 17:00	17:01- 19:30	10:31- 22:00	22:01- 24:00
Duration	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.0

The values calculated were the amounts of energy provided by solar thermal storage or boiler for space heating or cooling, the amount of energy picked up by air handler coil (cooling mode), and the energy ejected by the evaporative tower. These values were calculated as:

$$\text{Energy Rate} = \frac{(\text{Water Flow})(\text{Temp. Differential})(8.333\ \text{BTU/gal.-F}^{\text{O}})(60\ \text{Min.})}{(\text{Duration of Observation})}$$

so that the resulting figures are reported as BTU/hour. The same estimates of accuracy apply as were described earlier in Section 4, except that the temperature differentials were often smaller, so that accuracy is reduced.

Unfortunately, the coil temperature sensors were not calibrated until September 1978, so the measurement of actual BTU's entering or leaving the house cannot be directly calculated. Possible backup measures are also inadequate. Presumably, the temperature of air returning from the house corresponds to interior house temperature (TIN), whereas the temperature of air sent into the house will differ from house interior temperature. According to Mike Forster, the only air temperature measured was of air returning from the house. Furthermore, the air flow measurements consistently reported much lower flow rates than can be assumed to have occurred, so that energy added or removed from the house cannot be measured via air flow.

The energy removed from the house during cooling is measured as a temperature differential across the absorption chiller (TC2-TC1). The possibility exists, however, that the cold water coil loop and the hot water loop for driving the absorption chiller are in physical contact. In fact, the water might be mixing. Thus calculations of energy removed via cooling may include energy removed from the hot water loop.

The economizer never operated in the demo unit, intentionally by design. On the other hand, in the rental unit, the economizer was on less than 5% of the time between 12:00 and 22:00 in July-August, and almost never at any other time. This situation is partially explained by the fact that the rental unit was fitted with a signal mechanism to inform the occupants when they could open windows. The lack of air flow data presented further economizer data analysis in the rental unit. Nevertheless, it is difficult to believe that in a year's worth of observations, the windows were always open when needed.

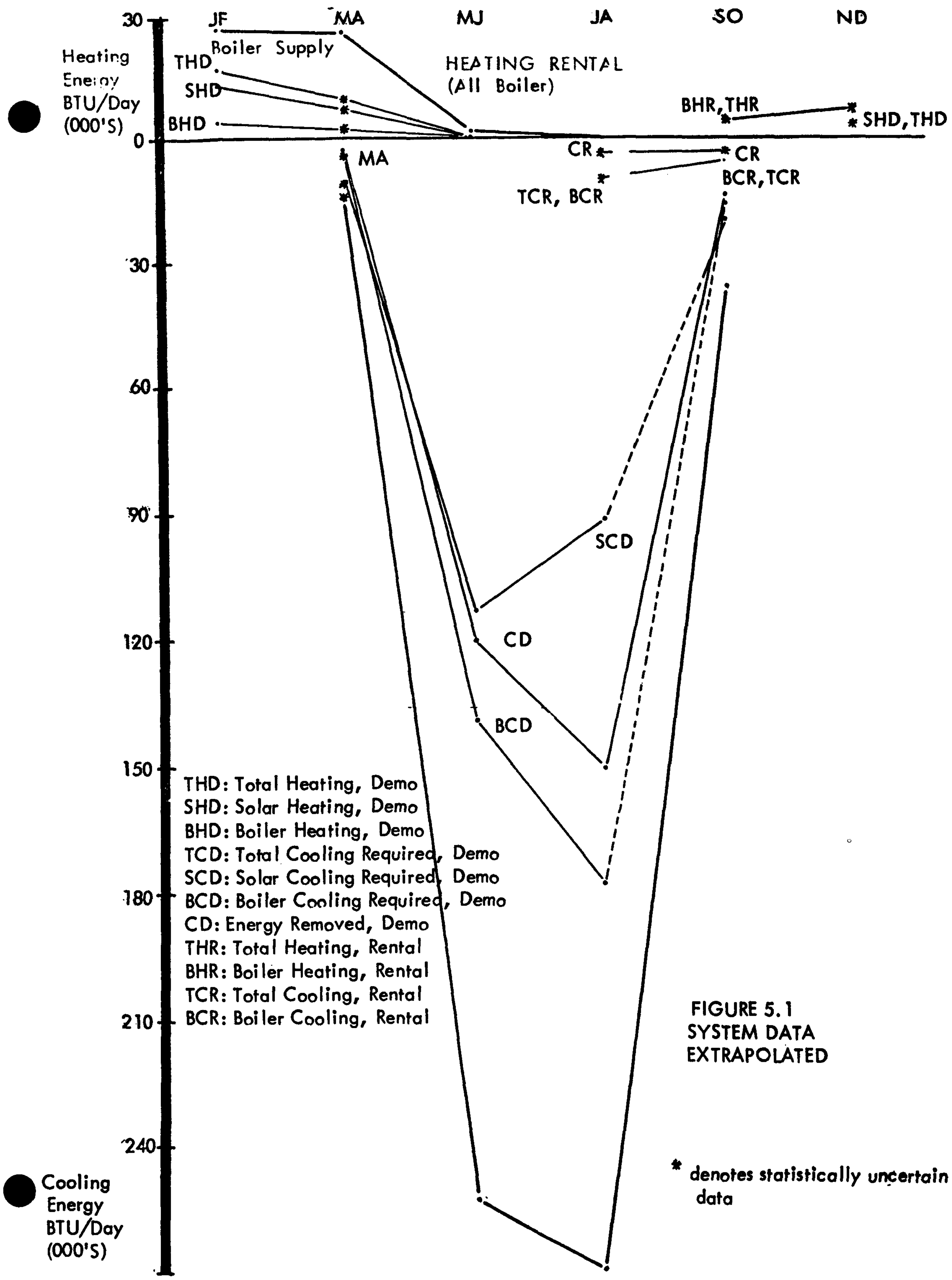


FIGURE 5.1
SYSTEM DATA
EXTRAPOLATED

* denotes statistically uncertain data

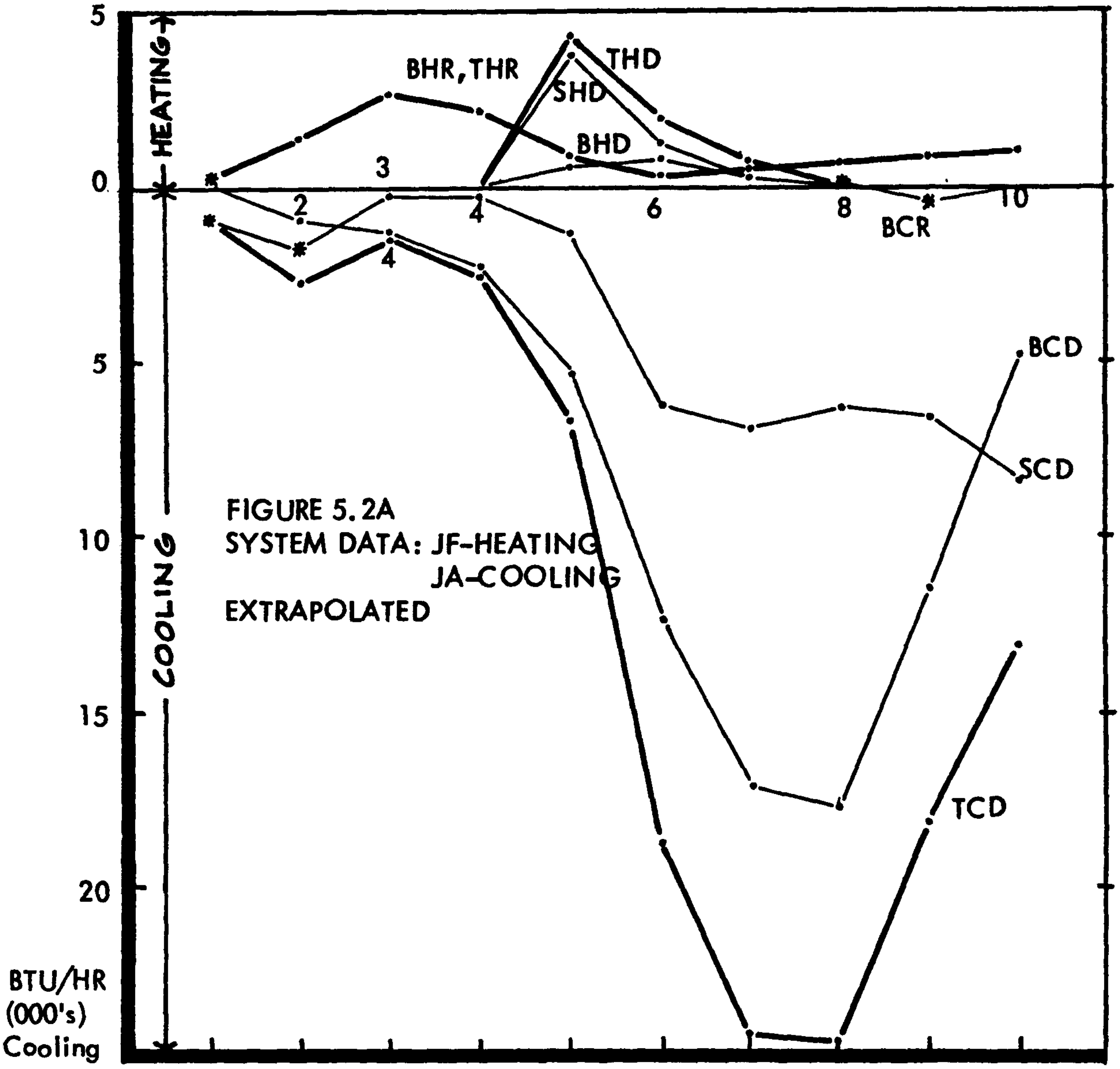


FIGURE 5.2A
SYSTEM DATA: JF-HEATING
JA-COOLING
EXTRAPOLATED

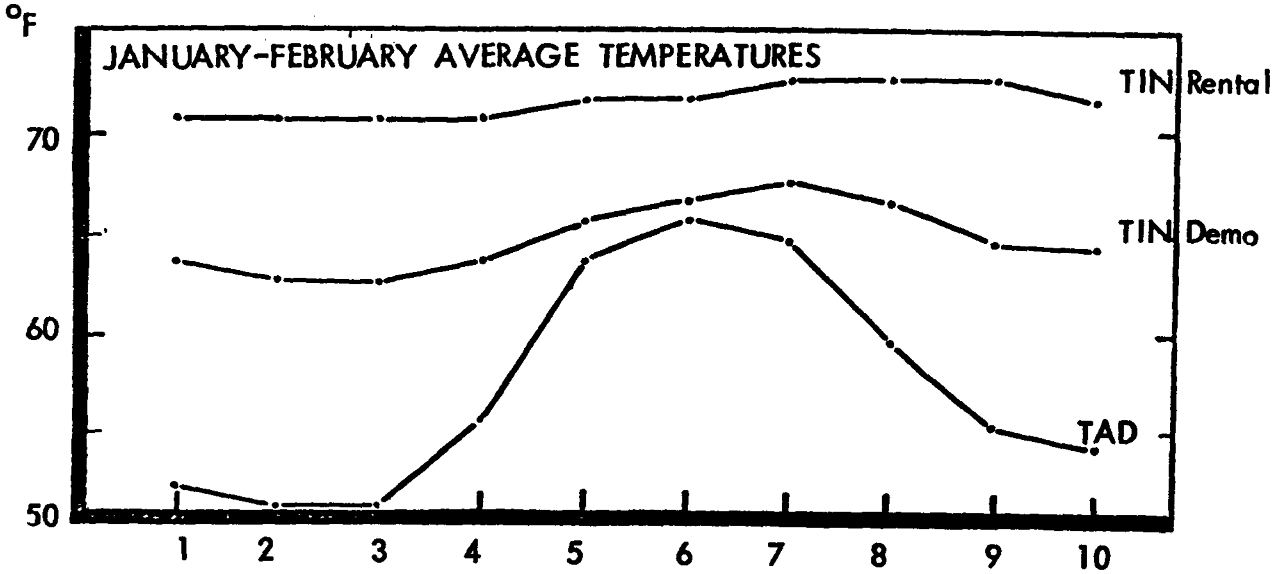


FIGURE 5.2B

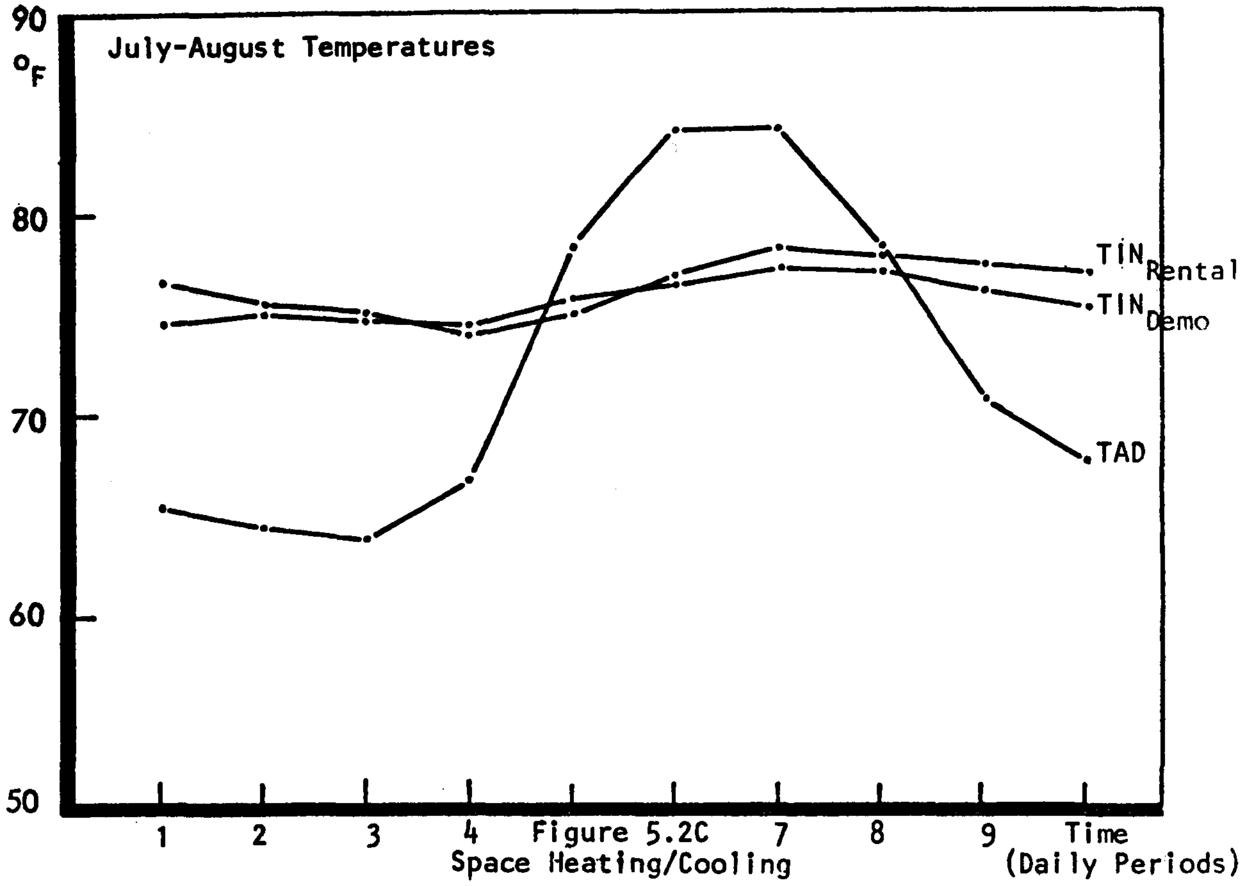


Figure 5.2C
Space Heating/Cooling

A control problem does exist in the rental system, however, because energy from solar storage was never used for either heating or cooling in the year observed. The storage temperatures were quite adequate during both heating and cooling periods to justify its use. Instead, the boiler was used exclusively.

Finally, heating/cooling data for both units in March-April, September-October, and November-December is extremely difficult to analyze because both heating and cooling occurred but neither was in sizable quantities or for extended periods of time. The only obvious criterion for cooling, positive run time for pumps 4 and 5, was not reliable because the run times observed per thirty minutes were short (e.g., 5 minutes). Cooling data may be mixed with heating data. Furthermore, the run times per observation were so short that transient noise probably messes up the data.

Seasonal Heating/Cooling

Figure 5.1 illustrates the heating and cooling loads on an extrapolated basis, i.e., the data represents the expected energy requirements for a typical day in each month-pair. The obvious point is that, whereas the rental and demonstration units consumed similar amount of heating energy, the air conditioning load on a sealed house is enormous, whereas opening windows, presumably the solution in the rental unit, virtually eliminated the cooling load.

In the demo, cooling was accomplished by an almost equal mix of solar and boiler energy. In July-August, when the solar energy should have been at its peak perofrmance, its contribution dropped off instead. This result is quite counter-intuitive; as Figure 4.6c illustrates, the demo collectors performed better in July-August than in May-June. The explanation may lie elsewhere; in particular, observations were recorded in which the solar storage contributed sizable amounts of negative energy to cooling, i.e., the boiler heated water was pumped into solar storage. This effect of course, increases the energy contribution of the boiler for "cooling" at the same time that it reduces the energy contribution of solar storage for cooling.

Several issues regarding the use of solar energy for absorption cooling will be addressed later. Figure 5.1 does illustrate, however, for the two data intervals in which air conditioning occurred, that the absorption chiller realized operating efficiencies of 47% and 57% (BTU's removed/thermal BTU's consumed = CD/TCD).

Hourly Heating/Cooling

The data illustrating the distribution of heating/cooling throughout a day, Figure 5.2A suggests several conditions that arise regarding both heating and cooling. First, the heating load in the rental unit occurs much as one would expect, with the bulk of it required in the early morning hours when ambient conditions have been low for some time. (The apparent lag between ambient conditions and internal conditions is roughly 5 hours). Contrary to plan, the rental occupants maintained the internal temperature consistently above 68 degrees F, as Figure 5.2B confirms, so that the night setback did not occur.

In contrast, the demo unit shows a heating response which is peculiar yet welcome, if it is realistic. Namely, night setback did occur, since internal

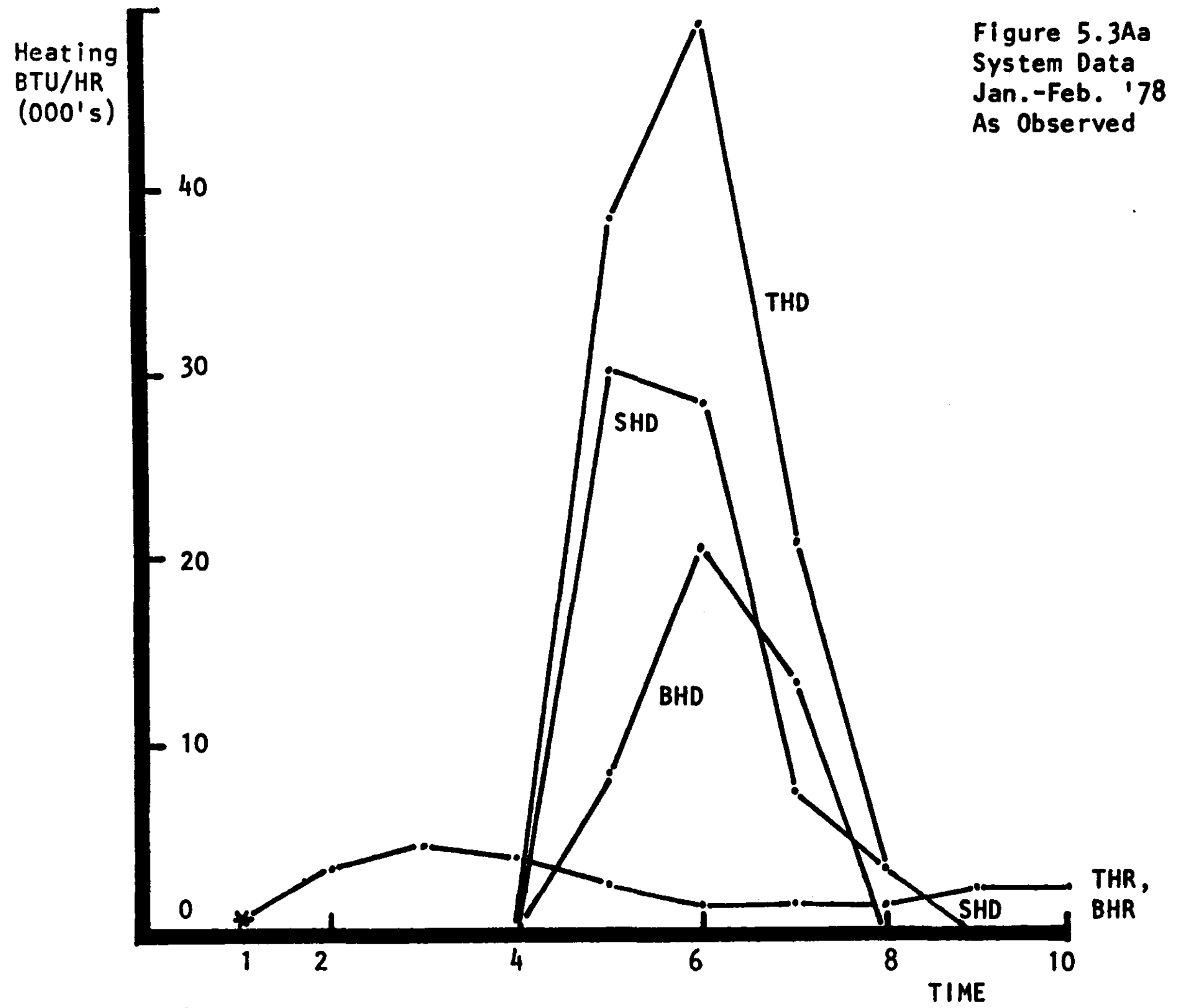


Figure 5.3Aa
System Data
Jan.-Feb. '78
As Observed

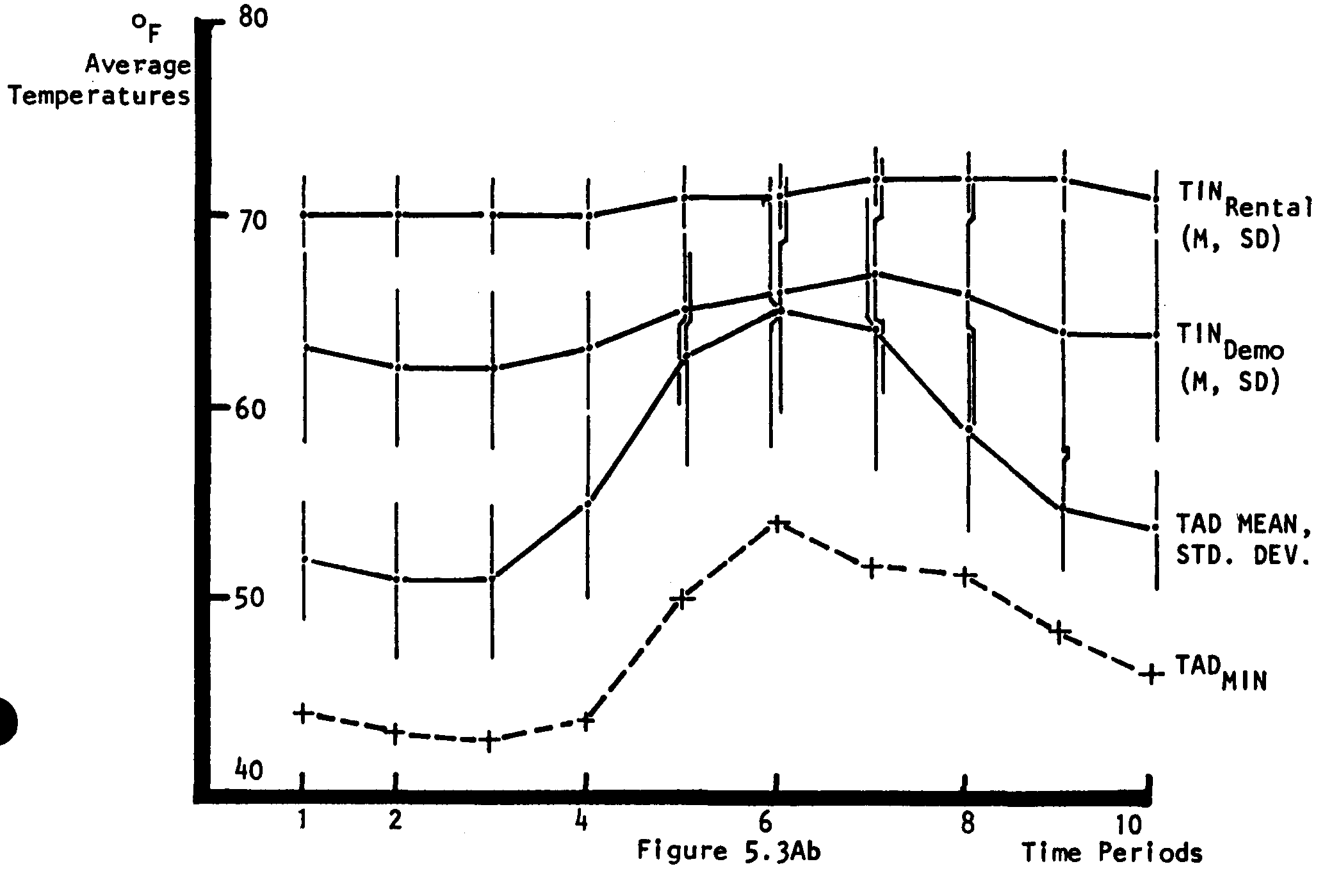
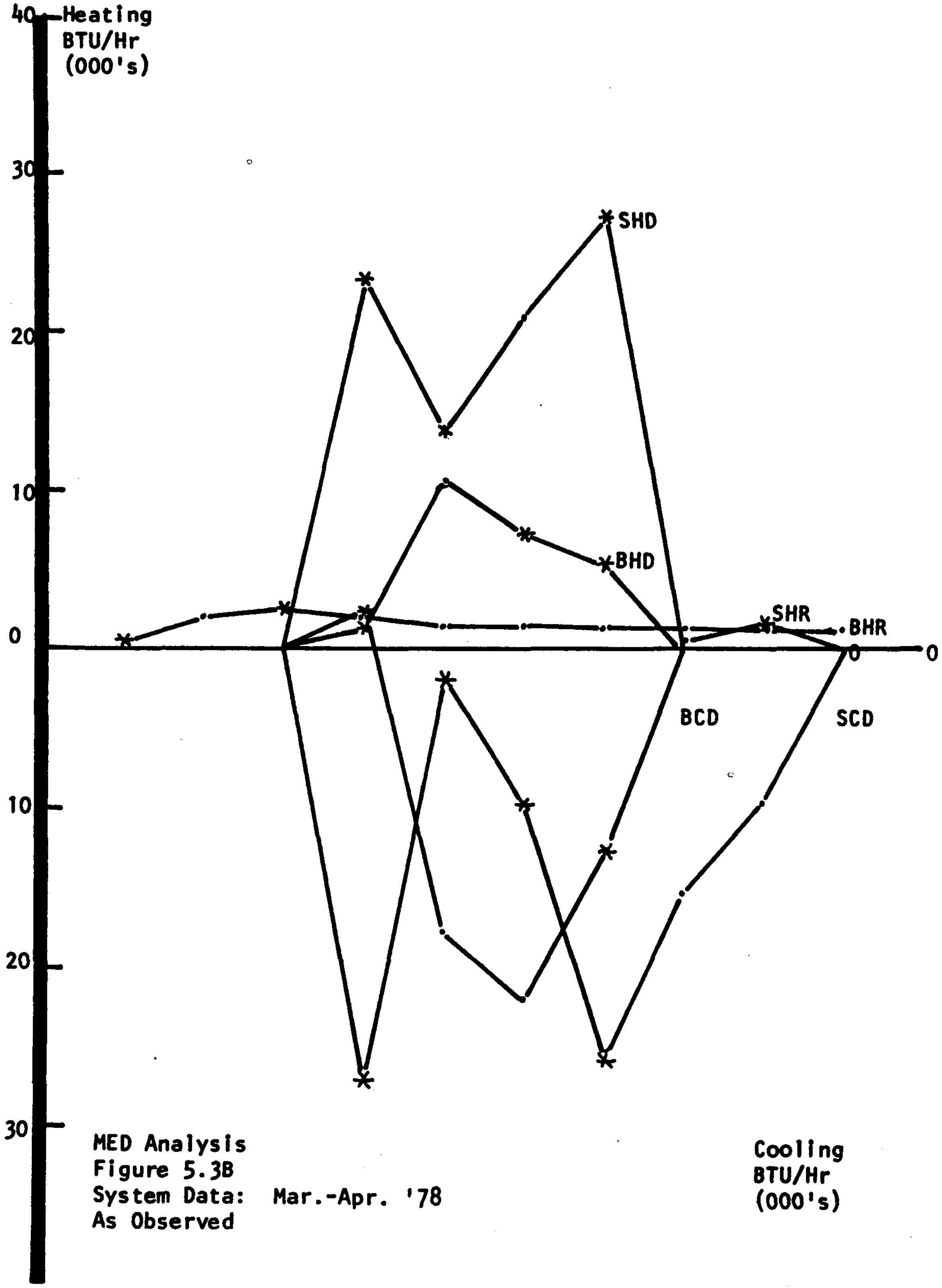


Figure 5.3Ab

March-April H/C Observ. Avg.



MED Analysis
Figure 5.3B
System Data: Mar.-Apr. '78
As Observed

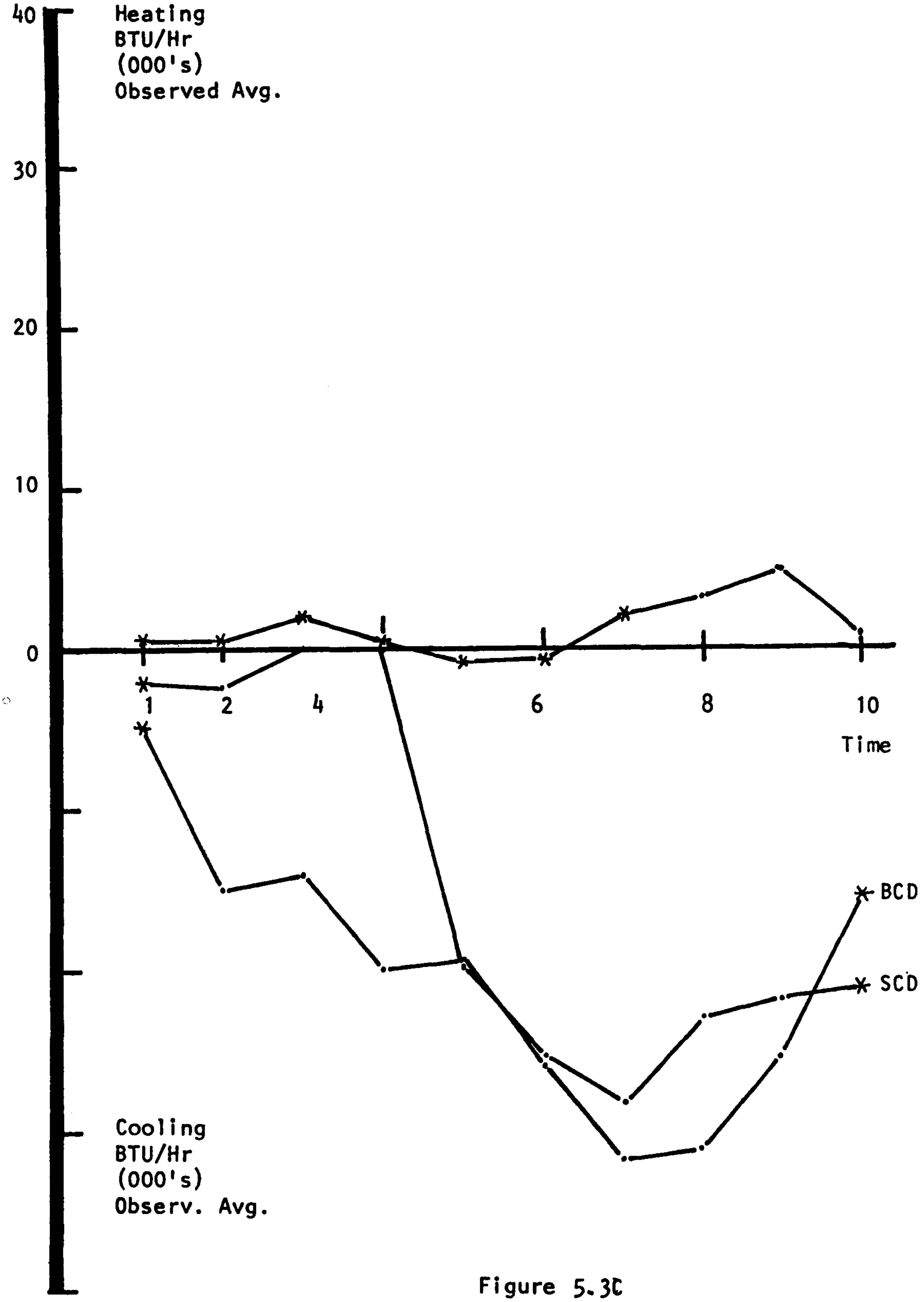


Figure 5.3C
System Data: May-June '78
As Observed

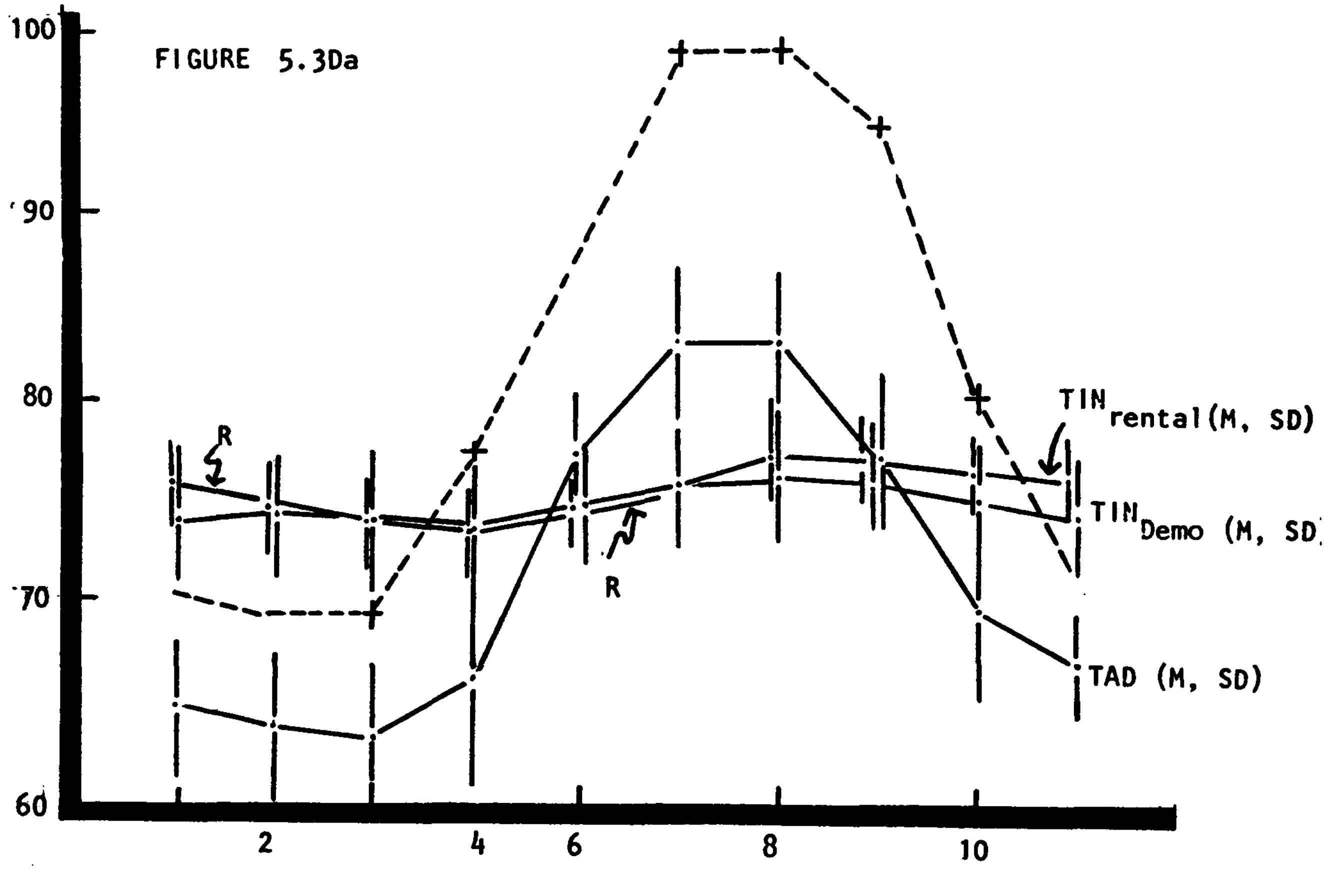


FIGURE 5.3Da

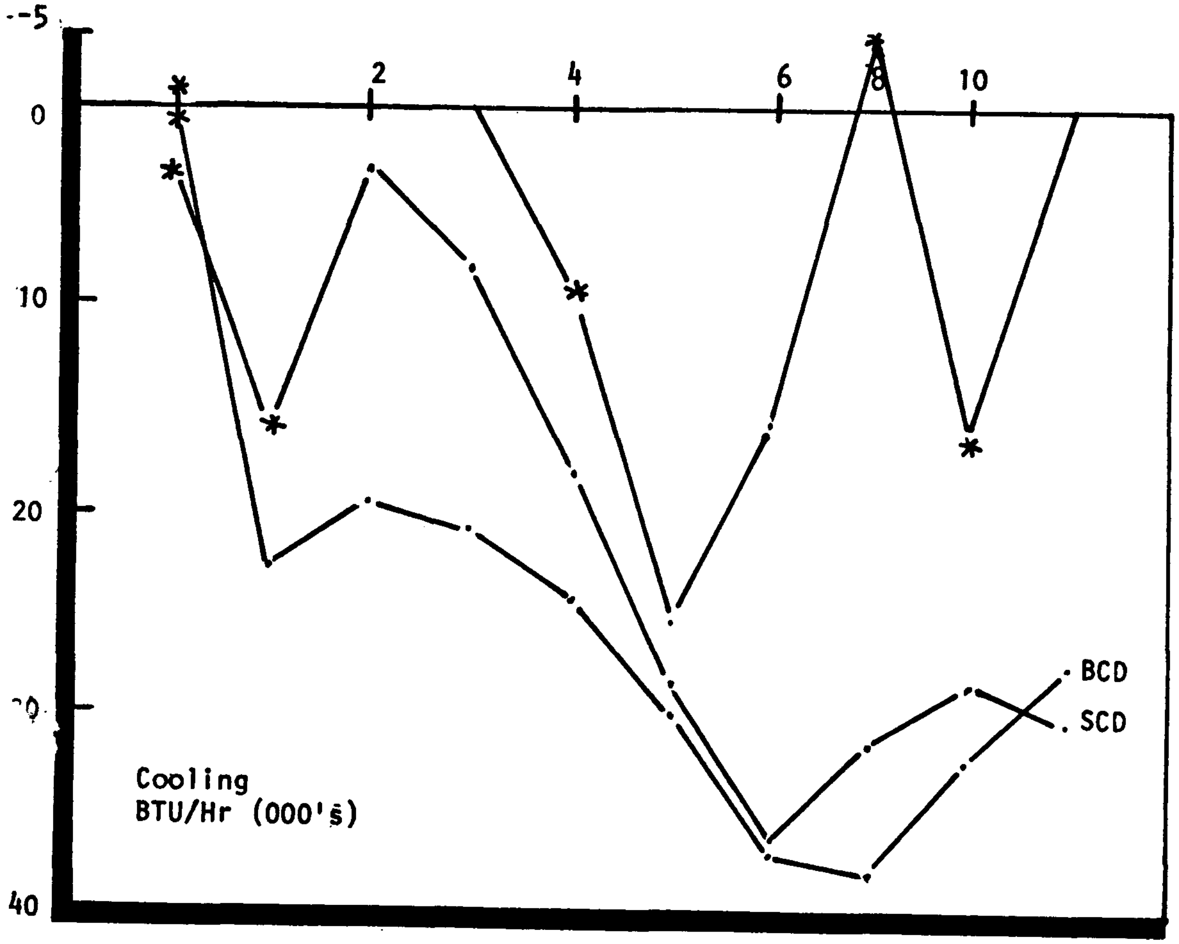


FIGURE 5.3Db
Systems Data: July-Aug. '78
As observed

temperatures dropped substantially in the early morning hours, But the heating load did not occur until period 5, corresponding to 12:30-15:00. Furthermore, the possibility of out of phase timers is ruled out by the drop in heating in period 6. Whereas the condition is beneficial with respect to heating when the solar collectors are most productive, storage temperatures seldom dropped below the minimum of 90 degrees F at any time of day.

Actually, control problems may have occurred, since very low internal temperatures were recorded on several occasions. This conclusion is reinforced by the fact that heating in the demo occurred less than 1% of the time) over all observations throughout the day), whereas the rental unit also benefitted from an internal load, whereas even the hot water heater was turned off in the demo unit.

With respect to cooling, Figures 5.2A and 5.2C emphasize the contrast achieved, presumably by opening windows. Although the internal temperatures in both houses tracked almost identically throughout the day, the demo unit, with closed windows, no economizer performance and little internal load, consumed almost ten times more energy per day than the rental unit required for heating. With open windows, essentially neither economizer nor air conditioning was required to maintain almost identical interior temperatures (if the data is correct).

As Observed Data

Figures 5.3A-D provide some insight into how the heating/cooling systems performed when they were observed in operation. Since the duration of operation is typically short for an observation under normal operating conditions (e.g. 5 minutes pump 3 operating per 30 minutes), it is conceivable that a 30 minute interval in which the heating system is "on" is not recorded because no heat was used. What these figures do not show, then, is how much energy was used when the system was on.

Figure 5.3Aa reinforces earlier suspicions concerning heating in the two houses. In the rental unit, the heat was supplied via the boiler in a fairly even pattern throughout the day. Heating occurred in approximately 30-50% of the observations, depending upon time of day. Presumably one-third or so of the days in January-February were sufficiently cold to merit heat and heating occurred throughout the day. The average length of time that pump 3 operated was approximately 5-7 minutes per 30 minute interval.

Figure 5.3Ab presents the temperature conditions that occurred throughout the January-February interval. In this graph, a new notation is adopted to convey additional information. The vertical lines above and below each data point represent one standard deviation from each point. In lay terms, if the temperature observations are all reasonably distributed around the average value, then 65% of the observations occur within one standard deviation of the average value (See Appendix A). This range of temperature is identified by the vertical lines. Finally, the "+" series indicates the lowest (highest) ambient temperature observed in a particular time period in Figure 5.3Ab (5.3D1). Although Figure 5.3Ab is somewhat difficult to read, what it shows is that the interior temperature of the rental unit varied little over a day, whereas the interior temperature in the demo unit varied as much as the outside temperature. Furthermore, the rental interior temperature remained consistently above 68 degrees F, whereas the demo interior temperature rarely exceeded 70 degrees F.

The energy provided for heating in the rental unit appears to follow a reasonable pattern, given the lack (or failure) of night setback. In the demo unit, however, the data suggests that heating was only supplied when someone manually forced it on in the afternoons. When it was on, pump 3 was observed to run for an average of 22-30 minutes per 30 minute observation. The number of observations in which the system was on was less than 3% of all observations.

The data for March-April is quite noisy because it included both heating and air conditioning, but little of either. May-June data is better, especially for air conditioning. Figures 5.3B-C illustrate performance during these time periods.

The as observed data for July-August (Figures 5.3Da, 5.3Db) presents a more clear picture regarding cooling performance. As stated before, cooling in the rental unit was slight on an extrapolated basis: fewer than 4% of the observations. Analysis will, therefore, concentrate on demo cooling.

The data plotted in Figure 5.3Db is probably not unduly inflated and is representative of cooling behavior. Typically, cooling required pump 3 to operate continuously to supply hot water to the chiller. Pump times averaged roughly 28 minutes per thirty minues observed. The data points representing period 1 are suspect because much of the data for this interval is lost when observation durations are calculated. Some behavior between period 10 and period 2 is the more likely situation in period 1.

Figure 5.3Db identifies the marginal importance of the boiler versus solar storage as a function of time of day. The solar storage cannot maintain the high temperatures necessary to drive the chiller in the early morning hours.

Most importantly, of course, Figure 5.3Da and 5.3Db emphasize how internal temperatures can be maintained in the rental unit without cooling, presumably by opening windows. A peculiarity, which leads one to suspect errors in data, is that the internal temperature varies less in the rental unit than in the demo unit, in spite of the latter unit using significant amounts of air conditioning. (43% of July-August observations)

Graphs for September-October and November-December were not prepared because the data indicated performance similar to March-April.

Chiller

In some respects, we are less able to analyze the chiller and tower than, say, the solar collectors. First, air conditioning occurred only in the demo unit with a degree of frequency, and this performance occurred almost exclusively in July-August. More importantly, chiller/tower operation tends to occur for very short intervals of time (relative to 30 minute observation periods) so that transient effects cannot be detected except in aggregate. More detailed study of the data, for example segregating observations by duration, may provide greater insight.

The overall chiller/tower/air handler performance is described in a later section on Systems Analysis and Economics. Briefly, the coefficient of performance of the chiller is approximately 0.5, as it is also on a global basis, recognizing energy sources and operating costs. Depending upon the mix of fuels, the overall efficiency (energy removed/energy consumed) can vary between 0.35 and 1.8. Capital equipment costs vary inversely, of course, at the household level.

We pursued the chiller/coil/tower operation further with the hope that we might gain some insight into how the chiller and tower perform. In general, we found that a few variables could account for a very high percentage of the variation in performance, although the coefficients do not contain much meaning. The coefficients in these equations were calculated according to ordinary least squares methods, using air conditioning data for all hours of the day throughout July and August, 1978.

The first equation, (1), focuses on chiller performance from the coil side. ECC is the BTUs removed from the coil circuit per hour. TC2D is the water temperature (degree F) entering the chiller, and FRC2 is the flow rate in gallons/minute. The numbers in parentheses are the standard errors of the coefficients and the averages are for the variables themselves. The $r^2 = .79$ indicates that this equation can account for 79% of the variance in the observed values of ECC.

One interpretation of this equation is that the energy removed by the chiller drops by 733 BTU/hour for every 1 degree rise in the input water temperature. Similarly, a rise of 1 gallon per minute in the flow rate implies that the chiller would remove 2213 BTU/hour more from the coil. This would suggest that chiller performance could be improved 13% by raising the average flow rate in the coil circuit, if all of the assumptions covering regressions hold. (Specifically, the flow rate must be uncorrelated with the other variables.)

$$\begin{array}{llllll} (1) & ECC = & 733TC2D & + 2213FRC2 & + 43965 & r^2 = .79 \\ & & (20) & (66) & & \\ & \text{Avg:} & 17,325 & 62 & 10.1 & \end{array}$$

The interesting result found in exploration of equation (1) is that the energy provided to the chiller from the boiler and solar storage does not play a significant role in accounting for variation in ECC. Evidently, variations in energy provided do not effect ECC significantly.

$$\begin{array}{llll} (2) & ECC = & 0.43\ ECT - 5427 & r^2 = 0.93 \\ & & (0.006) & \\ & \text{Avg:} & 17,325 \quad 55,261 & \end{array}$$

Equation (2) represents another attempt to get at a relationship between energy supplied and withdrawn. ECT is the energy in BTU/hour that are removed from the chiller on the tower side.

On the tower side of the chiller, equation (3) and (4) indicate the results when ECT is regressed against the energy provided by the boiler/solar storage. In the first relationship, which is quite spare, the r^2 is not especially high, but the coefficient on energy supplied (ENER2) is quite significant. This relationship might be stronger (i.e. higher r^2) were it not for the fact that ECT also represents energy removed from the tower. Thus the tower and chiller are coupled, which suggests that additional study with simultaneous equations would be valuable.

The second equation pushes to the other extreme, achieving an r^2 of .93 but sacrificing significance on the coefficients. Furthermore, the second expression contains variables which are obviously correlated: FLOW is the flow in the boiler/solar storage loop and AIT is the temperature of this water when it enters the chiller, so that ENER2 is related to FLOW * AIT.

$$\begin{array}{llll} (3) & \text{ECT} = 1.4\ \text{ENER2} + 10{,}257 & & r^2 = .67 \\ & \qquad\ (0.3) & & \end{array}$$

$$\begin{array}{llllllll} (4) & \text{ECT} = & .19\text{ENER2} & - 688\ \text{TC2D} & + 4960\ \text{FLOW} & + 360\ \text{AIT} & - 23{,}680 & r^2 = .93 \\ & & (0.3) & (35) & (126) & (16) & & \end{array}$$

Finally, we examined the performance of the tower. Equation (5) introduces several new variables which are similar to variables in equation (4). FLOT is the tower circuit flow rate, TAM2 is the ambient temperature when the pump (P4) is on, and TAW is the humidity (in %). ERAT is a constructed variable equal to TTID * FLOT. In some sense, it represents an energy intensity measure when it is introduced, TTID does not contribute to reduction in the unexplained variance. At the same time, while ERAT is in the equation, the coefficients of the other variables are difficult to interpret. The obvious advantage of the relationship is that it accounts for 90% of the variance in ECT.

$$\begin{array}{llllllll} (5) & \text{ECT} = & 214\ \text{ERAT} & - 14715\ \text{FLOT} & + 531\text{TAM2} & - 328\text{TAW} & + 41{,}696 & r^2 = .90 \\ & & (2.6) & (252) & (42) & (18) & & \end{array}$$

Clearly, the equations just presented are both comforting and discomforting. Unlike the situation with the solar collectors, a few variables can account for a high percentage of the variation in energy removed from the coil (ECC) and energy expended to do so (ENER2). At the same time, the values of the coefficients, while generally having the proper sign, are not so easy to interpret in any absolute sense. One of the difficulties is that the tower and chiller are linked, so that equations representing performance of one component implicitly contains performance of the other. Secondly, the strong relationship between energy intensity of supply (i.e. ERAT and similar variables in other studies not presented) suggests that a log-linear relationship might be more relevant. Finally, we examined relationships between energy removed and other conditions, such as temperatures and flow rates. Other issues which we should explore are relationships between operating conditions and operating efficiency.

The domestic hot water system included a preheat cycle which was designed to partially heat domestic water destined for the hot water heater. In the event that preheated water becomes too hot, however, a mixing valve was installed so that cold water could be added to the hot water heater to avoid excessively high temperatures in the heater. Hot water from the domestic hot water heater entered an Ultra Flow unit which would regulate the temperature of the water sent to particular destinations in the house.

The instrument diagram in Appendix B indicates the basic domestic water system configuration. It does not indicate where solar collector make-up water is pulled out of the system (in particular, whether FCW is domestic use only or includes solar collector operation).

Calculations

The analysis of the domestic hot water system was based on the time blocking of data as done before. The amount of energy supplied was by either solar storage preheat or by the domestic hot water heater (henceforth referred to as the "heater"). For a given time interval in the day, the calculations were:

$$E\ \text{preheat} = (TMO - TMI)(FDT)(8.333)(60\ \text{min/duration})$$

$$E\ \text{preheat} = (TD2 - TD1)(FDW)(8.333)(60\ \text{min/duration}),$$

where duration is the length of time in the observation interval. The calculation of hot water energy use is contingent upon accurate meter readings. The flow meters are not accurate below approximately 1 gallon/minute. Thus any use at a rate below this level probably is not recorded. Unfortunately, probably a significant amount of domestic water use is at a rate below 1 gallon/minute. Certainly the use of hot water will be below this rate, so that estimates of hot water use will be low. The Ultra Flow water distribution system contributes to this "problem" because it reduces water flow significantly in comparison with more conventional systems.

Only data from the rental unit was examined, since the hot water heater in the demo was turned off (intentionally).

Analysis

The results derived from the rental unit are suspect, and firm conclusions cannot be reached. Although total water consumption levels appear to be normal, logical inconsistencies exist between the flows measured through the preheat loop versus the heater, suggesting that either valves failed or flow meters misfunctioned.

The data which throws a shadow on the analysis is shown in Figure 6.1. The amount of water preheated exceeds the amount reported to flow through the heater in September - October, May - June, and July - August. Barring the September - October observations, the data would suggest a failure of the flow meter for FDW.

The September - October data (1977, a year earlier) suggests that the meter did not fail but that the mixing valve and a check valve failed so that preheated water re-entered the cold water stream. This idea is not so far fetched; the mixing valve itself probably assumes that a pressure drop controls flow direction. If the valve adjusts to mix preheated water with cold water, the preheated water could simply flow the other way. A check valve is presumably located upstream from the mixing valve to prevent reserve flow. If the pressure drops are slight, however, then the valve may become stuck in an open position.

Several other possibilities exist to explain flow discrepancies, but the data is not consistent with any of them. Figure 6.1B suggests that the FDW measurements are related to the preheat temperature TMO; the higher is TMO, the lower is FDW. According to the Handbook, cold water is mixed with preheated water when TMO exceeds 140°F. This behavior is consistent with Figures 6.1 bearing in mind that the data points represent averages. Perhaps FDW measures flow into the heater but net of preheated water, i.e. it is upstream of the mixing valve. Yet FDW + FDT varies too much over the year to be realistic.

The evidence in Figure 6.1B does not resolve the issue. Whereas TM1 and TMO appear to be logically consistent, TD2 fluctuates alarmingly, considering that each data point represents the average temperature of water leaving the hot water heater (based on 400 - 500 observations).

Furthermore, TD2 varies throughout the day, being lowest when volume used is least and highest when volume is high; the result is contrary to intuition, unless the temperatures are affected by transient conditions when use is slight.

The house maintenance logs do not provide any clear evidence that would explain the low hot water heater meter readings. On October 20, 1977, the water flow meter "on inlet to water heater" was removed and cleaned, which strongly suggests that flow had been impeded. This situation would explain the September - October 1977 reading. No further changes were made except a cleaning of the impeller on the "house flow meter" (2/22/78) and a cleaning and adjusting of "cold water solenoid valves" (3/17/78) and the "water mixing valve" (6/13/78). An entry between 3/25/78 and 4/5/78 is unreadable except for the word "shower". It was ignored.

Based on this evidence, it is possible that the heater flow meter functioned poorly in September - October, 1977, was cleaned then, and operated satisfactorily until May - June, 1978, when it again became clogged. As of August 10, 1978, (the end of the log), it had not been cleaned.

Mix of Energy Sources

If we ignore the data for September - October, May - June, and July - August, and we assume that the flow meters FDT and FDW operated properly at least relative to each other (an assumption supported by the data as illustrated in Figure 6.1A), then the data for January - February, March - April and November - December sheds some light on the mix of energy supplied for hot water heating. Solar storage preheating provided between 54 (January - February) and 90 (March - April) percent of the energy required for hot water consumption.

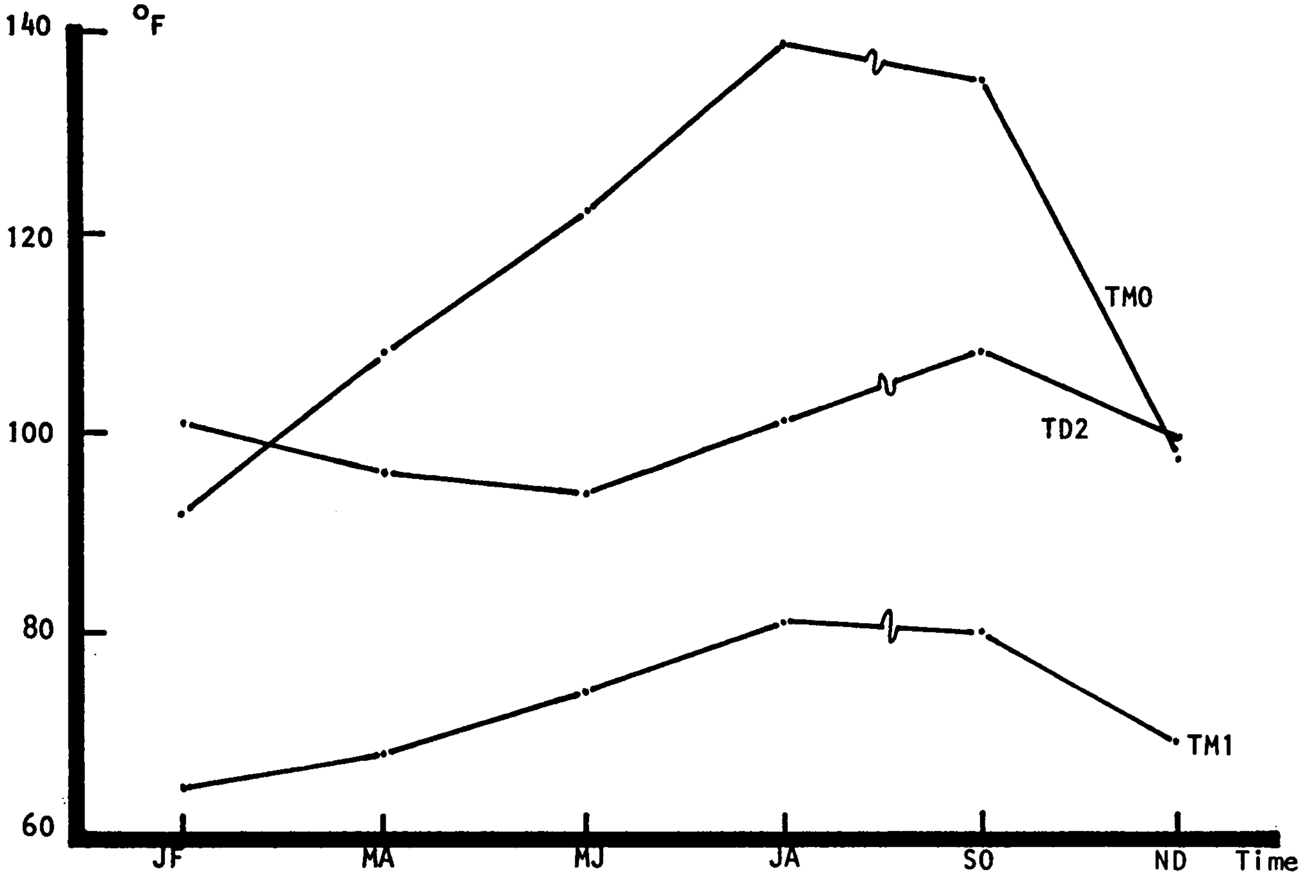


Figure 6.1

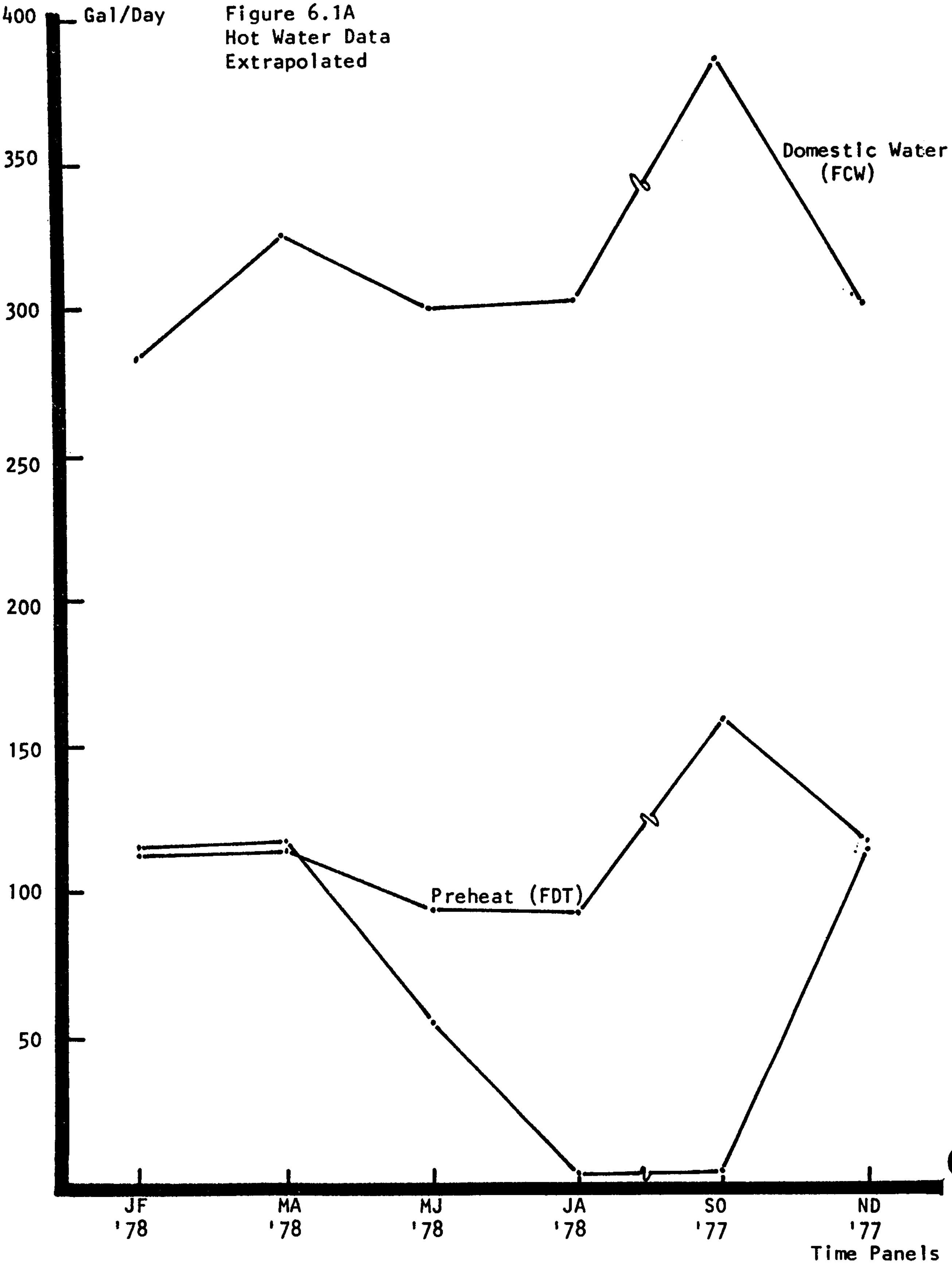


Figure 6.1A
Hot Water Data
Extrapolated

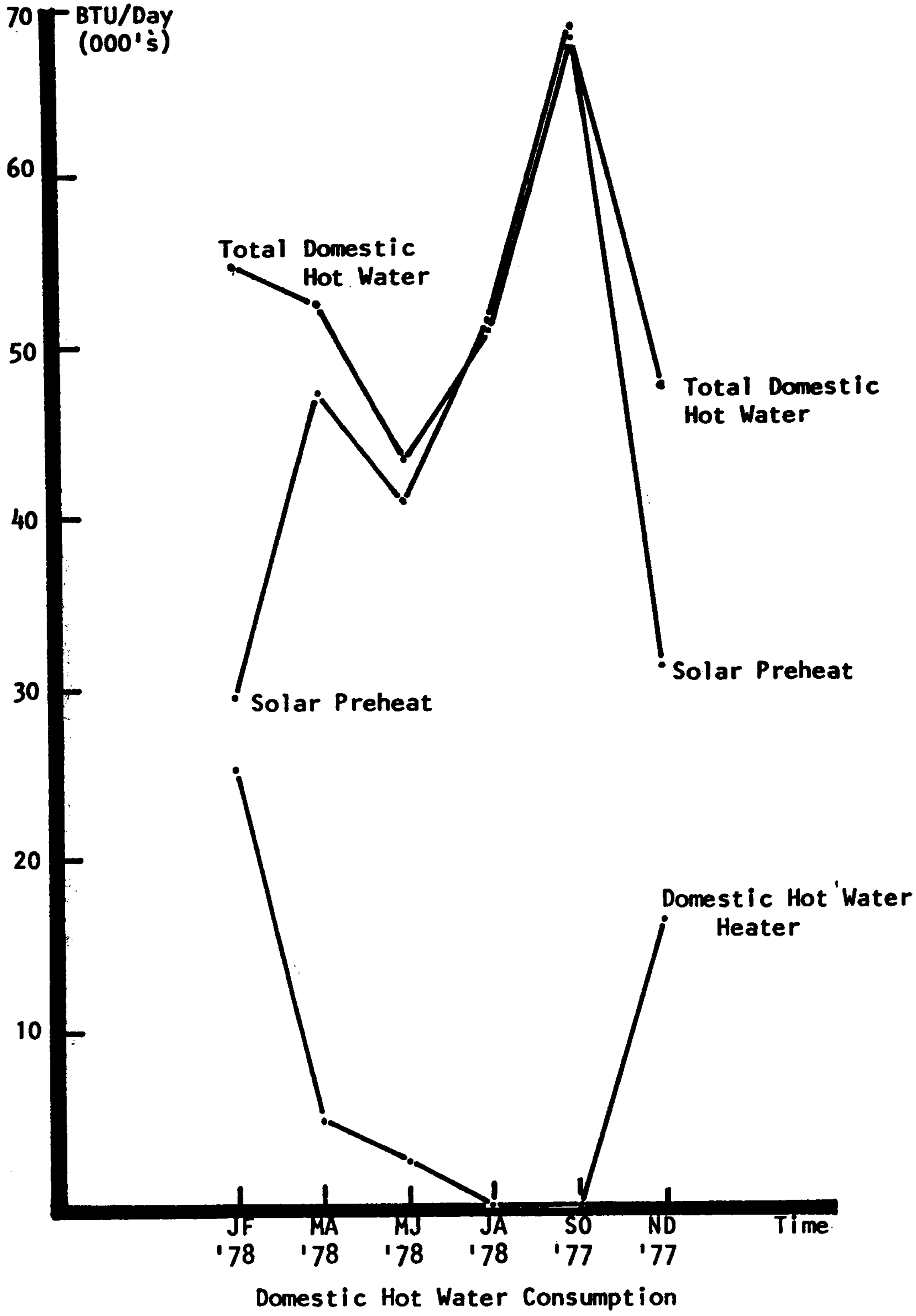


Figure 6.2
Hot Water Data
Extrapolated

If the total domestic hot water consumption figures for January - February, March - April, and September-October can be trusted to indicated total hot water consumption, then we can surmise that solar preheating provides 100% of the hot water energy needs in the summer months. In fact, the energy supplied by preheat in July - August is sufficiently high that we can assume that the hot water heater seldom operated.

Hourly Data

The data illustrated in Figures 6.3A - B provides some insight into how water is consumed throughout a day. The patterns are slightly different from what one would expect for most households, but the data appears to be realistic for the occupational lifestyle of the tenants. Basically, the consumption data suggests a 3 - 4 hour delay in consumption throughout the day. Usage picks up around 10 - 12:00 AM after the lowest usage levels which occur around 7:30 AM - 10:00 AM. Water usage is high in the afternoon (10:00 AM - 3:00 PM) and the evening (5:30 PM - 10:30 PM). Some water usage occurs between 10:30 PM and 5:00 AM. In the summer months (May - August), heavier water use occurs between 3:00 PM and 5:30 PM.

On both an extrapolated and "an observed" basis, the water consumption levels are not sufficiently high to assure that flows are accurately measured. The highest flow rates, in period 5, are only 40 - 60 gallons per hour on an observed basis. These calculations are based on 30 minute observations, so that the maximum average flow rates are 25-30 gallons per 30 minutes. These rates are approximately equal to the minimum flow rates that are measurable. Of course, the flows probably occur for less than 30 minutes in a 30 minute observation, so the actual flow rates are most likely higher. On the other hand, the flow rates just quoted are for total water flow; hot water flows are lower.

Figure 6.3A, B
Hot Water Data
Rental Unit

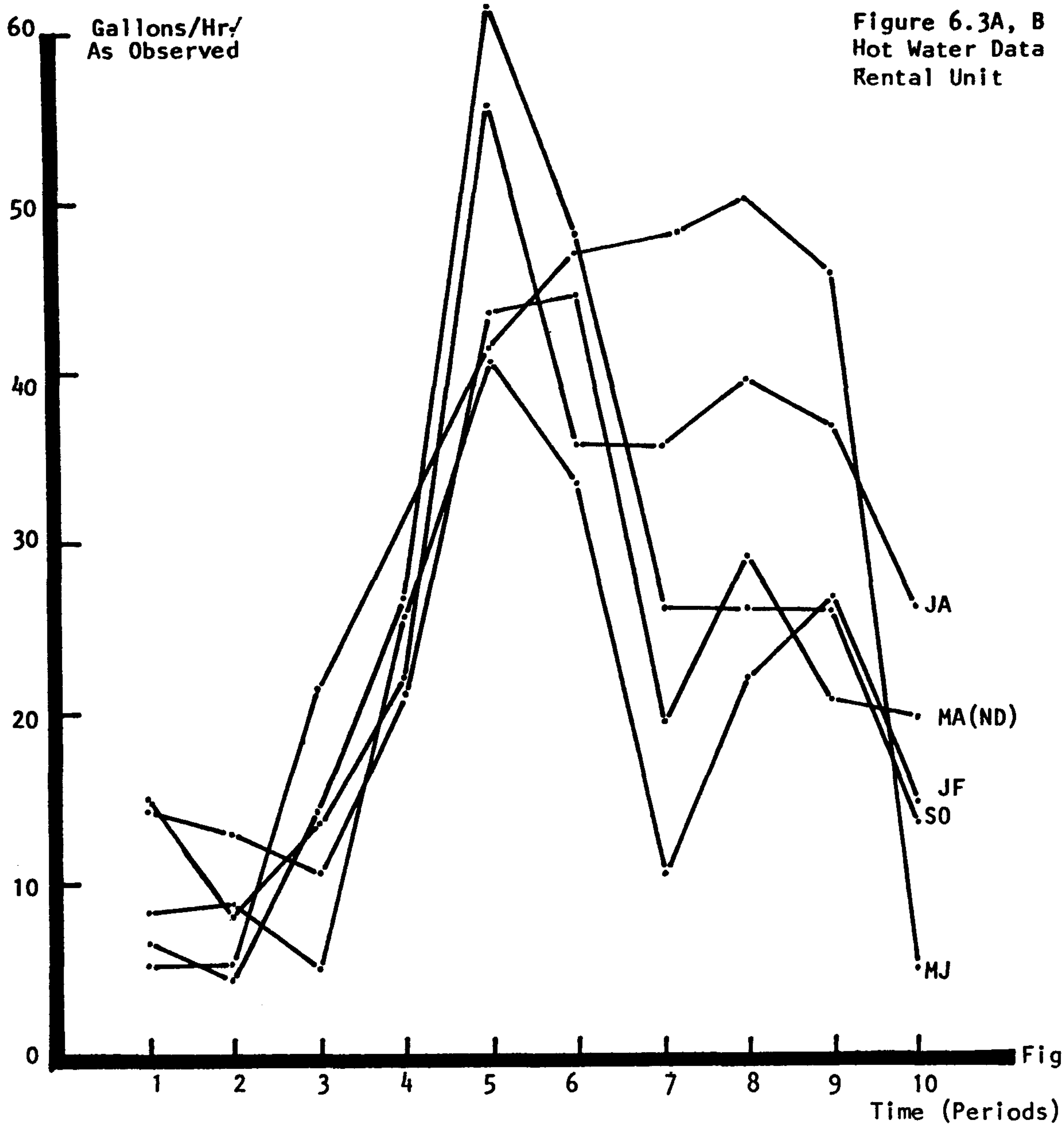
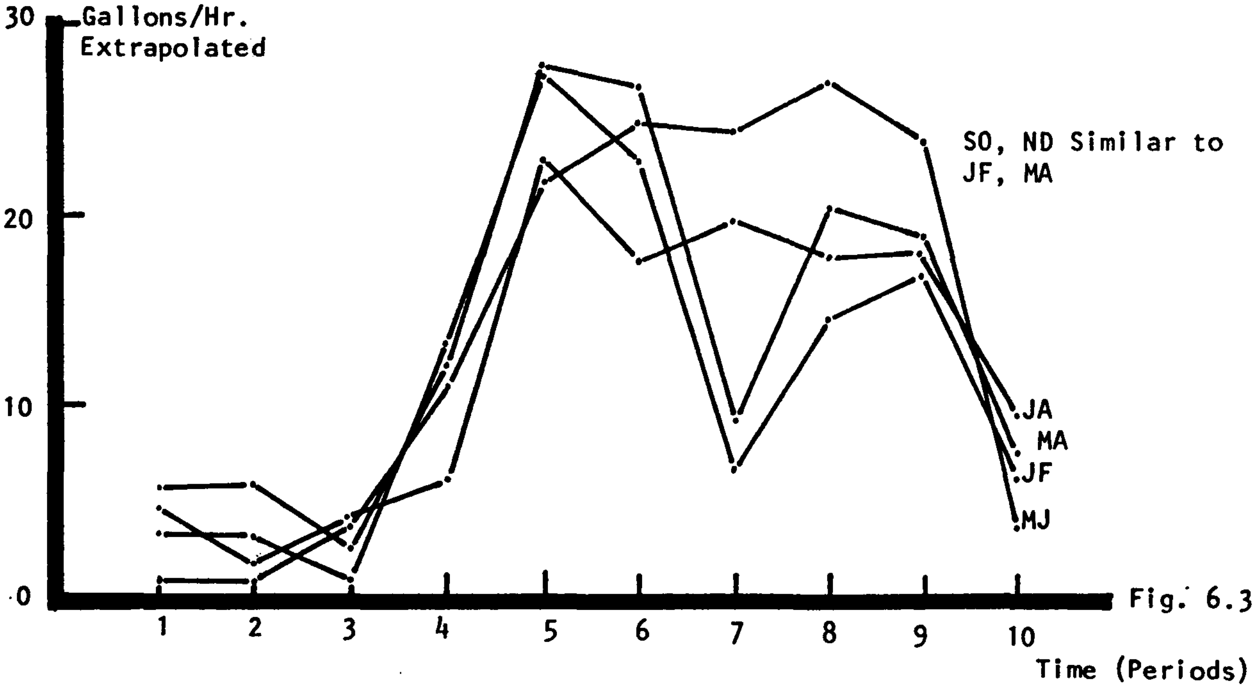


Fig. 6.3A



SO, ND Similar to JF, MA

Fig. 6.3B

In the previous sections we have reviewed and analyzed data mostly in terms of either end use or source. What we have not done is cross-checked results by examining the relationship between energy supplied and energy used. We must therefore examine how well we can account for all energy flows.

Unfortunately, the lack of absolutely reliable temperature measurements across the coil prevent us from identifying how much energy actually enters or leaves the house via the mechanical system. Air flows through the air handler are unrealistic also. In the solar collectors, we have calculated losses except for dumping, and we have performed a similar analysis for the chiller. What remains is the thermal storage tank for the solar collectors.

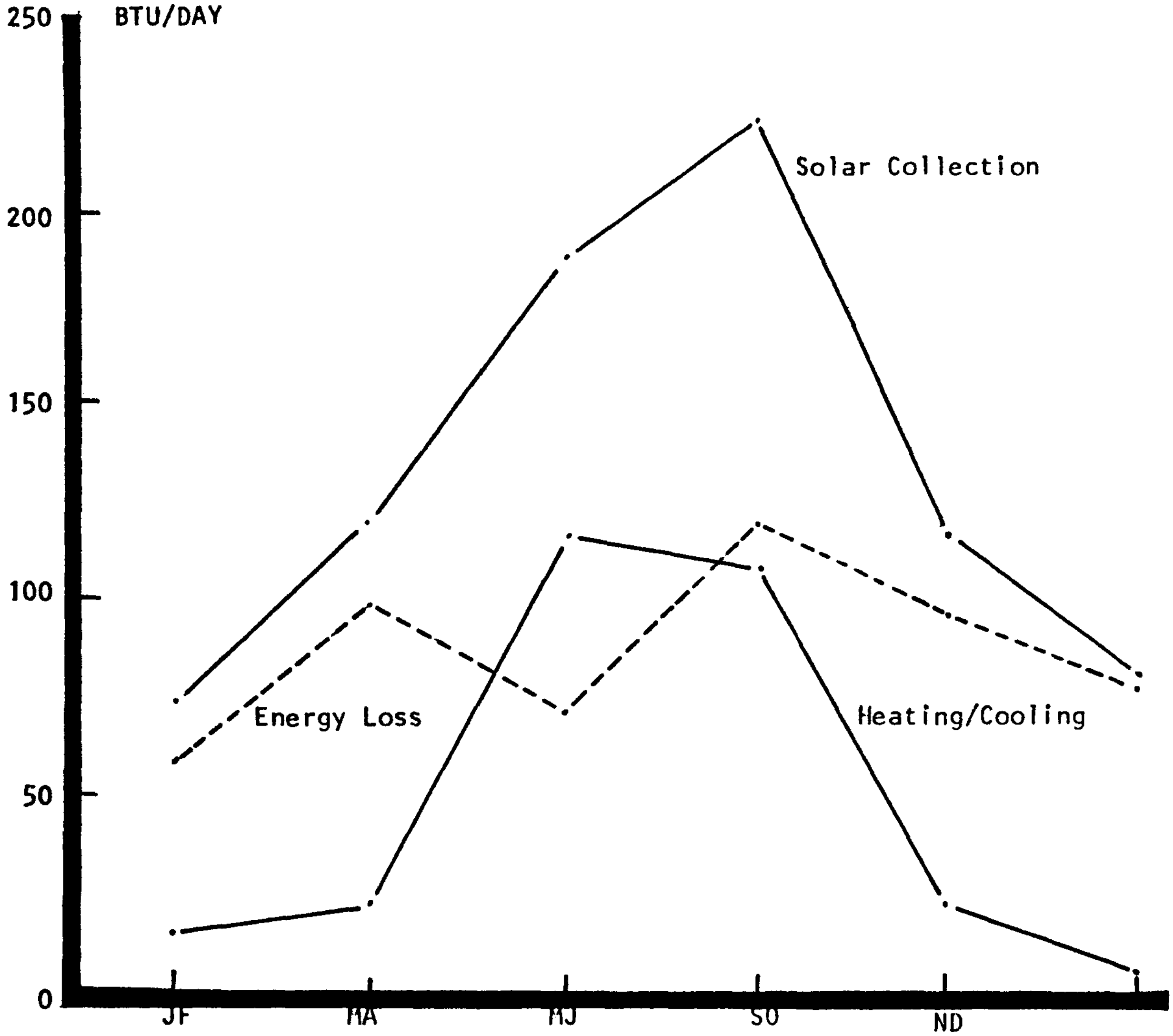
Figures 7.1 and 7.2 provide an accounting for energy deposited and withdrawn from the solar storage tanks. The data points are calculated by a slightly different procedure than some earlier analysis to cross-check calculation procedures. The numbers generally agree quite well. The one exception is September - October data on energy collected by the rental unit from the solar collector. The data suggests that the unit either lost enormous amounts of energy at night (e.g., 5,000 BTU/hr. extrapolated), or an instrument malfunction occurred. Clearly, the amount of energy used for hot water preheat cannot exceed the amount collected. In the demo unit, almost no energy was used for domestic hot water preheating; space heating and cooling were the major uses. In the rental unit, no energy was used for space heating/cooling; domestic hot water preheat was the only use.

Both Figures 7.1 and 7.2 show an alarming amount of energy for which there is no accounting. Especially in the demo unit, the excess of energy collected over the amount used is often more than 50% of the amount collected. We might safely exclude the possibility that the difference is attributable to instrument failure, because the "error" is always of one sign (+ or -) and it occurs in both units. Of course, it could be attributable to a systematic error, such as improper placement of a temperature sensor.

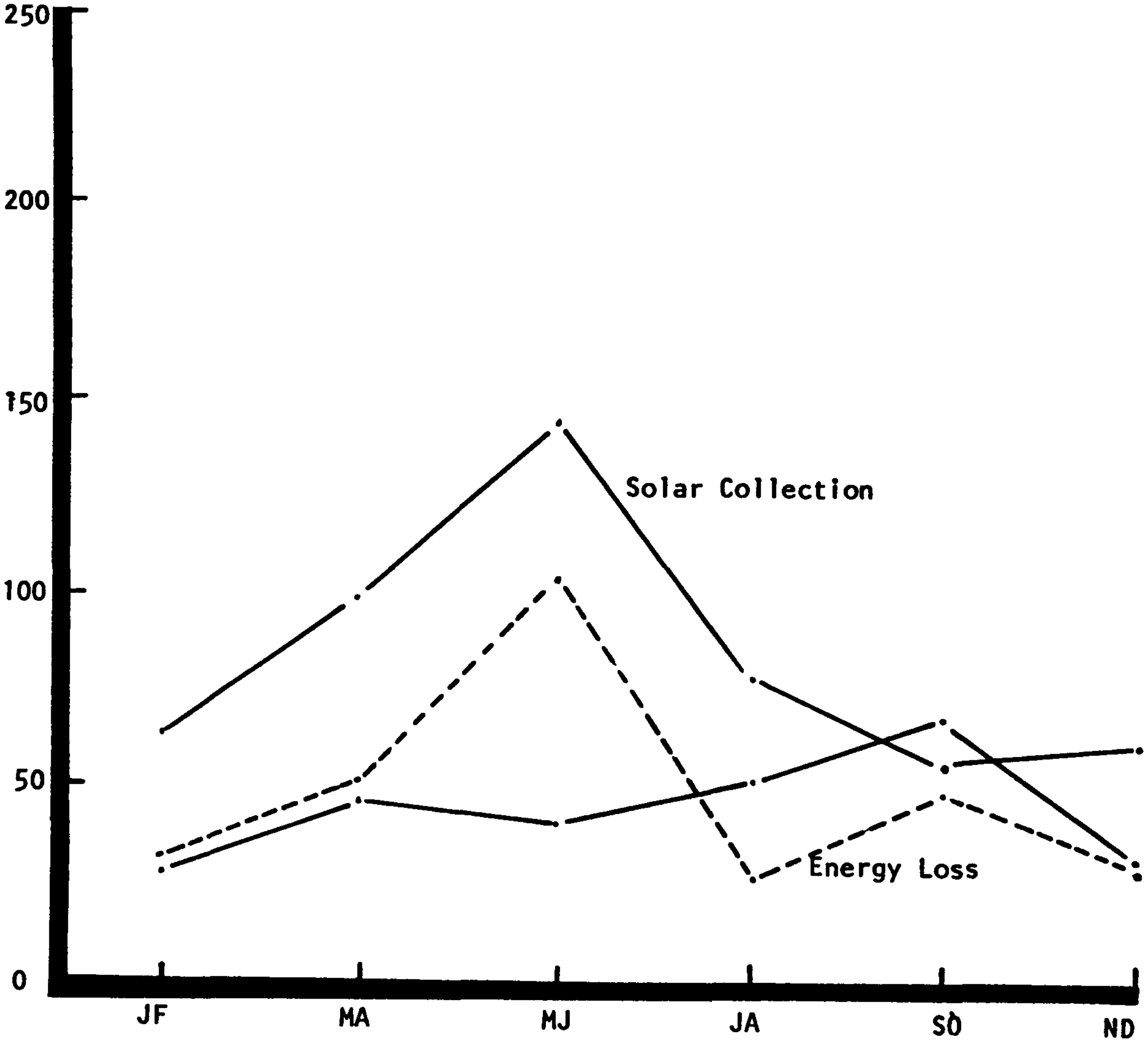
Some preliminary exploration of the data leads to the hypothesis that much of the discrepancy can be accounted for by several sources of thermal loss. Although thermal loss may not be the sole explanation, losses do vary according to the temperature differential between the tank and the ambient conditions. A difficulty in representing this hypothesized relationship is that temperature differentials vary throughout a daily cycle as well as over the year; average daily differentials are different in January versus, say, in August.

Within a day, the duration of a temperature differential level is important. If energy is drawn shortly after it is placed in storage, then tank temperatures either do not rise or remain high only briefly. The difficulty in proving the relationship is that the data for tank temperatures represents an average over the same interval for which the energy added and withdrawn is calculated. Thus the comparison of the net energy added versus change in tank temperature can only be performed indirectly. This study should be done.

From another approach, at least two alternative means can be found for accounting for losses of the magnitudes realized. One possibility is thermosiphoning. The temperature differential between the tank and the water lines through the



Solar Storage
Figure 7.1
Extrapolated Data
Demo Unit



Solar Storage - Rental
Figure 7.2
Extrapolated Data

coil or boiler could stimulate flow through the solar storage/boiler/coil circuits. A flow of approximately 6 - 12 gallons per hour is sufficient to account for 100% of the largest losses realized. This flow rate would not be detectible by the flow meters and is quite reasonable with respect to by-passing pumps.

Yet another means of loss is through the tank walls. If the insulation in the tank vault is assumed not to exist, and the ground is assured to be an infinite heat sink, then the losses can again be accounted for wholly by energy flow through the tank walls and the concrete vault walls. The discovery of densely packed insulation in the vaults, and a repacking of the insulation in the rental unit vault, provides an opportunity to test this hypothesis.

No conclusion can be reached at this time as to whether, and how, energy losses can occur from the collector storage tanks. More study is necessary. What can be said is that the evidence is strong that heavy losses are occurring, and the thermosiphoning hypothesis is a plausible means by which the losses can occur. The situation emphasizes again, as with collector lead line losses, that very small temperature differentials with large flows or large differentials with small flows can greatly diminish the operating performance of a mechanical system.

Economics of Chiller Performance

The global or broad perspective of chiller/tower performance is illustrated in Figure 2.2. This aggregate analysis indicates that the solar storage and boiler provided approximately 260,000 BTUs to the Arkla chiller: 100,000 BTU came from solar storage at a cost of 15,000 electrical BTU's (plus amortization) to operate the collectors. The 160,000 BTUs provided from the boiler requires 200,000 BTU of gas (0.8 efficiency) plus amortization. The boiler and solar energy is supplied to the chiller at an electrical cost of 10,000 BTU per day (Pump 3). The tower operates with a circulation pump (P4) and a fan, collectively requiring 20,000 BTU.

According to Figure 2.2, the chiller removes energy from the coil at the rate of 130,000 BTU/day: the chiller coefficient of performance is approximately 0.5. This energy removed costs approximately 20,000 BTU/day in fan and pump (P5) operation. Summing up, the chiller/tower/air handler with solar/boiler energy supply removes 130,000 BTU/day at a total cost of 200,000 gas BTU plus 65,000 electrical BTU plus system amortization. (If solar storage is used for domestic water heating, these figures may drop slightly.) The overall efficiency rate is thus approximately 0.50; the increased electrical costs are offset by the energy supplied by solar collectors. If the solar energy is replaced by a conventional boiler system, the overall energy efficiency drops to 0.35. If solar energy is used exclusively, the efficiency rises to 1.8. Of course, equipment costs are much higher than for compressor cooling.

Data Integrity

The analysis of data as collected from the MED houses could proceed in a variety of directions, depending upon what one wishes to know and how confident one wants to be of the results. Ultimately, however, if any sense of how a system can be expected to perform is desired, some statistical analysis is required.

The reasoning and basic procedures for some statistical analyses can be shown most quickly via an example. Consider the data shown in the following Table A1. We are examining, say, the water flow through flow meter FSS (see diagram, Appendix C) for the hours given in a particular week. A 0.0 value implies that the meter was monitored in that time interval, but that no flow was registered.

We emphasize that no flow was registered because we have no way of knowing whether or not flow occurred without actually sticking our finger in the pipe. On Tuesday between 13:00 and 13:30, for example, the registered flow was negative, since the leters technically cannot register negative, or reverse flows, we have to assume that a calibration error occurred. Thus we must reivew all data to check for inconsistencies and absurdities (e.g., -423° F in the solar collector?).

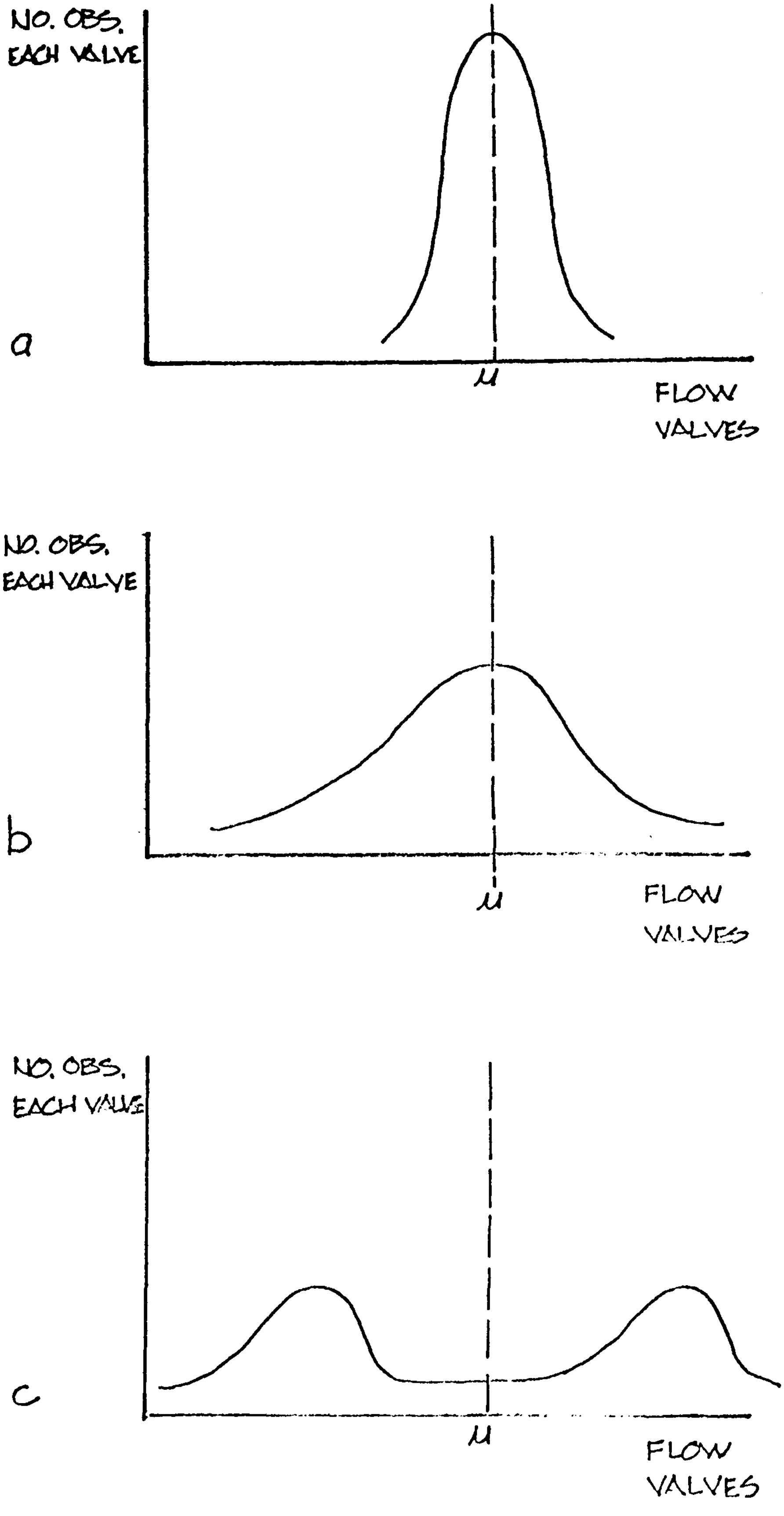
TABLE A1
Hypothetical FSS Flow Data, Week Beginning April 1, 1978

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
12:30	NA	NA	NA	NA	NA	NA	NA
13:00	5.0	X	25.0	0.0	27.3	15.0	X
13:30	30.2	-0.1	6.1	0.0	-0.2	33.3	X
14:00	100.2	15.6	45.3	0.0	1.0	18.4	X

In Table A1, "NA" indicates that data exists for the observation, but our interest is on the interval 12:30 - 14:00. Since the flow data is cumulative flows, we must know when the last observation was made so that we can calculate the interval over which the flows occurred. We simplified this example by assuming that observations were made at 12:30, 13:00, etc. exactly for Monday-Sunday. In practice this didn't happen. The X's, in fact, indicate that data does not exist for those observations.

The question of what we do about absurd or missing data is a serious one. One alternative is to ignore it, but then we encounter the problem of how to measure the cumulative performance. We can't simply add the numbers we do have and assume no flows occurred when we weren't looking or the meter malfunctioned. Another alternative is to extrapolate by finding the average flow for the intervals we have observed satisfactorily and hypothesizing that, on the average, this performance occurred over all intervals. If we do this, then we must assure ourselves that the missing observations are not systematically associated with particular flow values. The fact that our observations are for 30 minutes or more precludes much analysis of very short term

FIGURE A 1


NO. OBS.
EACH VALVE
a
μ
FLOW
VALVES
NO. OBS.
EACH VALVE
b
μ
FLOW
VALVES
NO. OBS.
EACH VALVE
c
μ
FLOW
VALVES

phenomena. We can calculate flow rates only if we know the amount of time that the pump was on within the 30 minutes.

The issue of how to portray system behavior "when it is operating" is a difficult one to resolve. If 0.0 flows are normal, i.e. the system need not be on all the time, then we must analyze both how it performed when it did operate and what its average - extrapolated performance was. To examine the former, simply picking a "good" observation like 14:00 on April 1st is truly foolish. How can one justify looking at one exceptionally good flow and claiming that it represented system performance?

Means and Standard Deviations

One method for measuring system performance is to calculate the average of all the flows. In this case, the average is $u = (5.0 + 30.2 + 100.3 + 15.6 + 25.0 + 6.1 + 45.3 + 27.3 + 1.0 + 15.0 + 33.3 + 18.4)/12 = 23.9$. (We round to the nearest one tenth, commensurate with the accuracy of the original data).

The average or mean value, as it is called, may not convey enough information about flows. For example, the flow values may vary greatly, or they may all be very similar in value. We could calculate the absolute difference between each observation and the mean value, add these differences, and report this measure of variation between observed values and the mean value. This measure could tip us off about differences in data value distributions like Figure A1b and A1c versus A1a.

The measure we do use to account for variation is the standard deviation, which equals the square root of the sum of the differences squared (for all observations) divided by the number of observations. For example, if:

$$s^2 = (5.0 - 23.9)^2 + (30.2 - 23.9)^2 + (100.3 - 23.9)^2 + \ldots + (18.4 - 23.9)^2/12,$$

The standard deviation can be a very useful measure if the data follows a symmetric and "one humped" pattern as in Figures A1a and A1b. If this is the case, then approximately 65% of all flow values lie in the interval between U-S and U+S. Thus, the smaller the standard deviation (Figure A1a versus A1b), the more certain one can be of predicting a flow value.

It should be obvious now that, if the data is more similar to Figure A1b than A1a, then a greater range of values is likely to occur. Each observation is more difficult to predict. Since our calculation of the mean value is based on observations, then the reliability of the calculated mean to imply what is the true average behavior drops. Alternatively, as the data becomes more noisy, we must have more observations to be sure that we are perceiving the "true" situation.

We therefore introduce another measure of data behavior called the standard error. It is calculated as:

$$s_u = \sqrt{s^2/12}$$

Su is a measure of the reliability of our calculation of the mean, u. It tells us, for example, that the "true" means value of flows is within the range ($U - S_u$, $U + S_u$) with 65% probability. In our analysis here, if S_u exceeds 10% of the average value U, then we treat the data with much more caution; the chances that U is within ± 10% of the true mean are less than 65%. Clearly, decreasing the value for S_u requires increasing the number of data points, for s^2 remaining constant.

Data Blocking

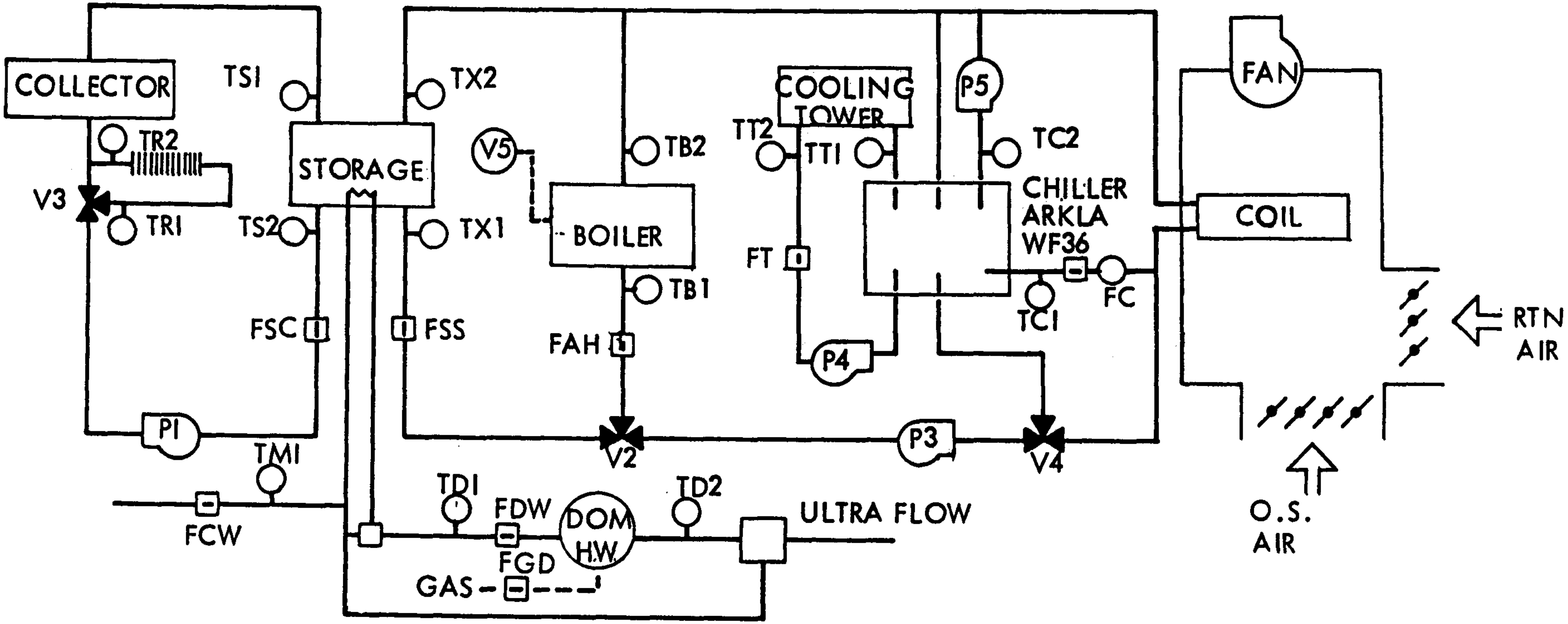
With our brief introduction to statistical analysis, we can return to the actual data analysis. As should now be obvious, one data point has almost no meaning. From Table A1, we might end up with a value ranging from 0.0 to 100.3 if we selected only one observation. True, on the average we would pick a value close to 23.9, but having picked only one value, we have absolutely no idea how close or far we are from the average. Thus, with many observations of a subsystem within MED, we can justify conclusions. Aggregate conclusions about the MED houses, however, are inherently shaky; we have only two houses, hence two sets of observation points.

If we proceed by calculating means and standard deviations for a set of data including many observations, then we can be more confident of perceiving the true situation. But how do we pick the set of observations? If we look at all flows within a day, we can't say how flows vary over the day. Furthermore, any one day is probably similar to other days in the same month (ignoring weekday-weekend effects), so we would be performing the same analysis many times (for each day), but each day would have relatively few data. We could group data by month to improve our analysis (S_u diminishes), but variations within a day are not detectable.

For most of the analyses performed in this study, the greatest amount of system variation was thought to occur on a daily basis and on a seasonal basis. To capture these changes and yet assure that the statistics contained a high level of accuracy (small S_u), the data was broken into daily time intervals such as is shown in Table A1. Instead of gathering one week's worth of observations, however, the data was analyzed in bimonthly subsets. Typically, an analysis of a system involved calculating means, standard deviations, and standard errors for 60 subsets of data: 10 daily time intervals and 6 bimonthly intervals (September 1977 - August 1978). Daily phenomena were calculated by summing the results over the 10 daily intervals.

FIGURE I

SENSOR LOCATIONS



The graphs, tables and in general statistical analysis presented in the main body of this report draws heavily on the summarized data in this appendix. This data is for the most part a summary of mean values, standard deviations, and sample size information for different instrument readings and constructed variables. An identification list accompanies each set of data.

The general form of the data follows the format illustrated in Figure A2.

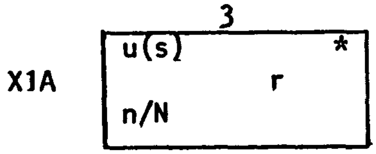


Figure A2

The mean value for a variable called X1A, observed in period 3, is denoted by u, and it normally is placed in the upper or upper left position in the box. The standard deviation, if present, follows it and is contained in parenthesis. A *, if present, indicates that the data is quite suspect: the standard error exceeds 0.1u. In some tables, a + indicates that the standard error approximately equals 0.1u. The number of observations used in calculating u and s is n, and the number omitted is N. If N is not given, then it may be calculated according to the value given for it for another variable in the same column (time period). The variable r, if present, is typically written in with pencil in the lower right corner; it is the extrapolated value of X1A when the n observations used to calculate u omitted any zero or erroneous observations. Hence, $r = (u)(n)/(n + N)$.

Solar Data

This data focuses on performance of the solar collectors during the daylight hours only; data before 6:00 was ignored, as was data after 20:00. Data for which the line voltage deviated from 100mv by more than ± 10mv or calibration voltage differences exceeded ± 1mv was ignored. When values 0.0 are excluded, data represents "as observed" conditions.

Variables

HPC - Solar insolation incident on a meter mounted in the solar collector plane, it presumably measures direct plus diffuse (total) insolation, given in BTU/Hr-S.F. Observation was ignored if its value was below 5.0 BTU/Hr.-S.F.

HH - Total solar insolation incident on a meter mounted in a plane horizontal to the earth's surface - BTU/Hr.-S.F. Observation was ignored if its value was below 5.0 BTU/Hr.-S.F.

HHD - Intended to be diffuse insolation incident on a meter mounted in a horizontal plane, with a metal band oriented to block out direct sunlight. Metal band was not always adjusted properly - BTU/S.F.-Hr. Observation was ignored if its value was below 5.0/BTU/Hr.-S.F.

Period	6:00 - 9:30 1 4	9:31 ~~11:00~~ - 12:00 2 2.5	12:01 - 2:30 3 2.5	2:31 - 5:00 4 2.5	5:01 - 8:00 5 3	① Total 14.5
HPC	29.6(39) 258/13 28.2	135(80) 174/0	147(93) 187/0	80(72) 181/1	2(6) * 185/59 -1 0	1030
HH	38.6(43) 221/50	127(72) 174/0	124(74) 187/0	54(49) 180/2	1.9(4) * 82/162	923
HHD	25.5(30) 221/50	52(28) 174/0	52(38) 187/0	26(26) 181/1	1.3(24) * 76/168	431
TAD	53.7(4.8) 271/0	63(5.4) 174/0	65(6) 187/0	64(6.7) 182/0	58(4) 244/0	60

DUR	30(0) 156/115	30(4) 170/4	29.8(2) 187/0	30(0) 157/25	30(0) 11/233	
TIND	63(4) 271/0	64(4) 174/0	66(5) 187/0	67(6) 182/0	66(6) 244/0	
EPID	7.7(10.9) 59/212	22(11) 117/57	27(7) 159/28	27(8) 141/41	21(12) 120/124	
CGCD	29(91) * 37/234 3.9	58(55) 112/62 37	71(58) 148/39 56	39(31) 119/63 25.5	1.6(25) * 9/235 0	540 312
CGSD	34(167) * 37/234 4.6	54(60) 112/62 34.7	65(46) 148/39 5.1	35(31) 122/60 23.5	-2.5(23) * 9/235 0	513 291
CGSD/CGCD						.95 93
CGCD/HPC						.52 30
LOSD	-5(98) * 37/234	4.2(33) * 112/62	4.3(3) 144/43	3.9(28) 119/63	4.1(3.9) 9/235	
LSCD	99(88) * 52/219	29(51) 108/66	12.4(27) * 140/47	9.4(16) 127/55	27(40) 116/128	
TINR	70(2.2) 271/0	70.7(1.6) 174/0	71(1.6) 187/0	71(1.7) 182/0	72(1.8) 244/0	
EPIR	29.3(3.6) 80/191	28(6) 119/55	28.7(5) 154/33	29.9(.9) 156/26	28(5) 141/103	
CGCR	22(26) 53/218 4.3	64(33) 114/60 42	65(40) 153/34 53.2	38(51) 140/42 29.2	-3(19) * 11/233 0	496 328
CGSR	15(26) 53/218 2.9	59(32) 114/60 38.6	61(38) 155/32 50.5	31(37) 142/40 24.1	-11(18) * 11/233 0	404 294
CGSR/CECR						.81 .90
CECR/HPC						.48 .32
LOSR	6.2(3.3) 53/218	4.6(3.7) 114/60	4.5(4.3) 153/34	5.2(4.9) 139/43	8.5(5) 11/233	
LSCR	6.0(2.8) 69/202	4.4(3.2) 101/73	5(5) 130/57	5.2(3.7) 131/51	5.6(3.3) 117/127	

Solar Data Jan.-Feb.
1978

Hourly Avgs.
BTU/HR-SF

As observed
Extrapolated - Pencil, Lower Right Corner

Period	1	2	3	4	5	Total
HPC	57(54) 382/0	181(82) 251/0	201(98) 257/0	122(76) 246/0	18(25) 181/175 9	1542 1515
HH	76(65) 371/11	188(82) 251/0	188(87) 257/0	100(60) 246/0	16(18) 147/209	1542
HHD	32(26) 372/10	82(39) 251/0	98(65) 257/0	58(41) 246/0	10.4(11) 153/203	753
TAD	58(6) 382/0	66(6) 251/0	68(7) 257/0	67(7) 246/0	62(5) 356/0	63.5

DUR	31.7(6.8) 306/76	30.4(5) 245/6	30(1.9) 257/0	30.6(5) 246/0	30(0) 95/261	
TIND	67(3.4) 382/0	69(3) 251/0	71(3.9) 257/0	72.4(4) 246/0	72(4) 356/0	
EPID	28(11) 191/191	29(4) 244/7	30(1) 257/0	28(5) 233/13	28(6) 107/249	
CGCD	28.9(43) 168/214 12.7	76(48) 232/19 70	85(66) 246/11 81	35(39) 231/15 33	16(19) * 35/321 1.6	653 514
CGSD	25.0(43) 168/214 11.0	72(48) 233/18 67	79(63) 247/10 76	29.8(39) 231/15 28	10(19) * 35/321 1	582 473
CGSD/CGCD						.89 .92
CGCD/HPC						.42 .34
LOSD	4.0(2.3) 168/214	5.1(4) 227/24	5.5(8) 217/40	5.0(3) 203/43	5.2(2.7) 35/321	
LSCD	13.8(15) 175/207	6.4(19) * 223/28	8.6(14) 217/40	8.3(10.4) 203/43	14(17) 107/249	
TINR	71(1.6) 382/0	72(1) 251/0	72(1.2) 257/0	72(1.4) 246/0	73(1.4) 356/0	
EPIR	29(8) 149/233	30(1.2) 251/0	30(.7) 257/0	30(0) 246/0	27(5.7) 138/218	
CGCR	37(53) 134/248 13	66(42) 240/11 63	85(58) 254/3 89	35(37) 246/0 35	8.6(16) ~ 74/282 0	638 507
CGSR	27(53) 134/248 9.5	57(40) 240/11 54	74(56) 254/3 73	24(36) 246/0 24	-1.6(15) * 74/282 0	490 415
CGSR/CGCR						.77 .82
CGCR/HPC						.41 .33
LOSR	9.4(3) 134/248	9.1(4) 239/12	10(4) 240/17	11(4) 237/9	10(4) 73/283	
LSCR	9.3(4.1) 135/247	7.6(4.3) 235/16	8.7(3.7) 239/18	9.5(3) 237/9	11(2) 137/219	

Solar Data March-April, 1978 Hourly Averages

Period	1 4	2 2.5	3 2.5	4 2.5	5 3	Total
HPC	~~[illegible]~~ 56(54) 47 ~~[illegible]~~ 194/39	226(54) 140/0	269(59) 169/0	215(58) 166/0	74(61) 177/172 37	2221 2055
HH	~~56(54)~~ 84(73) ~~194/39~~ 196/37	255(56) 140/	272(61) 169/	194(59) 166/	54(49) 199/	2300
HHD	~~84(20)~~ 26(22) ~~[illegible]~~ 198/35	56(32) 140/	87(56) 169/	118(48) 166/	45(39) 197/	891
TAD	84(6) 233/0	76(8) 140/	80(8.6) 169/	79(9) 166/	71(9) 349/	73
DUR	38(13) 170/	31(7.5) 130/	31(8.1) 168/	29.8(3.4) 165/	30(0) 157/	
TIND	70(3) 233/	73(2.4) 140/	74.5(2.7) 169/	75(2.3) 166/	74(2.5) 349/	
EPID	36(17) 144/	29(4.3) 131/	30(2.3) 169/	30(2.4) 166/	27(7) 166/	
CGCD	18(38) ~ 102/ 7.9	90(37) 108/ 69	121(49) 147/ 105	87(45) 144/ 75.5	40(34) 105/ 12	937 680
CGSD	15(39) ~ 6.6 102/	85(37) 110/ 67	115(50) 149/ 101	79.9(47) 147/ 70.7	38(39) 114/ 12	873 648
CGSD/CGCD						.93 .95
CGCD/HPC						.42 .33
LOSD	2.8(3.1) 102/	4.1(2.2) 108/	5(4) 134/	5.2(3.7) 118/	3.9(3.3) 93/	
TINR	73(2) 233/	73(2) 140/	75(3.2) 169/	76(4) 166/	76(4) 349/	
EPIR	25(11) 66/	29(3.8) 130/	30(2.7) 169/	30(2.4) 166/	27(5) 109/	
CGCR	26(45) * 7.4 66/	82(41) 119/ 70	101(47) 156/ 93	62.9(44) 160/ 61	27(40) 91/ 7	800 604
CGSR	16(47) * 4.5 66/	73(49) 119/ 62	89(46) 156/ 82	49(43) 162/ 48	13(38) 92/ 3.4	630 505
CGSR/CGCR						.78 .84
CGCR/HPC						.36 .29
LOSR	NA	8(21) ~ 118/	12.2(5) 137/	12.2(4) 114/	15(9) 77/	
LSCR	20(33) 66/	9.7(4.7) 110/				

Solar Data May-June, 1978 Hourly Average

Period	1	2	3	4	5	Total
HPC	41(37) 26 280/169	207(46) 216/0	289 (11) 232/0	245(38) 240/0	75(63) 268/204 42	2241 2082.5
HH	60(55) 280/	240(44) 216/	287 (10) 232/	215(40) 240/	60(48) 279/	2275
HHD	26(21) 281/	43(23) 216/	47(28) 232/	82(56) 240/	40(36) 278/	654
TAD	65(4) 449/	78(24) 216/	83 (4) 232/	83(4) 240/	74(5) 472/	75

DUR	32(8) 242/	30.3(4.8) 213/	4.4 30(~~8.1~~) 168/	30.5(4.7) 240/	30.4(4.4) 224/	
TIND	74(2.8) 449/	75(2.5) 216/	76(2.7) 232/	76.7(3.3) 240/	76(4.2) 472/	
EPID	41(16) 347/	30(0) 216/	30(0) 232/	30(0) 240/	30(3) 441/	
CGCD	5.4(54) * 164/ 0	104(94) 198/ 95	139(49) 214/ 128	99(59) 225/ 93	50(36) 207/ 22	1026 834
CGSD	-.4(64) * 164/ 0	101(94) 198/ 93	133(48) 214/ 123	92(61) 225/ 86	42(37) 207/ 18	939 791
CGSD/CGCD						.91 .95
CGCD/HPC						.45 .40
LOSD	5.8(15) 164/	4.1(2.2) 108/	5.2(4.0) 186/	6.9(4) 164/	8.4(5) 198/	
TINR	74(1.5) 449/	75(1.5) 216/	76(2) 232/	77.7(2.5) 240/	77(1.7) 472.	
EPIR	31(13) 151/	30(1) 216/	30(0) 232/	30(.3) 240/	28.5(5) 368/	
CGCR	-25(66) 109/ -6	79(29) 193/ 71	109(35) 100 212/	64(50) 225/ 60	26(28) 203/ 11	608 575
CGSR	-51(73) 109/ -12	54(29) 193/ 48	84(35) 77 212/	38(51) 225/ 36	0.822(29) * 203/ 0	238 354
CGSR/CGCR						.39 .61
CGCR/HPC						.27 .28
LOSR	NA	24(6.8) 192/	25(6) 193/	25(4.6) 140/	25.6(6) 195/	
LSCR	29(15) 97/	Q				

Solar Data - July-August 1978 Hourly Average

Period	1	2	3	4	5	Total
HPC	25(31) 248/22 24	171(59) 156/0	243(46) 169/0	183(58) 171/0	39(43) 138/106 22	1709 1654
HH	32(39) 249/	174(56) 156/	216(41) 169/	138(49) 171/	16(23) 207/	1496
HHD	18(23) 253/	87(56) 156/	75(53) 169/	40(23) 171/	6(8) 209/	595
TAD	57(14) 270/	69(12) 156/	75(12) 169/	75(11) 171/	67(11) 244/	67

DUR	29.6(3) 144/	31(8) 152/	30.3(3) 168/	30.3(3) 171/	30(3) 93/	
Tind	72(9) 269/	71(9) 156/	72(10) 169/	74(11) 171/	74(10) 244/	
EPID	23(11) * 9/	27(6) 144/	30(1) 169/	30(0) 171/	28(5) 192/	
CGCD	-11(17) * 3/ 0	44(64) ~ 142/ 40	98(58) 160/ 93	52(46) 161/ 49	14(29) * 93/ 5.3	483 466
CGSD	-15(17) * 3/ 0	38(64) ~ 140/ 34	93(60). 155/ 85	45(47) 155/ 41	8(29) * 93/ 3	404 406
CGSD/CGCD	-1					.83 .87
CGCD/HPC						.28 .28
LOSD	3.5(3) * 3/	5(2) 139/	4.3(3) 123/	5.4(2) 124/	5.7(2) 90/	
TINR	73(2) 240/	74(1) 141/	75(2) 150/	75(2) 151/	75(1) 216/	
EPIR	30(3) 258/	30(.02) 156/	30(0) 169/	30(0) 171/	30(2) 236/	
CGCR	4.6(16) * 140 2.4	63(28) 147/ 59	92(27) 151/ 82	50(35) 151/ 44	8(25) * 85/ 0	552 472
CGSR	-3.6(16) * 140/ 0	54(27) 147/ 51	83(27) 151/ 74	40(35) 151/ 35	-2(25) 85/ 0	422 400
CGSR/CGCR						.76 .85
CGCR/HPC						.32 .28
LOSR	8.2(1) 140/	9.3(6) 147/	9.2(2) 131/	9.7(2) 118/	9.8(1) 79/	

Solar Data September-October, 1977 Hourly Average

Period	1	2	3	4	5	Total
HPC	39(39) 30 315/100	143(64) 254/0	160(69) 272/0	65(60) 268/5	31(25) * 10/375 0	1169 1040
HH	41(39) 311/	129(53) 254/	125(50) 272/	40(38) 273/	11(10) * 12/	932
HHD	21(18) 311/	66(36) 254/	40(20) 272/	16(12) 273/	6.6(4) 10/	408
TAD	58(6) 415/	69(8) 254/	75(29) 272/	71(12) 273/	63(5) 385/	66

DUR	30.1(2) 239/	30.2(3) 251/	30.7(6) 271/	30.4(5) 215/	37(20) * 9/	
TIND	68(5) 415/	69(4) 254/	71(5) 272/	73(5) 273/	72(6) 385/	
EPID	3.8(7.6) * 30/	24(9) 156/	28(6.4) 237/	21(11) 224/	11(13) 124/	
CGCD	3.1(12) * 17/ 0	72(57) 43 151/ ~~50~~	70(55) 229/ 59	32(27) 168/ 20	10(7) * 8/ 0	477 305
CGSD	-0.04(11) * 17/ 0	69(57) 151/ 41	71(80) 229/ 60	28(26) 168/ 18	4.7(6) * 8/ 0	434 298
CGSD/CGCD						.91 .98
CGCD/HPC						.41 .29
LOSD	3.2(27) ~	3.0(21) * 151/	-1.4(43) * 225/	3.7(4) 167/	5.3(2) 8/	
TINR	72(1.6) 415/	73(2) 253/	74(2) 272/	74(2) 273/	74(2) 385/	
EPIR	20(11) 55/	29(4) 235/	30(2) 266/	30(1) 268/	22(12) 129/	
CGCR	4.3(11) * 33/ 0	59(32) 178/ 41	67(46) 208/ 51	26(24) 167/ 16	2.6(6) * 8/ 0	405 270
CGSR	0.09(11) * 33/ 0	54(31) 178/ 38	60(37) 208/ 46	20(23) 167/ 12	-6.8(7) * 8/ 0	315 240
CGSR/CGCR						.78 .89
CGCR/HPC						.35 .26
LOSR	4.2(27) 33/	5.2(3) 178/	5.7(5) 206/	6.2(4) 165/	9.4(2.8) 8/	

Solar Data November-December 1977 Hourly Average

TAD - Ambient temperature, $^{\circ}$F; all values used unless observation value $<$ 0°F.

DUR - The duration of the observation interval, calculated by subtracting the time of the previous observation from the time of the current observation. If the calculated value DUR $\leq$ 1.0 minute or DUR $\geq$ 90.0 minutes, the observation was discarded. No attempt was made to calculate DUR for the first observation after midnight.

TIND- Interior temperature, $^{\circ}$F, demo; all values $\leq$ 30.0°F and 100.0°F discarded.

EP1D- Time that demo solar collector pump was on, minutes per observation.

CGCD- Energy collected across the demo collector, BTU/S.F.-hr., where S.F. is square foot of collector. Calculated as CGCD=(TS4 - TS3) * FSC * 8.333 * 60.0/(DUR * 270.0) Values for TS3, TS4 exceeding 219.0°F or less than 0.0°F discarded. Excludes calculations with value $\leq$ 0.0.

CGSD- Energy stored in demo tank, in BTU/Hr. per S.F. of collector. Calculated as CGSD = (TS1 - TS2) * FSC * 8.333 * 60/0(DUR * 270.0). Values for TS1, TS2 exceeding 219.0°F or less than 0.0°F discarded. Excludes calculations with values $\leq$ 0.0.

LOSD- Energy lost between demo collector and storage when dump was not in operation (i.e. V3 $\leq$ 0.0). Calculated as CGCD - CGSD (BTU/Hr. - SF).

LSCD- Energy lost between demo storage outlet and collector inlet, when V3 $\leq$ 0.0, provided that flow rates, FSC/EP1, exceeded 1.0 gal/min but not 10.0 gal/min. Calculated as LSCD = (TS2D - TS3D) * 8.333 * (FSC/EP1) * 60.0/270.0. Excludes values $\leq$ 0.0.

TINR- Rental unit equivalent of TIND

EP1R- Rental unit equivalent of EP1D

CGCR- Rental unit equivalent of CGCD

CGSR- Rental unit equivalent of CGSD

LOSR- Rental unit equivalent of LOSD

LSCR- Rental unit equivalent of LSCD

Hot Water Data

In contradiction to the title, the Hot Water Data actually contains several types of data calculations other than hot water analysis in the rental unit. The name was simply an identification code for organizing data. All of this data was calculated subject to the voltage and DUR conditions described for the Solar Data. More data was included in this study than was tabulated, including TMID, TMOD, TD2D, TT2D, FCWD, FDTD, FDWD, ETFD, ECD, ESD, EHD, EWD FXID, LSSD, ECBLD, ECBD, and corresponding variables for the rental unit.

Demonstration Unit

TS2D - Temperature from TS2 demo sensor (See Figure B1), °F. Values less than 30.0°F ignored.

TX1D - Temperature from TX1 demo sensor, °F. Values less than 30.0°F ignored.

ECD1 - Energy collected at the demo storage tank from the solar collector, BTU/Hr., including calculations with values of zero (extrapolated data). Calculated as ECD1 = FSC * (TS1 - TS2) * 8.333 * 60.0/DUR.

ESD1 - Energy supplied for demo space heating/cooling, BTU/Hr., extrapolated basis (values of zero included). Calculated as ESD1 = FSS * (TX1 - TX2) * 8.333 * 60.0/DUR

EHD1 - Energy supplied for hot water preheating, demo, extrapolated basis. Calculated as EHD1 = FDT * (TM0 - TM1) * 8.333 * 60.0/DUR

LSSD1- Energy "loss" or energy unaccounted for in given observation interval, not considering tank temperature changes. Calculated as LSSD1 = ECD - EHD - ESD (extrapolated).

ECLD - Energy drop across cooling tower temperature sensors, presumably energy emitted by cooling tower. All temperature values permitted, but calculation performed only if pump 4 operated (EP4>0.0): ECLD = FTD * (TT1D - TT2D) * 8.333 * 60.0/DUR.

Rental Unit

TS2R - Rental equivalent of TS2D

TX1R - Rental equivalent of TX1D

TM1R - Temperature sensor TM1 in rental, values below 30°F ignored.

TM0R - Temperature sensor TM0 in rental, values ≤ 30°F ignored.

TD2R - Temperature sensor TD2 in rental, values ≤ 30°F ignored.

FCWR - Flow through meter FCW in rental, values of zero ignored.

FX1R - Difference in rental flow meters FDW - FDT, excluding values of 0.0.

ECR1 - Rental equivalent of ECD1

ESR1 - Rental equivalent of ESD1

EHR1 - Rental equivalent of EHD1

EWR1 - Energy provided by rental domestic hot water heater, including values of zero (extrapolated). Calculated as EWR1 = FDW * (TD2 - TD1) * 8.333 * 60.0/DUR

LSSR1 - Rental equivalent of LSSD1

Hot Water
Demo
January-February

	1	2	3	4	5	6	7	8	9	10	Tot
TSZD	131(38)	121(36)	123(33)	124(34)	131(25)	136(27)	144(28)	146(31)	137(34)	130(33)	132
	13/53	16/84	24/138	23/128	103/54	133/37	119/48	84/76	51/109	19/47	
TXID	X	X	X	X	128(16)	125(13)	117(36)	101(0)	X	X	
					21/	8/	7/	1/			
ECDI	-202 * (990)	-136 (890) *	-107 (875)	2180 (22000)	9250 (15350)	13670 (13200)	6320 (8500)	-518 (2434) *	-564 (1350)	-470 (1260)	73,792
	33/33	100/	161/1	151/[illegible] *	155/	170/	166/	160/	159/	66/0	273/4
ESDI	0(0)	0(0)	0(0)	0(0)	4080 * (11970)	1340(6300) *	280 (1815)	23(286) *	0(0)	0(0)	14,307
	33/33	100/	161/	151/	155/	170/	166/ *	160/	159/	66/	
EHDI	0(0)	0(0)	0(0)	1.9(21)	17(135) *	62(560)	59(630)	0(0)	0(0)	0(0)	350
	33/33	100/	161/	161/	155/	170/ *	166/ *	160/	159/	66/	
LSSDI	-202 * (940) 33/33	-136 (890) *	-107	2180 * (22400) 151/	5750 * (17900) 155/	12280 (14830) 170/	5980 (8700) 166/	-540 (2430) 160/	-564	-470	59,137 80%
ECLD	X	X	X	X		X	X	X	X	X	

Hot Water Data
Demo
March-April

	1	2	3	4	5	6	7	8	9	10	Tot
TS2D	157(30)	143(32)	139(29)	144(23)	157(25)	160(28)	173(27)	169(31)	163(30)	169(29)	158.2
	30/75	33/98	59/162	153/93	239/12	264/3	233/13	81/173	70/185	28/74	
TX1D	X	X	X	154(20)	135(39)	137(34)	180(25)	183(8)	177(4)	X	
				6/	21/	23/	29/	28/	8/		
ECD1	-1000 (-1750)	-827 (1580)	-690 (-1315)	4720 (10100)	18490 (13200)	21300 (16880)	7780 (10523)	-225 (2690)	-1070 (-1900)	-1040 (1845)	119,115
	53/52	131/	221/0	246/	247/	257/	246/	253/	255/	102/	441/7
ESD1	0(0)	0(0)	0(0)	505(4900)	980(4900)	1500 * (6150)	3160 * (9580)	1780 * (5700)	324 * (1865)	0(0)	20,422
	53/52	131/	221/	246/ *	247/ *	257/	246/	253/	255/	102/	
EHD1	0(0)	0(0)	0(0)	9.9(135)	86(632)	91(611) *	33(384)	0(0)	0(0)	0(0)	550
	53/52	131/	221/	246/ *	247/ *	257/	246/ *	253/	255/	102/	
LSSD1	-1000	-827	-690	4204 (11300)	17500 (14900)	19744 (-18037)	4590 (13400)	-2004 (5704)	-1390 (2690)	-1040 (1845)	98,237
				246/	247/	257/	246/	253/	255/	102/	82%
ECLD	X	X	X	665 (780)	2830 (2624)	16070 (12700)	24990 (11370)	15716 (2700)	8327 (2450)	X	
				2/	6/	11/	27/	28/	8/		

Hot Water Data
Demo
May - June

	1	2	3	4	5	6	7	8	9	10	Tot
TS2D	162(5)	155(9)	150(11)	149(9)	160(15)	166(20)	175(17)	174(20)	170(19)	171(11)	171.2
	17/59	18/47	29/69	93/37	122/18	155/13	150/16	119/56	54/120	17/52	
TXID	167(3)	164(0)	X	X	169(3)	173(7)	178(7)	175(6)	173(9)	174(9)	
	8/	1/			18/	75/	77/89	70/	44/130	16/	
ECDI	-254(840)	-226 (1030)	-56(1120)	3174 (-9380)	19550 (12850)	27770 (15860)	19285 (12710)	6430 (12700)	-564 (2050)	134(1530)	188,040
	37/ *	65/ *	98/ *	130/	130/	167/	168/	174/	174/	69/ *	696/9
ESDI	1140(4500)	38(310)	0(0)	0(0)	2855 (-8200)	11160 (-13970)	12743 (-8900)	9260 (-13000)	5430 (-11530)	4840 (-11360)	116,245
	37/ *	65/ *	98/	130/	130/	167/	168/	174/	174/	69/ *	
EHDI	0(0)	0(0)	0(0)	9.6(110)	2.2(19)	68(590)	15(18)	1.16(15)	0(0)	0(0)	240
	37/	65/	98/	130/ *	130/	167/ *	15/	174/	174/	69/	
LSDI	-1390 (4340)	-264 (-1130)	-56(1120)	3165 (-9390)	16700 (12500)	16560 (15690)	6300 (16000)	-2827 (15690)	-5990 (11095)	-4700 (10290)	71,020
	37/	65/	98/ *	130/ *	130/	167/	151/	174/	174/	69/ *	
ECLD	15240 (12540)	21960 (9320)	20835 (8211)	30950 (-7630)	28790 (19590)	38120 (20170)	45130 (18800)	43280 (22840)	38495 (25016)	31080 (22640)	
	14/	15/	15/	7/	35/	108/	130/	136/	94/	29/	

Hot Water Data
Demo
July - August

	1	2	3	4	5	6	7	8	9	10	Tot
TS2D	173(15)	160(3)	157(4)	162(11)	169(17)	183(14)	193(13)	197(13)	193(15)	186(15)	177.3
	56/37	40/53	60/81	149/75	201/15	216/15	224/15	218/18	193/43	73/22	
TX1D	174(8)	169(4)	165(2)	137(18)	169(9)	174(6)	178(6)	179(13)	180(11)	181(9)	
	26/	10/	4/	9/	15/	50/	45/	48/	54/	26/	
ECD1	-300(1320)	-815 (1120)	-567 (840)	-448 (14860)	25340 (25380)	33710 (15650)	24900 (16300)	9790 (10130)	-1611 * (3490)	-660 (3380)	224687
	46/	93/	141/	224/ *	213/	228/	224/	236/	236/	95/ *	837/4
ESD1	5790 (10900)	1710 (5850)	90(700)	109(940)	1280 (5210)	6420 (13640)	8190 (2000)	6260 (14080)	6525 * (15025)	8295 (15190)	107,825
	46/	93/	141/ *	224/ *	213/ *	228/	45/	236/	236/	95/ *	
EHD1	0(0)	0(0)	0(0)	0(0)	24(217)	12(123)	45(120)	1.5(16)	0.07 (1.1)	0(0)	206
	46/	93/	141/	224/	213/ *	228/ *	~~45~~ 240/ *	236/	236/	95/	
LSSD1	-6090 (10430)	-2530 (5740)	-660 (1050)	-153 (14860)	24040 (25670)	27280 (14025)	17500 (15600)	3532 (11650)	-8140 (12220)	-8950 (12480)	119,047
	46/	93/	141/	224/ *	213/	228/	240/	236/	236/	95/ *	
ECLD	28740 (18140)	25650 (20360)	29540 (25600)	38104 (23800)	48014 (26980)	53480 (25910)	36720 (12000)	62800 (21270)	55580 (28718)	44040 (20950)	
	14/	14/	11/	24/	50/	129/	148/	145/	120/	41/	

Hot Water Data
Demo
September - October

	1	2	3	4	5	6	7	8	9	10	Tot
TSZD	179.9(2)	178.8 (.2)	170(2)	168(4)	168(14)	172(17)	185(14)	188(14)	179(6)	176(7)	175.9
	2/51	3/74	5/116	7/114	133/8	158/0	165/0	169/0	37/130	6/56	
TXID	X	X	X	177(13)	179(6)	190(7)	183(7)	175(.7)	X	X	
				4/	10/	13/	16/	2/			
ECDI	-202 (1030)	-211 (1050)	-209 (1012)	-222 (1116)	10580 (16470)	25370 (15970)	13270 (12650)	-740 (6980)	-911(1780)	-236 (1070)	116,340
	26/27	76/ *	121/ *	121/ *	140/ *	158/	165/	169/	166/ *	62/	431/4
ESDI	0(0)	0(0)	0(0)	732(5480)	1820 (7130)	2533 (9470)	2760 (9270)	234 (2250)	0(0)	0(0)	20,200
	26/	76/	121/	121/ *	140/ *	158/	165/	169/ *	166/	62/	
EHDI	0(0)	0(0)	0(0)	.2(1.6)	143(724)	16(176)	81(460)	22(300)	0(0)	0(0)	655
	26/	76/	121/	121/ *	140/ *	158/ *	165/ *	169/ *	166/	62/	
LSSDI	-202	-211	-209 *	-955 (5590)	8620 (17760)	22820 (18550)	10430 (13590)	-990 (6760)	-911	-236 (1070)	95700
				121/ *	140/ *	158/	165/	169/ *		62/0	
ECLD	X	X	X	23960 (20960)	40420 (29650)	35380 (25820)	37040 (20600)	20590 (9542)	X	X	
				4/ *	19/	18/ *	27/	2/ *			

Hot Water Data
Demo
November - December

	1	2	3	4	5	6	7	8	9	10	Tot
TSZD	124.7(0)	147(23)	120(17)	120(22)	139 (27)	146(30)	156(30)	158(30)	161(31)	157(30)	142.9
	1/111	3/	13/263	20/231	161 /92	230/42	211/62	107/168	22/253	5/104	
TXID	X	X	X	X	143(23)	110(13)	155(6)	145(0)	X	X	
					3/	5/	3/	1/			
ECD1	0(0)	-12.0 (110)	-42(230) *	-.8(750)	11080 (15040)	16420 (21160)	4720 (6710)	-154(1190)	-234 (900)	-66 (340) *	79,311
	57/	166/ *	276/0	251/ *	251/	271/	273/	275/	275/ *	109/	294/4
ESD1	0(0)	0(0)	0(0)	0(0)	222(2490)	203 (2013)	460(4520) *	104(1730)	0(0)	0(0)	2472
	57/	166/	276/	251/	251/ *	271/ *	273/	275/ *	275/	109/	
EHD1	0(0)	0(0)	0(0)	5,4(85)	99.6(1300)	49(300)	7(42)	0(0)	0(0)	0(0)	402
	57/	166/	276/	251/ *	251/ *	271/ *	273/ *	275/	275/	109/	
LSSD1	0(0)	-12.0	-42(230)	-6(760)	10760 (15450)	16170 (21350)	4250 (7720)	-260(2000)	-234	-66	77439
	57/	*	276/ *	251/ *	251/	271/	273/	275/			
ECLD	X	*	X	X	226 (307)	6150 (9450)	X	X	X	X	
					2/	7/					

Hot Water Data
Rental
January - February

	1	2	3	4	5	6	7	8	9	10	Tot
TSZR	130(28) 24/42	129(26) 35/65	129(22) 50/112	125(23) 50/101	111(26) 108/49	116(29) 141/29	122(33) 140/27	127(33) 103/57	127(30) 83/77	127(30) 31/35	124.2
TXIR	X	X	X	X	X	X	X	X	X	X	
TMIR	63(2) 14/52	60(3) 7/	62(2) 12/	63(3) 43/	66(7) 77/	66(2) 77/	68(4) 51/	67(3) 75/	66(2) 66/	65(2) 11/	64.6
TMOR	84(20) 14/	88(20) 7/	78(19) 12/	97(26) 43/	87(18) 77/	92(19) 77/	92(23) 51/	113(33) 75/	96(21) 66/	95(21) 11/	92.2
TDZR	91(25) 14/	97(31) 7/	76(24) 12/	109(27) 43/	112(20) 77/	111(18) 77/	96(19) 51/	104(22) 75/	113(18) 66/	105(21) 11/	101.4
FCWR	8.3(7) 24/	8.9(8) 34/	4.9(3) 19/	13(14) 78/	20(24) 105/	17(22) 111/	6(9) 95/	11(15) 104/	13(15) 100/	7.4(10) 27/ *	270
FXIR	0(0) 2/	-.1(0) 2/	-.1(0) 3/	0.2(.3) 29/	.4(.6) 47/	.16(.6) 46/	-.02(.3) 14/	0.02(.5) 41/	.33(.46) 42/	-.1(.3) 4/	1.97
ECRI	-1380 (2200) 33/	-1321 (2120) 100/	-775 (1870) 161/	1523 (4640) 151/	10390 (10150) 155/	13507 (11170) 170/	6580 (9700) 166/ *	-1043 (3140) 160/ *	-1250 (2250) 159/	-1500 (2250) 66/	62577 232/4
ESRI	0(0) 33/	0(0) 100/	0(0) 161/	0(0) 151/	0(0) 155/	0(0) 170/	0(0)	0(0) 160/	0(0) 159/	0(0) 66/	0
EHRI	25(130) 33/ *	34(176) 100/ *	35(320) 161/ *	1475 (3700) 151/	2150 (4670) 155/	3060 (8250) 170/	388 (2200) 166/	2400 (6430) 160/	1990 (4800) 159/	325(1260) 66/	29542
EWRI	26(145) 33/ *	23(119) 100/ *	18(163) 161/ *	1230 (4160) 151/	4065 (9050) 155/	2310 (6200) 170/	134 (1080) 166/	46(3100) 160/	1860 (4880) 159/ *	470(3060) 66/	25220 54,762
LSSRI	-1403 (2200) *	-1354 (2140) 100/	-810 (1950) 161/	48(5250) 151/	8230 (10650) 155/	10450 (11900) 170/	6196 (9750) 166/	-3450 (7470) 160/	-3240 (6120) 159/	-1820 (2590) 66/	~~96077~~ 33027
FCWR	8.34 3.03 24/42	8.89 5.0 34/66	~~12~~ 4.91 .57 19/143	12.78 6.51 78/73	20.34 13.60 105/52	17.21 11.24 111/59	5.85 3.33 95/72	10.99 7.14 104/56	13.40 8.37 100/60	7.44 3.04 27/39	~~139.67~~ 282.55
FDTR	1.32 9/ .12	2.40 .096 4/96	2.600 .048 3/	11.23 34/ 2.49	16.19 6.49 63/94	14.37 5.49 65/105	2.26 .51 38/129	7.08 2.69 61/99	11.41 3.85 54/106	6.43 .88 9/57	112.81
FDWR	1.3 9/ .19	2.35 4/96 .094	2.50 3/ .046	11.39 34/ 2.50	16.20 6.60 64/93	14.49 5.54 65/105	2.25 .51 38/129	7.21 2.70 60/100	11.66 3.93 54/106	6.39 .87 9/57	114.05 226.86
											220

Hot Water Data
Rental
March - April

	1	2	3	4	5	6	7	8	9	10	Tot
TS2R	195(13)	142(12)	137(13)	133(18)	139(24)	148(26)	159(28)	165(23)	154(14)	160(13)	147.2
	24/81	24/107	50/171	117/129	246/5	254/3	246/0	114/140	60/	24/	
TXIR	X	146(0)	150(0)	150(19)	X	X	X	181(9)	156(2)	139(0)	
		1/	1/	5/				5/	9/	1/	
TMIR	65(3)	65(3)	64(3)	66(2)	67.7(2)	69(3)	71(4)	71(4)	68(3)	68(3)	67.5
	18/	14/	15/	88/	115/	119/	86/	132/	107/	21/	
TMOR	101(24)	99(27)	100(33)	102(26)	110(22)	111(22)	111(22)	119(28)	120(25)	104(22)	107.7
	18/	14/	15/	88/	115/	119/	86/	132/	107/	21/	
TD2R	82(23)	89(25)	90(29)	100(25)	110(20)	107(19)	93(19)	94(20)	100(21)	97(19)	96.2
	18/	14/	15/	88/	115/	119/	86/	132/	107/	21/	
FCWR	14(25)	13(19)	10.6(19)	10(12)	22(26)	22(30)	9.6(14)	14(19)	10.4(14)	9.8(15)	334
	39/ *	59/ *	48/ *	142/	158/	152/	129/	175/	168/	37/ *	
FXIR	-.37(.46)	-.27(.19)	.23(.54)	.14(.3)	.3(.5)	.2(.7)	.09(.5)	.28(.4)	.02(1.1)	0(.4)	1.55
	3/ *	6/ *	6/ *	39/	67/	72/185	30/ *	69/ *	50/ *	9/ *	
ECRI	-1231 (-2330)	-925 (2070)	-970 (1980)	4260 (11100)	15100 (11000)	19870 (15080)	6432 (9770)	-990 (-3100)	-1200 (2290)	-1260 (2500)	98345
	53/	131/	221/	246/	247/	257/	246/	253/ *	255/	102/ *	364/4
ESRI	0(0)	0(0)	0(0)	2.1(23)	0(0)	0(0)	0(0)	6(71)	21(300)	3(31)	80
	53/	131/	221/	246/ *	247/	257/	246/	253/ *	255/	102/	
EHRI	127(540)	123(613)	274(2350)	1230 (3900)	4300 (9400)	4880 (12230)	1315 (5290)	3740 (9300)	2580 (6650)	435(1900)	47292
	53/ *	131/	221/ *	246/	247/	257/	246/	253/ ~	255/ ~	102/ *	
EWRI	7.3(111)	-31(364)	-12(163)	554 (2800)	1430 (5040)	1030 (4350)	-88 (1830)	-744 (2930)	-310 (2840)	166(2400)	4922
	53/	131/	221/ *	246/	247/	257/	246/ *	253/ *	255/ *	102/	52,214
LSSRI	-1360 (2320)	-1050 (2100)	-1242 (3000)	3020 (12000)	10800 (13700)	14990 (17400)	5120 (10380)	-4730 (9790)	-3800 (7000)	-1702 (3044)	50970
	53/	131/	221/ ~	246/ *	247/	257/	246/	253/	255/	102/	
FCWR	14.25 5.29	12.95 5.83	10.66 2.3	10.52 6.07	21.82 13.7	22.25 13.16	9.58 4.81	14.53 10.0	10.37 6.83	9.84 3.57	~~158.77~~
	39/66	59/72	48/	142/104	158/93	152/105	129/117	175/79	168/87	37/65	324.25
FDTR	3.32 .28	4.59 .28	12.19 .44	6.24 1.77	14.11 6.07	15.42 6.42	5.61 1.35	8.23 3.60	7.60 2.50	4.18 .69	114.5
	9/96	8/123	8/	70/	108/143	107/150	62/189	111/143	84/171	17/85	
FDWR	3.20 .27	4.39 .27	12.36 .45	6.41 1.50	14.30 6.15	15.7 6.47	5.84 1.36	8.56 3.67	7.61 2.51	4.13 .69	115.725
	9/96	8/	8/213	69/177	108/143	106/151	60/186	109/145	84/171	17/85	
											230.2

Hot Water Data
Rental
May - June

	1	2	3	4	5	6	7	8	9	10	Tot
TSZR	X	X	X	141(21)	150(26)	163(27)	175(26)	185(21)	139(16)	X	
				66/64	130/10	162/6	164/2	100/75	11/163		159
TXIR	X	X	141(0)	X	155(0)	182(8)	169(0)	168(0)	X	X	
			1/		1/	2/	1/	1/			
TMIR	73(9)	72(9)	70(3)	69(2)	73(9)	76(5)	75(5)	77(6)	74(3)	79(3)	73.8
	7/64	4/61	9/	32/	53/	51/	48/	53/	47/	5/	
TMOR	108(30)	107(42)	116(23)	107(21)	116(19)	127(25)	141(27)	141(31)	133(28)	129(36)	122,5
	7/	4/ *	9/	32/	53/	51/	48/	53/	47/	5/	
TDZR	74(5)	73(10)	103(16)	98(21)	97(19)	100(17)	97(17)	100(17)	110(20)	90(14)	94.2
	7/	4/	9/	32/	53/	51/	48/	53/	47/	5/	
FCWR	5,3(5) *	5,3(5)	21(9)	13(20)	20,7(30)	23(33)	24(37)	25(38)	23(37)	5(4)	410
	12/	8/ *	17/	54/	72/	70/ *	66/ *	76/	71/	22/	
FXIR	-4.4(6)	-4.7 (-0)	-12(28)	-2,8(6)	-5,5(10)	-4(13)	-9(19)	-3.8(7)	-11(19)	-3.3(3)	-147.8
	2/ *	1/	6/	18/	32/ *	32/ *	32/	40/	30/ 8,16	3/	
ECRI	0(0)	0(0)	0(0)	2230(9360)	18280 (13700)	22740 (13280)	13300 (11700)	1515 (8660)	-252 (1030)	0(0)	144,532
	37/	65/	98/	130/	130/	162/	162/	174/	174/	69/	535/4
ESRI	0(0)	0(0)	0(0)	0(0)	0(0)	na	X	0(0)	0(0)	0(0)	
	37/	65/	98/	130/	130/			174/	174/	69/	
EHRI	182(1080)	56(450)	640 (3330)	1260 (4750)	2430 (7140)	2720 (8200)	2800 (4000)	2210 * (6730)	3812 (10620)	214(1230)	4095
	37/ *	65/	98/ *	130/ *	130/	167/	43/ *	174/	174/	69/ *	
EWRI	-4(25)	-.84 (-6.8)	190(2240)	230 (2240)	330 (1730) *	148 * (2130)	-200 (1000) *	159 * (2580)	118(1300)	-5(31)	~~965~~ ~~2425~~
	37/ *	65/	98/ *	130/ *	130/	167/	40/	174/	174/	69/	43378
LSSRI	-182(1080) *	-56 (450)	-640 (3330)	966 (9500)	15840 (15520)	20025 (14480)	10220 (13400)	-692 (10660)	-4065 (10650)	-214 (1230)	103,112
	37/	65/	98/ *	130/ *	130/	167/	162/	174/ *	174/	69/	
FCWR	5.33	5.30	21.19	13.33	20.73	23.48 *	23.98 *	24.97 *	22.83 *	5.08	
	.90	.65 *	3.67 *	5.54	10.66	9.78	9.53	10.89	9.31	1.62	~~148.92~~
	12/59	8/57	17/81	54/76	72/68	70/98	66/100	76/99	71/103	22/47	297,45
FDTR	4.55	4.80	24.54 *	11.07	9.60 *	18.09 *	11.72 *	8.900 *	16.14	3.43 *	
	.13	.07 *	2.00	1.70	2.88	3.98	3.03	2.24	3.62	.15	93.5
	2/69	1/64	8/90	20/110	42/98	37/131	43/123	44/131	39/135	3/66	
FDWR	0.300	0.100	15.26 *	9.46	6.10 *	16.77 *	5.32	6.96 *	8.02 *	0.200	
	*	.00 *	1.24	1.31	1.61	3.19	1.28	1.35	1.66	.00 *	55.09
	1/70.00	1/64	8/90	18/112	37/103	32/136	40/126	34/141	36/138	2/67	145.63

Hot Water Data
Rental
July - August

	1	2	3	4	5	6	7	8	9	10	Tot
TSZR	X	X	X	168(9)	176(11)	188(11)	197(8)	202(6)	201(2)	199(1.6)	1331
	194	186	178	109/115	197/19	214/17	224/15	213/23	125/111	4/	190
TXIR	135(0)	X	X	X	~~79(?)~~ X	X	X	X	202(0.0)	X	
	1/92				[illegible]/				1/		
TMIR	80(2)	80(2)	78(3)	79(3)	79.2(2)	81(2)	84(3)	85(4)	83(3.5)	81(2)	81.0
	20/	13/80	16/	23/	67/	75/	77/	69/	89/	20/	
TMOR	142(28)	146(24)	134(35)	125(29)	126(23)	138(24)	151(23)	145(29)	149(26)	138(21)	139.4
	20/	13/	16/	23/	67/	75/	77/	69/	89/	20/	
TDZR	92(14)	90(14)	102(24)	104(20)	103(18)	102(17)	109(14)	103(13)	111(15)	99(15)	101.5
	20/	13/	16/	23/	67/	75/	77/	69/	89/	20/	
FCWR	15(25)	8.8(5)	14(20)	11(18)	28(34)	18(29)	18(28)	19.7(31)	18.4(26)	13(19)	403.
	28/ *	20/	36/	62/	90/	111/	130/	106/	115/	34/	
FXIR	-9.7(14)	-4.5(3)	-14(13)	-12(9)	-19.6 (14)	-11(15)	-9.8 (13)	-7.4(12)	-11.7(14)	-10(13)	-23.5
	14/	10/ *	12/ *	16/ *	64/	56/ *	62/ *	55/	69/	15/	
ECRI	0(0)	0(0)	0(0)	-6700 (15410)	13213 (8530)	21170 (10870)	10000 (13800)	-280 * (7650)	-5680 (6140)	-290(1770)	78727
	46/	93/	141/	224/ *	213/	228/	239/	236/	236/	95/	291/4
ESRI	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	X	0(0)	0(0)	0(0)	0
	46/	93/	141/	224/	213/			236/		95/	
EHRI	1020 (3090)	332(1190)	755 (3300)	825 (3930)	3590 (9170)	2870 (9080)	3012 (3000)	2143 * (7627)	4390 (10570)	1854 (7310)	51175
	46/ *	93/ *	141/ *	224/ *	213/	228/ *	62/	236/	236/	95/	
EWRI	-21(62)	-6.3(26)	-3.8(20)	-.83 (16)	-3.7 (46)	-6.5(44)	-10(7)	-10.0 (45)	-14.6 (50)	-16.8 (83)	-22
	46/	93/ *	141/ *	224/ *	213/	228/	240/	236/	236/	95/	50349
LSSRI	-1020 (3090)	-332 (1190)	-755 (3300)	-7580 (15750)	9625 (11000)	18300 (11820)	6800 (14400)	-2423 (9495)	-10070 (11780)	-2150 (7460)	2706
	46/	93/ *	141/ *	224/ *	213/	228/	240/	236/	236/	95/	
FCWR	15.01	8.84	13.76 *	10.96 *	27.82	17.91	17.83	19.73 *	18.44	13.00	~~148.48~~
	4.52 *	1.90	3.51	3.03	11.59	8.61	9.70	8.86	8.78	4.65	
	28/65	20/78	36/105	62/162	90/126	111/120	130/109	106/130	115/121	34/61	301.92
FDTR	10.06	4.68	14.84 *	12.24 *	15.08	11.25	10.02	7.63 *	11.89	10.5	
	1.51	.50 *	1.26	.87	3.77	2.72	2.60	1.78	3.48	1.66	92.57
	14/79	10/83	12/129	16/208	54/162	56/185	62/177	55/181	69/167	15/80	
FDWR	0.44	0.18	0.36	.287	0.53	0.34	0.28	0.29 *	0.31	0.36	
	.05	.02	.03	.02	.103	.00	.05	.04	.07	.03	1.81
	10/83	9/84	11/130	15/209	42/174	39/192	46/193	35/201	52/184	9/86	94.4

Hot Water Data
Rental
September - October 1977

	1	2	3	4	5	6	7	8	9	10	Tot
TS2R	170.8 (-12)	165(11)	180(12)	154(12)	155(15)	164(18)	178(17)	185(18)	179(17)	174(15)	168.4
	49/4	70/7	110/11	115/6	141/0	159/0	165/0	165/4	157/10	58/4	
TX1R	X	X	X	X	X	173(0)	X	176(0)	X	X	
						1/		1/			
TM1R	77,8(14)	69.5 (-6)	84(17)	76(3)	81(11)	85(14)	85(14)	82(11)	83(14)	76(2)	79.9
	14/	3/	5/	26/	78/	63/	34/	73/	68/	7/	
TMOR	130(30)	108.9 (49)	147(18)	127(15)	131(18)	139(24)	143(30)	142(35)	153(27)	131(19)	135
	14/	3/	5/	26/	78/	63/	34/	73/	68/	7/	
TD2R	96(21)	83.7 (-30)	115(30)	111(15)	115(14)	117(19)	113(17)	108(19)	116(19)	103(15)	108
	14/	3/	5/	26/	78/	63/	34/	73/	68/	7/	
FCWR	6,6(5)	4.2(3)	14.0(12)	15(21)	31(37)	24(34)	13(24)	13(26)	13(17)	6,7(7)	348
	22/	13/	10/	61/	106/	107/	96/	122/	105/	22/ *	
FX1R	-3,9(5)	-1,6(0)	-12.6 (6)	-14(14)	-20(22)	-18(21)	-13(19)	-11(27)	-7,7 (71)	-7,6(11)	-269.7
	9/	1/	5/ *	25/	74/	61/ *	30/ *	63/ *	63/	6/ *	
ECR1	-5107 (1630)	-4960 (1670)	-5000 (2612)	-631 (4650)	15160 (7500)	22890 (7600)	11620 (9525)	-2650 (5540)	-4720 (1860)	-5070 (1930)	56368
	26/	76/	121/	121/	140/	158/	165/	169/	166/	62/	209
ESR1	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	
	26/	76/	121/	121/	140/	158/	165/	169/	166/	62/	
EHR1	411(1580) *	16.5 (144) *	556(2900)	2640 (7080)	7910 (12780)	5810 (12090)	2450 (8950)	3520 (10070)	3390 (7025)	710(3530) *	68177
	26/	76/	121/	121/	140/	158/	165/	169/	166/	62/	
EWR1	-7,6(37) *	-,11(1) *	-1,96 (11) *	-6(30)	-4,8 (34) *	-8,8(28) *	-4,6(20) *	-9,2(35) *	-9,7 (24) *	-2,8(14) *	-137
	26/	76/	121/	121/	140/	158/	165/	169/	166/	62/	68,040
LSSR1	-5520 (2110)	-4976 (1680)	-5560 (3914)	3220 (8580)	7250 (14980)	17080 (13930)	9230 (13120)	-6170 (10860)	-8110 (6610)	-5780 (3160)	49630
	26/	76/	121/	121/	140/ *	158/	165/	169/ *	166/	62/	
FCWR	6.6(5)	4.2(3)	14.0(12) *	15(21)	31(37)	24(34) *	13(24)	13(26)	13(17)	6.7(7) *	385
	22/ 2.74	13/ .71	10/ 1.16	61/ 7.56	106/ 23.3	107/ 16.15	96/ 7.56	122/ 9.38	105/ 8.17	22/ 2.38	
FDTR	3.98	1.70	12.82 *	14.46 *	20.49	18.50 *	13.59	11.12	7.87	7.75 *	158.85
	9/44 .67	1/76 .02	5/116 .53	25/96 2.99	74/67 10.75	61/98 7.09	30/135 2.47	63/106 4.14	63/104 2.97	6/56 .75	
FDWR	0.2	0.1	.22	.311	.42	.45	0.433 .05	0.27	.215	0.37	2.9
	5/48 0	1/76 0	5/116 .01	19/102 .05	65/76 .19	49/110 .14	18/147	43/126 .07	46/121 .06	3/59 .02	161.7

Hot Water Data
Rental
November - December 1977

	1	2	3	4	5	6	7	8	9	10	Tot
TSZR	110(26)	105(22)	107(22)	117(21)	120 (24)	125(27)	132(30)	127(33)	97(3)	96(2)	113.6
	15/	15/	20/256	37/214	180/73	209/63	213/60	96/179	50/225	18/91	
TXIR	X	X	X	X	X	X	X	X	X	X	
TMIR	66(3)	67(4)	67(3)	68(4)	69(3)	71(3)	72(4)	71(3)	70(3)	68(2)	68.9
	37/	23/	18/	55/	113/140	103/	51/	108/	100/	19/	
TMOR	85(13)	101(32)	93(23)	95(26)	96(22)	99(24)	93(23)	103(27)	107(28)	98(23)	97
	37/	23/	18/	55/	113/	103/	51/	108/	100/	19/	
TDZR	84.7(23)	91(22)	91(24)	103(23)	111(16)	109(13)	96(17)	108(15)	108(15)	95(21)	99.7
	37/	23/	18/	55/	113/	103/	51/	108/	100/	19/	
FCWR	8.5(10)	9.1(13)	10(13)	11(13)	22(25)	20(27)	10(19)	11(15)	14(17)	9.9(16)	309
	53/ *	48/	34/	131/	164/	168/	137/ *	158/	175/	38/	
FXIR	-0.137 (2)	-.79(2)	-.71(3)	-3(7)	-3.7(12)	-4.6(12)	0.3(1.2)	-.7(4)	-1.7(5)	0.29 (1.2) *	-37
	8/	9/ *	13/	36/ *	86/ *	63/ *	20/ *	84/	81/ *	10/	
ECRI	-367 (1280)	-150(740)	-135 (690) *	-25 (1100)	10300 (9700)	12520 (11210)	2930 (5900)	-464(1060)	-127 (350)	-128 (340)	60950
	57/	166/ *	276/	251/ *	251/	271/	273/	275/	275/ *	109/ *	226
ESRI	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	
	57/	166/	276/	251/	251/	271/	273/	275/	276/	109/	
EHRI	283(1750)	260(1020)	401(2600)	1070 (3680)	3025 (7254)	2790 (7480)	580(2970)	1530 (4270)	2050 (4790)	608 (4300)	31788
	57/	166/	276/ *	251/ *	251/	271/	273/ *	275/	275/	109/ *	
EWRI	150(900)	63(1520)	1.1(242)	640 (3470)	2240 (6330)	1360 (5370)	226(2280)	807 (4060)	990(4160)	148 (940)	16463
	57/	166/	276/ *	251/ *	251/	271/	273/ *	275/ *	275/ *	109/ *	47,651 [illegible]
LSSRL	-650 (2140)	-411(1230)	-540 (2680) *	-1096 (3960)	7270 (10270)	9730 (12256)	2350 (5940)	-1990 (4290)	-2180 (4260)	-740 (4300)	29730
	57/	166/	276/	251/ *	251/	271/	273/	275/	275/	109/ *	
FCWR	8.5(10) 3.69	9.1(13) 2.61	10(13) 1.23	11(13) 5.74	22(25) 14.26	20(27) 12.35	10(19) * 5.02	11(15) 6.32	14(17) 8.9	9.9(16) * 3.43	299.0
	53/	48/	34/	131/	164/	168/	137/	158/	175/	38/	
FDTR	11.54 1.04	8.49 .76	11.68 * 0.55	11.48 * 1.97	15.80 6.49	17.05 * 5.26	8.86 1.04	7.31 2.68	10.84 3.58	8.38 * 1.00	116.0
	11/101	15/152	13/263	43/208	104/149	84/188	32/241	101/174	91/184	13/96	
FDWR	11.44 1.03	8.02 .72	11.87 * .043	9.74 * 1.55	13.12 8.72	13.78 4.20	9.65 1.06	7.97 2.46	10.00 3.09	9.32 * 1.03	115.03
	11/101	15/152	12/264	40/211	101/152	83/189	30/243	85/190	85/190	12/97	231

Possible Boil-Offs-Hot Water Data

	Jan/Feb	1	2	3	4	5	6	7	8	9	10	Tot
	ECBLD	X	X	X	X	X	32548 (46228) * 2/168	8090 (14770) * 3/164	5807 (0) 1/159	X	X	
	ECBD	X	X	X	X	X	-139(0) * 1/169	-434 (100) * 2/165	X	X	X	
	ECBLR	X	X	X	X	X	11500 (11440) * 2/168	13700 (12030) * 2/165	X	X	X	
	ECBR	X	X	X	X	X	11500	13700	X	X	X	
	Mar-Apr											
	ECBLD	X	X	X	X	X	29780 (5065) 10/247	23400 (4875) 6/240	X	X	X	
	ECBD	X	X	X	X	X	30064 (6375) 7/250	29530 (0) * 1/	X	X	X	
	ECBLR	X	X	X	X	X	X	X	X	X	X	
	ECBR	X	X	X	X	X	X	X	X	X	X	
	May-Jne											
	ECBLD	X	X	X	X	23454 (9740) 502 * 3/137	10640 (9800) * 8/160 506	8610 (9800) * 6/160 307	14270 (19700) * 10/165 815	X	X	19.6/dy 5300
26	ECBD	X	X	X	X	23454 (5624) 502 * 3/137	10640 (9800) * 8/160 506	8025 (~~4860~~ 10900) * 5/16/242	14270 (19700) * 10/165 815	X	X	19.1/dy 5162
	ECBLR	X	X	X	X	4760 (6480) * 3/137 102	16520 (13720) * 7/161 668	8650 (11600) * 5/161 245	12950 (0) * 1/174 74	X	X	10.7/dy 2822
12	ECBR	X	X	X	X	6700 (7800) * 2/138 102	14860 (14240) * 6/162 530	115(166) * 3/163 2	12950 (0) 1/174 74	X	X	6.5/dy 1770

Possible Boil Offs

Jly-Aug	1	2	3	4	5	6	7	8	9	10	Tot'
ECBLD	X	X	X	X	X	X	X	X	X	X	
ECBD	X	X	X	X	X	X	X	X	X	X	
ECBLR	X	X	X	X	X	X	X	X	X	X	
ECBR	X	X	X	X	X	X	X	X	X	X	
Sept-Oct											
ECBLD	X	X	X	X	X	28960 (6320) 17/192	25470 (5500) 15/150	10320 (0) * 1/168	X	X	
ECBD	X	X	X	X	X	30430 (5760) 6/153	25700 (4800) 10/155	X	X	X	
ECBLR	X	X	X	X	27570 (3350) 5/136	25920 (7400) 19/140	17390 (7750) * 20/145	-2900 (3750) * 17/152	-5000 (580) 9/158	X	
ECBR	X	X	X	X	28790 (2260) 4/137	27530 (5590) 17/142	17390 * (7750) 20/145	-3030 (3610) * 13/156	-5075 (570) 3/164	X	
Nov-Dec											
ECBLD	X	X	X	X	X	29190 (0) * 1/271	X	X	X	X	
ECBD	X	X	X	X	X	29190 (0) * 1/271	X	X	X	X	
ECBLR	X	X	X	X	X	2200 (0) * 1/	60(0) * 1/272	X	X	X	
ECBR	X	X	X	X	X	2200 * (0) 1/	X	X	X	X	

FDTR - Rental measurements of flows FDT, as observed; zero values ignored.

FDWR - Rental measurements of flows FDW, as observed; zero values ignored.

Possible Boil Offs

ECBLD- Calculation of energy reported to have been stored in the demo from solar collection, but TS4 exceeds 215°F. Calculated as (BTU/hr.) ECBLD = FSC * (TS1 - TS2) * 8.333 * 60.0/DUR (As observed).

ECBD - Same as ECBLD, except condition is TS4 > 220.0°F.

ECBLR- Rental equivalent of ECBLD

ECBR - Rental equivalent of ECBD.

Systems Data

The Systems Data was the first systematic attempt to examine what systems were operating in each house, and when. This data preceded the Hot Water Data; it is all on an "as observed" basis. The same exclusionary rule on voltages and DUR applied here as in the Solar Data.

Demonstration Unit

TAD - Ambient temperature, °F

TIND - Demo interior temperature, °F, values < 0.0°F ignored.

ESD - Energy provided for space heating/cooling from solar storage. Calculation is ESC = FSS * (TX1 - TX2) * 8.333 * 60.0/DUR BTU/Hr.

EBD - Energy provided for space heating/cooling from boiler. Calculated as EBD = BAH * (TB1 - TB2) * 8.333 * 60.0/DUR.

ESHD - Energy provided by solar presumably for heating; same calculation as for ESD, but only on condition EP4 + EP5 ≤ 0.0.

EBHD - Energy provided by boiler for heating; same calculation as for EBD, but only if EP4 + EP5 ≤ 0.0

ESCD - Energy supplied from solar storage, calculated as for ESD, but only if EP4 > 0.0; presumably cooling data. BTU/Hr.

EBCD - Boiler energy for cooling; same calculations as for EBD, but only if EP4 > 0.0.

CD - Energy removed from the house, calculated as CD = FC * (TC2 - TC1) * 8.333 * 60.0/DUR, on condition that EP5 0. BTU/hr.

EP4D - Time that pump 3 is on; minutes/observation.

EALD - Time that fan is on low speed; minutes/observation.

EAHD - Time that fan is on high speed; minutes/observation. If reported time is<0.1, value is ignored (calibration error).

FAD - Volume of internal air recycled per hour, if volume exceeds 1.7 cubic feet/observation. Calculated as FAD = FRA * 60.0/DUR. C.F./Hr.

FOD - Volume of outside air used per hour, if volume exceeds 1.7 cubic feet/observation (calibration error). Calculated as FOD = FDA * 60.0/DUR. C.F./hr.

Variables TINR, ESR, EBR, ESHR, ESCR, EBCR, CR, EP3R, EALR, EAHR, FAR, FOR, are equivalent to the variable spelled the same except ending in "D". These variables are for the rental unit.

January-February 1978
Demo Hourly Data

	1	2	3	4	5	6	7	8	9	10	TOTAL
TAD	52(3) 72/0.	58(4) 109 ~~93~~/0	51(4) 177/0	55(5) 166/0	63(5) 174/0	65(7) 187/	64(7) 182/0	59(5) 175/0	55(3) 175/0	54(3) 72/	
TIND	63(5) 72/	62 ~~63~~(4) 109 ~~93~~/	62(4) 177/	63(3) 166/	65(4) 174/	66(6) 187/	67(6) 182/	66(6) 175/	64(6) 175/	64(5) 72/	
ESD	X	X	X	X	30100 3632	28500 1219	7700 253	3600(0) 1/	X	X	
EBD	X	X	X	X	8500 537	20700 774	13400	X	X	X	
TOT											
ESHD	X	X	X	X	30100 (16800) 21/3632	28500 (9000) 8/1219	7700 (6300) 6/253	3600(0) 1/	X	X	12760
EBHD	X	X	X	X	8500 (14400) 11/537	20700 (15200) 7/774	13400 (3400) 3/220	X	X	X	3330
TOT											16,590
ESCD	X	X	X	X	X	X	X	X	X	X	
EBCD	X	X	X	X	X	X	X	X	X	X	
Tot											
CD	X	X	X	X	X	X	X	X	X	X	
EP3D	X	X	X	X	22(10) 23/	24(10) 14/	30(0) 5/	7.6(0) 1/	X	X	
EALD	X	X	X	X	22(10) 21/	24(10) 14/	30(0) 5/	7.5(0) 1/	X	X	
EAHD	X	X	X	X	18(14)* 4/	X	X	~~[illegible]~~ X	X	X	
FAD	X 0	X 0	X	X 0	20100 0 (4800) 23/	16640 (7240) 14/	18320 (400) ~~[illegible]~~ 5/	~~[illegible]~~ 1/ 4980(0)	X 0	X 0	
FOD	X 40	X 61	X 97	X 86	X 90	X 96	X ~~98~~ 93	X 90	X 90	X 38	
DUR	60(0) 36/36	~~[illegible]~~ 49 (15) ~~[illegible]~~ 109/	29.8(2) 176/	30(0) 166/	30.3(4) 171/	29.8(2) 187/	30(0) 181/	30(0) 175/	30.2(2) 174/	30(0) 72/	

March-April 1978
Demo Hourly Data

	1	2	3	4	5	6	7	8	9	10	Total
TAD	55(4) 96/0	54(5) 123/0	54(4) 209/0	60(5) 226/	66(6) 231/	68(7) 237/	67(7) 226/	63(5) 234/0	58(4) 235/0	57(4) 94/0	
TIND	68(4) 96/	67(4) 123/	66(4) 209/	67(3) 226/	69(3) 231/	71(4) 237/	72(4) 226/	72(4) 234/	71(4) 235/	69.7(4) 94/	
ESD	X	X	X	24870 (26400) 5/ 550	10400 (13800) 21/ 945	16700 * (13000) 23/1620	25800 (12200) 25/2350	15/100	9642 (2940) 6/	X	
EBD	X	X	X	-700(3300) 4/ -12	13200 (13700) 17/971	15800 * (12000) 14/ 930	8800 * (13500) 9/ 350	X	X	X	
Tot											
ESHD	X	X	X	23900 * (36800) 3/ 310	13800 (15000) ~ 15/ 900	21000 (13000) 14/1240	27300 * (19000) 4/ 430	X	X	X	7320
EBHD	X	X	X	1400 * (1400) 3/ 18	10750 (10550) 11/ 510	7400 (12000) * 6/ 190	5700 * (13600) 5/ 125	X	X	X	211
Tot											943
ESCD	X	X	X	27060 * (7600) 2/ 240	1960 * (3700) 6/ 50	9600 * (10000) 9/ 360	25500 (11100) * 21/2370	15100 (7100) 18/1160	9600 (2900) 6/ 245	X	11060
EBCD	X	X	X	-2780 (3700) * 2/ -25	17700 (18500) 6/ 460	22000 (8800) ~ 8/ 740	12600 * (14400) 4/ 223	X	X	X	3500
Tot											145.6
CD	X	X	X	-73(182) * 2/ -1	664 (1700) 7/ 17	3990 (3300) 11/ 185	6800 (3800) 23/ 690	3620 (2650) 18/280	1031(900) 6/ 26	X	279
EP3D	X	X	X	6,2(8,6) 6/	14,5(11) 26/	18,6(10) 27/	15,7(7) 28/	9,2(4) 18/	5,8(2) 6/	X	
EALD	X	X	X	6.6(10) 5/	14.4(12) 21/	17(12) 17/	19(12) 8/ ~	X	X	X	
EAHD	X	X	X	1.7(2.3) * 3/	14.7(11) * 9/	24(10) 17/	14(7) 26/	10,9(5) 22/	6.7(3) 8/	X	
FAD	X 0	X 0	X 0	78(98) 6/	21160 (15400) 26/	32400 (18800) 32/	23045 (11200) 31/	17200 (8600) 22/	10400 (4400) 8/	X 0	
FOD	X 0	X 0	X 0	X 0	X 0	680(0) 0 1/	X 0	X 0	X 0	X 0	
DUR	60(0)	53(12)	37(12)	30(0)	30.4(5)	30.1(2)	30.6(5)	30(0)	30(0)	30(0)	56

May-June 1978
Demo Hourly Data

	1	2	3	4	5	6	7	8	9	10	Total
TAD	61(5) 71/0	~~63(5)~~ 59.8(5) 65/0	59.5(4) 98/0	66.4(6) 130/0	76.0(8) 140/0	79.9(9) 168/0	78.6(9) 166/0	74.4(9) 175/0	67.4(7) 174/	64.5(6) 69/0	
TIND	71(3) 71/	70(3) 65/	69.3(3) 98/	70.3 (3) 130/	72.8(2) 140/	74.5(3) 168/	74.9(2) 166/	74.7(2) 175/	73.6(3) 174/	72.6(3) 69/	
ESD	2250 *	~~[illegible]~~ 2485(0)	X	X	19800 (13110) 18/	24850 (9630) 75/11090	27970	22875 (10520) 70/	21470	20870 *	
EBD	5300 *	14960	14080	19940	~~[illegible]~~ 19700	~~[illegible]~~ 25950	31600	30950 (14090) 76/	25060	14870 * 19/	
Tot											
ESHD	X	X	X	X	X	39(0) 1/	X	X	X	X	
EBHD	X	X	X	X	X	X	X	X	X	X	
Tot											
ESCD	2250 * (12200) 8/ 250	2485 (0) 1/ 40	X	X	19800 (13110) 18/2340	25200 (9250) 74/11100	27970 (8900) 77/12770	22870 (10520) 70/9150	21470 (13510) 44/5930	20870 (15100) * 16/4840	112820
EBCD	5300 * (11200) 18/1340	14960 (5200) 15/2150	14080 (4600) 15/2160	19940 (4586) 7/1070	19700 (15760) 24/3380	25950 (18180) 51/7880	31600 (14080) 60/11420	30950 (14090) 76/13440	25060 (14470) 59/3500	14870 * (12250) 19/4010	139780
Tot											252,660
CD	1020 * (5000) 27/390	5075 (4700) 19/1480	5030 * (4226) 18/920	4900 (6700) 12/450	6760 (8100) 45/2170	11330 (9540) 120/3290	14010 (9700) 145/12240	13440 (10800) 152/11670	11430 (11180) 109/7160	8330 (9600) 35/4225	119,880
EP3D	26(18) * 23/	21(8) 15/	17(7) 15/	14(3) 7/	19(9) 37/	25(8) 109/	26(7) 131/	24(8) 137/	22(9) 94/	28(19) 29/	
EALD	60(0) 2/	60(0) 2/	50(17) 3/ *	30(0) 5/	30(.1) 3/	X	9(8) 3/	16(2) 5/	19(16) 3/	45(21) 2/ *	
EAHD	54(13) 56/	57(10) 40/	48(16) 48/	29(4) 44/	26(8) 71/	27(5) 127/	~~[illegible]~~ 27(6) 148/	27(6) 160/	28(5) 153/	43(17) 59/	
FAD	~~[illegible]~~ 29/ 40450 (13200)	41800 (10700) 40/	40650 (9060) 50/	38930 (12010) 49/	40820 (11380) 66/	43110 (10130) 125/	44040 (10560) 147/	43510 (11250) 154/	44660 (10430) 149/	45130 (8630) 58/	
FOD	X	~~2.8(0)~~ 1/ 280(0)	X	X	X	X	X	X	X	X	
DUR	56(12)	60(0)	60(0)	30.7(6)	30.7(7)	31.2(8)	29.8(3)	30(0)	30.2(2)	30(0)	

July-August
Demo Hourly Data

	1	2	3	4	5	6	7	8	9	10	Total
TAD	65(3) 93/0	64.0(4) 93/0	63.4(4) 141/	66.4(4) 224/	77.9(2.4) 216/0	83.5(4) 231/0	83.5(4) 239/	77.7(4) 236/	70.1(3) 236/0	67.2(2) 95/	
TIND	74(4) 93/	74.4(3) 93/	74.2(2.9) 141/	~~E~~ 74.0(3) 224/	75.1(2) 216/	76.0(3) 231/	76.7(3) 239/	76.4(4) 236/	75.4(4) 236/	74.8(5) 95/	
ESD	3340 ~~E~~	15930	3170	8142 E	18100	28850	36390	31440	28520 (19030) 54/	30300 (13180) 26/	
EBD	-650	23030	19700	20940	24110 (15650) 47/5250	30120	37010	38360	32250	27730 (11130)	
Tot											
ESHD	X	X	X	X	X	X	X	X	X	X	
EBHD	X	X	X	X	-9(0) 1/	X	X	X	X	X	
Tot											
ESCD	3340 * (19200) 26/930	15930✓ (9940) 10/1710	3170 (3200) 4/90	8142 (700) 3/110	18100 (9160) 15/1260	28850 (14480) 50/6240	36390 (12540) 45/6350	31440 (14300) 47/6260	28520 (19025) 54/6520	3030. (13180) 26/8290	91500
EBCD	-650 * (22000) 6/-42	23030 (13600) 4/990	19700 (13245) 9/1260	20940 (13450) 24/2240	24640 (15400) 46/5250	30120 (17140) 93/12130	37090 (14270) 108/15720	38360 (13830) 107/17390	32250 (16600) 82/11200	27730 (11130) 16/4670	177185
Tot											268685
CD	431(9200) 30/140 *	7700✓ (7600) 14/1160	10115 (9830) 11/790	12750 (9380) 24/1370	16350 (11300) 50/3780	17940 (10760) 132/10250	21820 (8650) 148/13510	22600 (8800) 145/13030	19810 (11580) 120/10070	14800 (8400) 41/6390	150160
EP3D	42(15) 33/	33(19) 16/	25(18) 74/	21(12) 29/	25(8) 57/	28(6) 142/	29(4) 158/	28.5(5) 155/	24.8(8) 130/	31.4(16) 45/	
EALD	X	X	X	X	8.5(0) 1/	X	X	X	X	.1(0) 2/	
EAHD	53(11) 84/	54(12) 79/	49(16) 102/	30(2) 159/	28(6) 172/	29(3) 212/	29.8(2) 230/	29.8(1) 226/	28(4) 226/	40(16) 90/	
FAD	43570 (15000) 39/	45220 (15530) 75/	49830 (12520) 96/	51400 (10450) 149/	48560 (13820) 156/	47580 (11860) 198/	47540 (10980) 220/	47560 (10880) 216/	45810 (13420) 216/	44200 (14700) 86/	
FOD	X	X	X	X	X	X	X	X	X	X	
DUR	60(0) 46/	60(0) 93/	60(0) 141/	29.9(1.4) 224/	30.3(5) 213/	30.3(4) 228/	30.5 (5) 239/	30.4(4) 236/	30.0(3) 236/	29.7(3) 95/	

September-October 1977
Demo Hourly Data

	1	2	3	4	5	6	7	8	9	10	
TAD	59.3 (9)* 53/0	59.3(8) 77/0	58 (8) 121/0	62 (8.4) 121/0	70.2(11) 141/0	75.3(11.9) 159/0	75.(11) 165/0	68.2(11) 165/0	62.4(10.7) 165/0	60.8 (9.6) 62/0	
TIND	73.6(9.5) 53/0	73.6 (8) 77/0	73 (7.5) 121/0	72.7(7.0) 121/0	72.0(9) 141/0	71.8(10.6) 159/0	73 (10.5) 165/0	74.3(10.7) 165/0	73.9(10.6) 165/0	74.2(9.6) 62/0	
✓ ESD	X	X	X	22,144(23,850) 4/117 0	25452	30795	28502	19764*	X	X	[illegible] 0
✓ EBD	X	X	X	16,584* (21692) 5/116 0	30385	19349	23654	X	X	X	224930 0
✓ ESHD	X	X	X	2243 (0)* 1/120 0	X	X	X	X	X	X	5607.5 0
✓ EBHD	X	X	X	21,229(0)* 1/120 0	X	X	X	X	X	X	53.05 0
ESCD	X	X	X	28,778* (24154) 713 3/118	25452(1072) 10/131	30795(1590)* 2511 13/146	28502(2468) 2764 16/149	19764 (8828)* 240 2/163	X	X	[illegible] 20097
EBCD	X	X	X	15423* (24798) 509 4/117	30,385* (26148) 2370 11/130	19349(21431)* 1825 15/144	23654(18399)* 2150 15/150	X	X	X	[illegible] 17,135
CD	X	X	X	5489 (7462)* 181 4/117	13576 (11884)* 1229 19/122	11225 (10523) 1553 22/137	12003 (7674) 1964 27/138	4171 (1575)* 50 2/163	X	X	37,232 116160 13942
EP3D	X	X	X	17.1 (11.1)* 5/116	21.7 (10.6) 19/122	19.9(10) 22/137	22.7(9.7) 27/138	23.6(8.9)* 2/163	X	X	
EALD	X	X	X	4.2 (3.8)* 2/119	19.5 (11)* 8/133	X	X	X	X	X	
EAHD	X	X	X	18 (11.7)* 5/116	20.8(11) 20/121	20 (9.6) 23/136	22 (10) 29/136	23.6 (8.9)* 2/163	X	X	
FAD	X	X	X	166 (124)* 6/115	201.4 (111) 27/114	208 (104) 23/136	218 (110) 29/136	251 (95)* 2/163	X	X	
FOD	X	X	X	9.1 (3.9)* 5/116	10.8 (4.2) 19/122	10.4 (3.8) 23/136	10.3 (3.8) 29/136	11.1 (3.5)* 2/163	X	X	
DUR	55.3 (4.9) 26/27	49.4 (14) 76/1	29.9 (.9) 121/0	29.5 (3) 121/0	31. (8.2) 140/1	30.3(3) 158/1	30.2 (2.6) 165/0	30.1 (2.3) 165/0	30 (0) 164/1	30 (0) 62/0	
				8C52058							

Systems Data
November-December 1977
Demo Hourly

	1	2	3	4	5	6	7	8	9	10	Tot
TAD	56.7(4) 112/0	55.8(4) 167/0	55.5(4) 276/0	59.5(5.9) 251/0	69 (7.7) 253/0	75(28.8) 272/0	71(12) 273/0	63.7(5.7) 273/0	59.4(4.4) 273/0	58.(4.1) 109/0	
TIND	69.3(6.2) 112/0	68.6(6) 167/0	68.1(5.5) 276/0	67.9(4.9) 251/0	64(3.6) 253/0	71.4(4.9) 272/0	72.6(5.5) 273/0	72 (5.8) 273/0	70.7(6.1) 273/1	69.8(6.5) 109/0	
ESD	X	X	X	X	8617(6138)* 3/250 220	10,995 (11190)* 5/267 202	41957 (13098)* 3/270 461	28648 (0)* 1/272 105	X	X	253167.5 2470
EBD	X	X	X	X	2912(5450)* 4/249 46	11661(14393)* 7/265 50	-12006* -44	X	X	X	1417.5 190
ESHD	X	X	X	X	27910 (1674) 2/251 220	10,995* (11190) 5/267 202	41957* (13098) 3/270 461	28648* (0) 1/273 105	X	X	311102.5 2470
EBHD	X	X	X	X	325(1597)* 2/251 3	4745(438)* 3/269 52	-12006* (0) 1/272 -44	X	X	X	-17340 5.5
ESCD	X	X	X	X	32.4(0)* 1/252 0	X	X	X	X	X	21.
EBCD	X	X	X	X	5498(7734)* 2/251 43	16,849(17842)* 4/268 248	X	X	X	X	[illegible] 727
CD	X	X	X	X	-35 (69)* 2/251 0	1917(2495)* 4/268 28	X	X	X	X	[illegible] 70
EP3D	X	X	X	X	9.7(9.8)* 5/248	16.6(11)* 13/259	17.8(11)* 6/267	21.8 (0)* 1/272	X	X	
EALD	X	X	X	X	9.6(9.8)* 5/248	11.9(11)* 8/264	13.7(12)* 8/265	11.(15)* 2/271	X	X	
EAHD	X	X	X	X	.2(.2)* 2/251	16 (13.9)* 8(264)	14.8(12.6)* 3/270	X	X	X	
FAD	X	X	X	X	83(63)* 4/249	142(130)* 13/259	134(85)* 6/267	143 (0)*	X	X	
FOD	X	X	X	X	X	7.9(3.5)* 6/266	6.5(3.8)* 2/271	X	X	X	
DUR	58.1(96) 57/55	50.(14) 166/1	30.1(1.8) 276/0	30.1 (1.8) 251/0	30.2(2.6) 251/2	30.7(6.5) 271/1	30.1(4.4) 273/0	30.2(3.6) 273/0	30.0(0) 273/0	30 (0) 109/0	

Systems Data
January-February 1978
Rental Hourly Data

	1	2	3	4	5	6	7	8	9	10	Tot
TAD	52(3) 72/0	57(4) 109 ~~93~~/0	51(4) 177/0	55(5) 166/0	63(5) 174/0	65(7) 187/	64(7) 182/0	59(5) 175/0	55(3) 175/0	54(3) 72/	
TINR	70(2) 72/	70(2) 109 ~~93~~/	70(2) 177/	70(2) 166/	71(1.6) 174/	72(2) 187/	72(1.7) 182/	72(2) 175/	72(1.7)	71(2) 72/	
ESR	X	X	X	X	X	X	X	X	X	X	
EBR	744(2576) 29/700	3361 (1680) 45/1390	4730(5650) 98/ 2620	4000 2070	2350 780	1450 333	1700 420	1700(2400) 590	2490 (1470) 920	2630 (955) 996	
Tot											
ESHR	X	X	X	X	X	X	X	X	X	X	
EBHR	744(2576)* 29/300	3361 (1680) 45/1390	4730(5650) 98/ 2620	4000(3190) 86/ 2070	2350 (2800) 58/780	1450 (1600) ~ 43/333	1700 ~ (3370) 45/420	1700(2400) 61/ 590	2490 (1470) 65/920	2630 (955) 27/770	26030
Tot											
ESCR	X	X	X	X	X	X	X	X	X	X	
EBCR	X	X	X	X	X	X	X	X	X	X	
Tot											
CR	X	X	X	X	X	X	X	X	X	X	
EP3R	6(2) 28/44	9.5(2) 44 ~~43~~/	13(11) 100/	7.4(7.2) 86/ ~	7.7(8) 58/ ~	9(11) 36/	7.8(10) 43/ *	5.5(8) 61/	3.3(4) 65/	4.7(3) 27/	
EALR	6.0(2) 28/	4.4(2) 44 44/	13(11) 100/	7.4(7) 86/	7.7(9) ~ 58/	9(11) 36/	7.8(10) 43/	5.5(8) 61/	3.3(4) 65/	4.6(3) 27/	
EAHR	.1(.06) 20/	.1(.02) 21/	.1(.02) 315/	.1(.03) 24/	X 14	.1(0) 7/	.1(0) 8/	.1(0) 14/	.1(0) 18	.12(.04) 18/	
FAR	~~13.6(5)~~ 1360(500 28/	1600(600) 44/	~~58(54)~~ 100/ 5800(5400)	~~31.6(30)~~ 86/ 3160(3000)	3000(3200) 58/ ~	4000 ~ (5000) 36/	3280 (9400) 43/	~~1205(18)~~ 61/ 2410(3500)	1640(2130) 65/	1632 (1780) 27/	
FOR	X 40	X 61	1.6(.2)? 97/	1.7(.1) ? 86/	X 90	X 96	X 93	X 90	X 90	X 38	
DUR	60(0)	~~60(0)~~ 49	29.8(1.7)	30(0)	30.3(4)	29.8(2)	30(0)	30(0)	30.2(2)	30(0)	61

Systems Data
March-April 1978
Rental Hourly Data

	1	2	3	4	5	6	7	8	9	10	Tot
TAD	55(4) 96/0	54(5) 123/0	54(4) 209/0	60(5) 226/	66(6) 231/	68(7) 237/	67(7) 226/	63(5) 234/0	58(4) 235/0	57(4) 94/0	
TINR	72(2) 96/	71(1) 123/	71(2) 209/	71(2) 226/	72(1) 231/	72(1) 237/	72(1.5) 226/	73(1.4) 234/	73(1) 235/	72(1) 94/0	
ESR	X	X	X	176	X	X	X	801	1840 (2500) 3/	317(0) 1/	
EBR	501(1554) 72/	X	2613	2100	1800	1490 (800) 86/	1390	1540	1390 (900) 167/	1490 1110	
Tot											
ESHR	X	X	X	176(143) 3/ * 2	X	X	X	801(84) 2/ 7	1840 (2500) 3/ 23	317(0) 1/ 3	90
EBHR	501(1554)* 72/375	2152(880) 91/ 1590	2613 (2060) 168/2100	2100 (1600) 157/1450	1800 (1700) 119/930	1490 510	1390 (745) 73/450	1540(1350) 126/830	1390 (900) 167/990	1490(760) 70/1110	25380
Tot											25470
ESCR	X	X	X	X	X	X	X	X	X	X	
EBCR	X	X	X	X	X	X	X	X	X	X	
Tot											
CR	X	X	X	X	X	X	X	X	X	X	
EP3R	3.5(1) 72/	X	~~8~~ 8(10) 168/	5.4(8) 158/	3.3(5) 124/	1.7(2) 87/	1.9(3) 70/	2.9(5) 126/	2.0(4) 166/	3.3(7) 70/	
EALR	4.2(6)~ 73/	6.1(10)~ 92/	8.8(10) 168/	6.4(9) 159/	4.3(7.5) 126/	3.3(7) 94/	2.7(6) 73/	3.4(6) 129/	2.0(4) 166/	3.3(7) 70/	
EAHR	.1(.02) 31/	.1(.01) 35/	.1(.000) 49/	.1(.02) 37/	.1(.000) 27/	.1(0) 11/	.1(.03) 11/	.1(0) 11/	.1(0) 22/	.1(0) 20/	
FAR	10(17)~ 73/	20(35)~ 92/	39(30) 168/	33.6(52) 158/	2435 ~ ~(5000) 121/	1800 (3920) # 91/	1400 ? (3200) 73/	1800 ~ (3400) # 129/	960 (2000) 166/	1060 (2400)~ 70/	
FOR	X 0	X 0	X 0	X 0	X 0	X 0	X 0	X 0	X 0	X 0	
DUR	60(0)	53(12) 123/	37(12) 209/	30(0) 226/	30.4(5) 226/	30.1(2) 237/	30.6(5) 226/	30(0) 231/	30(0) 235/	30(0) 94/	

Rental Hourly Data
Systems Data
May - June

	1	2	3	4	5	6	7	8	9	10	Tot
TAD	61(5) 71/0	59.8(5) 65/0	59.5(4) 98/0	66.4(6) 130/0	76.0(8) 140/0	79.9(9) 168/0	78.6(9) 166/0	74.4(9) 175/0	67.4(7) 174/	64.5(6) 69/0	
TINR	74(3) 71/	73(3) 65/	72.5(2) 98/	72.2(2) 130/	73.2(2) 140/	75.2(3) 168/	~~76.4(4)~~ 76.3(4) 166/	76.5(4) 175/	75.5(3) 174/	75.0(3) 69/	
ESR	X	X	X	X	X	X	X	X	X	X	
EBR	115	584	2090	170	-620	-341	2195	3390	4251 * (2830) 5/ 120	1164	
Tot											
ESHR	X	X	X	X	X	X	X	X	X	X	
EBHR	115(800) 4/ * 6	584(430) 4/ * 36	2090 * (2900) 7/ 150	171 * (4450) 5/ 6	-620 (2320) 6/ * -26	-341 (970) * 11/ -22	2195 (3580) * 5/ 66	3390 (0) 1/ 19	5150 (2290) 4/ 120	1164(0) 1/ 17	920
Tot											
ESCR	X	X	X	X	X	X	X	X	X	X	
EBCR	X	X	X	X	X	X	X	X	650(0) 1/ 4	X	
Tot											
CR	X	X	X	X	X	X	X	X	-120(0) 1/ -1	X	
EP3R	15(15) * 4/	24(8) 3/	29(19) 7/ *	15(9) 6/	14(14) * 3/	15(19) 2/ *	4.6(6) 2/ *	11.5(0) 1/	18(12) 4/	9(0) 1/	
EALR	60(0) 4/	60(0) 4/	46(18) 9/	28(7) 12/	23(12) * 11/	25(12) 6/	17(15) 7/	11.5(0) 1/	26(9) 12/	27(25) 4/ *	
EAHR	X	X	X	X	X	X	X	X	.6(0) 1/	X	
FAR	16800 ~~[illegible]~~ ~~13100~~ (360) ~~4~~ 2/	16930 (270) 4/	14660 (4780) 9/	15580 (3930) 12/	12800 (6790) * 11/	13940 * (6710) 6/	10900 * (6640) 6/	6380 (0) 1/	14590 (4920) 12/	11330 (7980) 4/	
FOR	X	X	X	X	X	X	X	X	X	X	
DUR	56(12) 71/	60(0) 65/	60(0) 98/	30.7(6) 130/	30.7(7) 130/[illegible]	31.2(8) 167/	29.8(3) 165/	30(0) 174/	30.2(2) 174/	30(0) 69/	

Systems Data
July - August
Rental Hourly Data

	1	2	3	4	5	6	7	8	9	10	Total
TAD	65(3)	64.0(4)	63.4(4)	66.4(4)	77.9(24)	83.5(4)	83.5	77.7(4)	70.1(3)	67.2(2)	
	93/	93/0	141/	224/0	216/0	231/0	239/	236/	236/0	95/	
TINR	76(1)	75(1.3)	74.3(1.4)	73.9 (1)	74.7(1.5)	76.2(2)	77.6(2)	77.7(2)	76.9(1)	76.4(1)	
	93/	93/	141/	224/	216/	231/	239/	236/	236/	95/	
ESR	X	X	X	X	X	X	X	X	X	X	
EBR	X	X	X	-,833	8690 * (10120)	25700	15660	-3590 * (14640)	16660 *	X	
					14/560			5/ -80			
Tot											
ESHR	X	X	X	X	X	X	X	X	X	X	
EBHR	X	X	X	-,833 (0)	-200(0) 1/	X	X	X	X	X	
				1/	-1						
Tot											
ESCR	X	X	X	X	X	X	X	X	X	X	
EBCR	X	X	X	X	9370 * (10245)	25700 (17880)	15660 (14680)	-3590 * (14640)	16660 (26450)	X	
					13/560	12/1340	17/1110	5/ -80	5/350 *		8200
Tot											
CR	X	X	X	X	-884 * (2600)	6740 (8000) *	4660 * (8000)	860 * (4300)	2505 (2200) *	X	
					13/ -53	15/440	20/390	8/ 30	5/ 53		2150
EP3R	X	X	X	X	18(9)	25(10)	26.8(7)	23.6(9)	15.2(12)	X	
					13/	15/	20/	8/	5/ *		
EALR	50(16) 7/	54(18) 8/	47(20) 12/	28(6) 8/	17(15) * 6/	15(13) 7/	21.5(10) 4/	27 (8) 15/	27(7) * 19/	42(16) 5/	
EAHR	X	X	X	X	22(10)	27(9)	27(7)	24(9)	17(13) *	X	
					15/	21/	20/	8/	5/		
FAR	12900 * (5540) 4/	14930 (5030) 8/	14830 (4220) 12/	13780 (5860) 8/	17840 (9440) 18/	23910 (7450) 24/	24560 (6180) 22/	18200 (6190) 22/	18230 (8230) 22/	16920 (213) 5/	
FOR	X	X	X	X	X	X	X	X	X	X	
[illegible]	60(0)	60(0)	60(0)	29.9(1.4)	30.3(5)	30.3(4)	30.5	30.4(4)	30.0(3)	29.7(3)	64

Systems Data
September-October 1977
Rental Hourly

		1	2	3	4	5	6	7	8	9	10	Tot
	TAD	59.3 (9)*	59.3 (8)	58(8)	62 (8.4)	70.2(11)	75.3(11.9)	75(11)	68.2(11)	62.4(10.7)	60.8(9.6)	
		53/0	77/0	121/0	121/0	141/0	159/0	165/0	165/0	165/0	62/0	
	TJNR	77.4(11)	75.8(9.2)	75(8.8)	74.9(8.3)	76.9(10.5)	79.(12)	79.9(12)	79.9(12)	79.6(12.2)	78.2(11)	
		53/0	77/0	121/0	121/0	141/0	159/0	165/0	165/0	165/0	62/0	
✓	ESR	X	X	X	X	X	X	X	X	X	X	
✓	EBR	552(1446)*	1947 (864)	2584 (959)	2893	2253	24659(22343)*	33283	24609*	1355*	1980*	23,1797.5
		6/47 62	10/67	20/101			4/155		(6507) 2/163			
✓	ESHR	X	X	X	X	X	X	X	X	X	X	X
✓	EBHR	552(1446)*	1947 (864)	2584 (959)	2893 (1007)	2253 (1934)	3566 (35)	X	19973 (0)*	1355 (638)*	1980 (1031)*	91772.5
		6/47 62	252 10/67	427 20/101	502 21/100	272 17/124	45 2/157		121 1/164	41 5/160	128 4/58	4561
✓	ESCR	X	X	X	X	X	X	X	X	X	X	X
✓	EBCR	X	X	X	X	X	34757 (13722)*	33283(18426)*	29238(0)*	X	X	55562
							500 2/157	1008 5/160	177 1/164			4213
✓	CR	X	X	X	X	X	6617(11134)*	18520(10334)*	19131(0)*	X	X	110,472
							124 3/156	561 5/160	116 1/164			2002
	EP3R	4.0(1.6)	2.9(15)	2.6 (.7)	2.7 (.7)	3.5(6.8)	12.9(11)*	27.3(5.9)	25.9(.4)	1.6 (.7)*	3.5(2.1)*	
		6/47	10/67	20/101	21/100	17/124	5/154	5/160	2/163	5/160		
	EALR	4.1 (1.7)	2.9 (1.5)	2.6 (.7)	2.7 (.76)	3.5(6.8)	4.9(2.6)*	X	26.2(0)*	1.6 (.7)*	3.5(2.1)*	
		6/47	10/67)	20/101)	21/100	17/124	2/157		1/164	5/160	4/58	
	EAHR	.1 (0)*	.1 (0)*	.1 (0)*	X	X	25.8(9.3)	30 (0)	27.6(0)*	10.4(16.9)*	X	
		2/51	1/76	3/118			6/153	7/158	1/164	3/162		
	FAR	7.4 (2.8)*	6.5 (2)	7.8 (2)	8.1 (2.1)	13.2 (24)	109 (72)*	143 (48.6)*	111.6 (47)*	38.1(70.3)*	7.1 (3.1)*	
		3/50	10/67	20/101)	21/100	13/128	8/151	7/158	2/163	5/160	4/58	
	FOR	1.8 (.1)	2.4 (8)	3.5 (.1)	3.4 (.1)	3.8 (1.3)	14.8(8.3)*	20 (6.8)	11.9 (10.6)*	7.1 (8.0)*	35(.1)	
		3/50	10/67	20/101	21/100	12/129	8/151	7/158	2/163	5/160	4/58	
	DUR	55.3 (14.9)	49.4 (14)	29.9(.9)	29.5(3)	31.(8.2)	30.3 (3)	30.2(2.6)	30.1(2.3)	30(0)	830(0)	
		26/27	76/1	121/0	121/0	140/1	158/1	165/0	165/0	164/1	62/0	

Systems Data
November-December 1977
Rental Hourly

	1	2	3	4	5	6	7	8	9	10	Tot
TAD	56.7(4)	55.8(4)	55.5(4)	59.5(5.9)	69(7.7)	75(28.8)	71(12)	63.7(5.7)	59.4(4.4)	58 (4.1)	
	112/0	167/0	276/0	251/0	253/0	272/0	273/0	273/0	273/0	109/0	
TINR	73 (1.6)	72.3(1.5)	71.7 (1.4)	71.8(1.6)	72.6(1.6)	73.5(1.8)	73.9(2)	73.9(1.9)	74.2 (1.7)	73.9 (1.7)	
	112/0	167/0	276/0	251/0	253/0	272/0	273/0	273/0	273/0	109/0	
ESR	X	X	X	X	X	X	X	X	X	X	X
EBR	248	1908	2113	2585	1760(2849)*	1382(2277)*	1697(785)	811 (1286)	3576 (1658)*	990 *	[illegible]
					39/214	29/243	16/257	13/260	25/248		
ESHR	X	X	X	X	X	X	X	X	X	X	X
EBHR	248(1729)*	1908(1539)*	2113(2420)	2585(1673)	1410(1713)*	1171(1967)*	1701(812)*	811(1286)*	3576 (658)*	990 (712)*	[illegible]
	57 26/86	445 39/128	666 87/189	546 53/198	206 37/216	116 27/245	93 15/258	39 13/260	527 25/248	799 12/97	6440
ESCR	X	X	X	X	X	X	X	X	X	X	X
EBCR	X	X	X	X	8242(10634)*	4234(5198)*	1640(0)*	X	X	X	35275
					2/251	2/270	1/272				261
CR	X	X	X	X	102.8(540)*	1159(1395)*	75.9(0)*	X	X	X	[illegible]
					2/251	2/270	1/272				24
EP3R	3.4 (3)	2.7 (1.7)	7.8 (9.8)*	6.6(8]	5.4(7.8)*	4.2 (2.2)*	1.8(.8)	5.1 (8.6)*	X	2.(1.3)	
	23/89	39/128	84/192	53/198	41/212	26(246)	16/257	13/260		12/97	
EALR	3.4 (2.9)*	2.9 (2.2)*	11.1(11.9)	12 (12)	9.6 (12)*	11(12.9)*	13 (14)*	14.8(14.8)*	11.3 (12.4)*	1.9 (1.3)*	
	23/89	40/127	94/182	64/187	47/206	33/239	25/248	19/254	26/247	12/97	
EAHR	.1 (0)	.1 (0)	.1 (0)*	X	1.3 (2.6)*	1.1(1.6)*	3.8 (7.7)*	X	X	X	
	3/109	6/161	9/267		7/246	4/268	6/267				
FAR	5 (2.1	7.3 (6.8)	36.4 (40)	38.9 (41)	35.8(42)	42 (45)*	49.9(46.5)*	64(46.8)*	49.1(40.5)*	5.3(1.3)	
	12/100	38/129	94/182	64/187	41/212	28/244	21/252	14/259	19/254	5/104	
FOR	2.2(1.5*	2.3 (.8)	3.7(.7)	3.8 (.6)	3.9(.7)	3.8(.7)	7.5(16)*	3.8(.4)	3.7 (.4)	3.4 (0)	
	12/100	40/127	93/182	63/188	33/220	24/248	23/250	14/259	21/252	6/103	
DUR	58.1(9.6)	50.(14)	30.1(1.8)	30.1(1.8)	30.2(2.6)	30.7(6.5)	30.1(44)	30.2(3.6)	30.0(0)	30 (0)	
	57/55	166/1	276/0	251/0	251/2	271/1	273/0	273/0	273/0	109/0	

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