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ENERGY EVALUATION AND COMPONENT CHARACTERIZATION DATA IN A RESIDENTIAL SOLAR MONITORING PROGRAM

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Abstract

The initial phase of performance analysis, data acquisition system development and short term component characterization of a two year residential solar energy monitoring program are presented. The purpose of the monitoring program is to accumulate both short and long term performance data which would be useful in optimizing system operation, determining possible improvements to the system configuration, validating simulation methods for predicting performance, and estimating the economics of the system.

1. INTRODUCTION

1.1 PROBLEM BACKGROUND

The number of systems utilizing solar energy for space and domestic hot water heating has been rapidly increasing, yet there is currently a scarcity of detailed performance data on operating solar heating systems and their components. Such information is necessary to quantitatively evaluate system and component performances so that areas for performance improvement, additional applications, and cost reductions may be identified. Contributing to the scarcity of good performance data is the lack of standard instrumentation guidelines. Several conventional measurements required for obtaining detailed performance data present specific problems in the instrumentation of a solar installation. These problems are mainly due to the relatively small temperature differences and flow rates that need to be accurately measured, and to the random and transient nature of weather requiring the acquisition of large amounts of data over long periods of time.

1.2 PROGRAM BACKGROUND

In the autumn of 1977 the Solar Energy Research Laboratory at the University of Tulsa began a two year Solar Home Energy Evaluation Project (SHEEP) designed to provide both short and long term quantitative data on the performance of the Gilcrease Hills Demonstration Solar Home. The objectives of SHEEP were to develop the instrumentation guidelines and to obtain the appropriate performance data necessary to characterize and evaluate both system and component performance. These data are essential in optimizing system operation and in determining possible improvements to the system configuration. Validation of simulation methods for predicting performance and estimation of the economics of the solar system also require such detailed performance information.

2. THE SOLAR INSTALLATION

2.1 THE HOUSE

The Gilcrease Solar Home was specifically designed to utilize solar equipment for space and domestic hot water heating in a two year demonstration and monitoring program. Located in northwest Tulsa in the Gilcrease Hills area, the solar home was oriented so that the 45° pitched roof and solar collectors faced due south. The floor area of the home is approximately 1750 ft^2. Using standard 2 x 4 construction, the walls and ceilings have been insulated to R-20 and R-30 respectively. The windows are double glazed insulated glass. Figure 1 is a photo of the south side of the solar home.

2.2 THE SOLAR SYSTEM

2.2.1 Design Considerations

The solar heating system was designed to provide approximately 75% of the space and domestic hot water heating requirements under normal operation and weather conditions.

The tank, pumps, plumbing and control unit were installed above ground in an insulated utility room. This allowed easy viewing for the public and easy accessibility for research.

2.2.2 System and Component Description

The solar heating system utilizes 370 ft^2 of roof mounted Lennox solar panels for collection and 1400 gallons of water in an epoxy lined steel tank to provide thermal storage. The collector array is manifold in the standard "Z" pattern and consists of two rows of twelve collectors, each connected in parallel horizontally and in series vertically. The heat transfer fluid in the closed fluid loop between the collectors and the heat exchanger is a 50% mix of ethylene glycol and distilled water. The service side of the heat exchanger loop uses tap water as the heat transfer fluid. The four modes of operation for the solar system can be traced in Figure 2. The heat paths of these four modes are:

(1) collector–heat exchanger–furnace coil–house
(2) collector–heat exchanger–storage tank
(3) storage tank–furnace coil–house
(4) storage tank–preheat coil–DHW tank–service DHW

When the house demands heat, first priority is given to mode (1). This allows the collectors to supply heat to the house without depleting storage and at temperatures below storage so that collectors can function even on partly cloudy or hazy days when the storage temperature is higher than collector temperature. Mode (3) has second priority for supplying space heat and when storage is depleted (storage temperature is less than 90°F) the gas furnace supplies the heating demands. The domestic hot water is preheated by passing through 50 feet of coiled copper tubing submerged in the storage tank before entering the conventional gas hot water heater. A tempering valve prevents hot water delivery temperature from exceeding 140°F. The solar system components, manufacturer and costs are listed in Table 1.

3. THE MONITORING SYSTEM

3.1 DESIGN CONSIDERATIONS

3.1.1 Transient Data

Due to the random and transient nature of weather and subsequent heating demands, it is necessary to collect and analyze large amounts of data over long periods of time, such as an entire heating season, to characterize the performance of the solar heating system. To preserve the detail of the data, intermittent scanning periods should be much smaller than the response time of the solar system and integration periods should be approximately equal to the time constant of the system.

3.1.2 Accuracy

In determining heat gains, heat losses and rates of heat transfer, the most critical measurements are the relatively small temperature differences and flow rates. Typically an accuracy of better than ± 1% of the measured value is sought, but as the temperature drop across the collector falls to 2°F, the accuracy is more likely to approach ± 10%. Therefore the temperature sensors should have an accuracy and interchangeability of better than ±.2°F over the temperature range.

The flow rates can be manually controlled and will generally fall between 4 and 10 gpm for the solar system and between .3 and 3 gpm for the domestic hot water. A flow rate accuracy of ± 1% should be maintained over the range of flow rates and temperatures with a variety of fluids.

3.3.3 Analysis

Some real-time on-site data analysis are necessary to provide rapid performance information feedback for optimizing solar system operation and troubleshooting both solar and data acquisition systems. Long term data analysis can be performed off-site with properly maintained data files.

3.1.4 Cost

The data acquisition system must acquire large amounts of data accurately over long periods of time at a relatively fast and flexible sampling rate and perform some real-time data analysis. These capabilities are generally very expensive ($20,000-40,000) requiring an on-site digital computer or a direct link to an off-site computer. In addition to instrumentation and equipment costs, installation, maintenance and operation costs deserve careful consideration.

3.2 THE DATA ACQUISITION SYSTEM

3.2.1 Computer

The heart of the data acquisition system developed for SHEEP is a microprocessor based 8-bit digital computer.[1] The computer was purchased from the Heath in kit form along with 24,000 bytes of static memory, serial and parallel interfaces, paper tape reader/punch and video terminal. These components are pictured in Figure 3 and listed with prices in

Table 2. Figure 4 is a block diagram showing the various links between computer, instrumentation and input/output devices. Signals from the temperature probes, pyranometer, and wind direction indicator are digitized by the analog to digital converter. Digital signals from the flow meters, wind speed indicator, watt meter and clock are fed into the programmable interval timers (PIT'S) which contain 16 bit down counters. The computer periodically reads the counters for rate and totalized information.(2)

3.2.2 Sensor Selection

Linearized thermistor circuits were chosen for temperature measurements because they have reasonably good accuracy and interchangeability (± .27°F) over the required temperature range and could be easily and inexpensively interfaced with the computer.(3) Periodic calibrations are performed to insure accuracy and determine probe stability over long time periods at wide ranges of temperatures. By carefully selecting those temperature probes which track each other closely over the temperature range, much better accuracy (± .1°F) can be obtained for the temperature difference measurements. The probes are mounted in thermal wells for easy removal from system.

Turbine flow meters are used to measure flows through collectors, furnace coil and domestic hot water preheat coil. The signals are readily interfaced with the PIT'S for flow rate and total flow information. The meters are rugged, serviceable, reliable and are capable of maintaining accuracy (± 0.5%) over the temperature range.

An Eppley 8-48 black and white pyranometer is used to measure insolation. Centered above the collectors the pyranometer is mounted on the 45° roof slope facing south and is calibrated at this orientation against a reference standard pyranometer, an Eppley PSP. The accuracy of the 8-48 is approximately ± 4% of the measured value.(7) Careful calibration should improve this to better than ± 2%.

The wind speed indicator has an accuracy of approximately ± 1 mph and a starting threshold of 1 mph. Both wind speed and wind direction indicators were readily interfaced to the computer.

A watt-hour meter was provided by the local electric utility and interfaced to the computer to measure the rate and total electrical energy consumption of the solar heating system.

Manually read instrumentation include 3 electric watt-hour meters, 3 gas meters and an air flow meter. The air flow meter and gas valves may be interfaced to the computer.

Table 2 includes the various sensors and costs.

3.4 DATA OUTPUT

Instantaneous real time results are displayed on the video terminal for troubleshooting and optimizing system operation. The paper tape punch provides inexpensive intermediate long term data storage. Once stored on paper tape the data can then be read onto the main computer via teletype and acoustic coupler for generating massive data files that are readily accessible for analysis. Individual data acquisition programs are stored on cassette tape.

3.5 SYSTEM OVERVIEW

The data acquisition system developed for SHEEP offers many important advantages. For a relatively very low cost system, massive data collection in appropriate time sequence and time scale at flexible sampling rates are obtained. Furthermore, good accuracy is maintained at a reasonable cost and some real-time data analyses are provided. The system design also provides much flexibility with relatively easy component interfacing and programming capabilities in two languages, Machine and Basic. The system can be upgraded with many compatible peripherals such as a floppy disk for mass storage and rapid information retrieval capabilities and/or line printer for on-site hard copy printouts.

4. PERFORMANCE DATA FOR THE FIRST YEAR

4.1 PERFORMANCE DURING 77-78 HEATING SEASON

While the data acquisition system was being developed and installed, performance for the first year was based on recorded gas consumption and climatological data for Tulsa. Gas meters furnished by Oklahoma Natural Gas were installed on the furnace and hot water heater supply lines. The meters were read periodically and the house space heating supplied by gas was calculated by:

$$\begin{pmatrix}\text{temperature corrected}\\ \text{gas consumption, ft}^3\end{pmatrix} \times \begin{pmatrix}\text{heat content of}\\ \text{gas, 913.5 BTU/ft}^3\end{pmatrix}^{*} \times \begin{pmatrix}\text{furnace system}\\ \text{efficiency, 75\%}\end{pmatrix} = \begin{pmatrix}\text{heat supplied}\\ \text{by gas, BTU}\end{pmatrix}$$

The heat loss rate of the house was determined by gas consumption during a twelve day period of no solar heat utilization (cloudy overcast days and storage depleted $< 90°F$).

* This value was provided by Oklahoma Natural Gas Company

This yielded a heat loss rate of 11,000 BTU/degree-day for the house which was used to determine the total heating requirements over any specified time period. The solar heating supplied was then assumed to be the difference between the heating requirements and the gas heating supplied. The space heating test period begins with November 16, 1977, the start up date for the solar heating system, and runs through the end of May 1978. The monthly space heating requirements and solar heating contribution for this time period are presented in Figure 5a and the monthly percents of possible sunshine are displayed in Figure 5b. By comparison with the normal space heating requirements and expected solar contribution (Figure 6a) and the normal percent of possible sunshine (Figure 6b), the relative effect that the colder and cloudier than normal months had on solar heating can be seen. For the entire heating period 77-78, solar contributed 46% of the space heating requirements using the heat loss rate of 11,000 BTU/DD. Higher heat loss rates that might have been encountered during times of greater house activity (larger infiltration losses) would have resulted in larger solar contributions since the gas consumption remains the same. For a heat loss rate of 13,500 BTU/DD (determined from heat load calculations) the solar heating contribution would have been 56%. The expected normal solar contribution in either case is at least 75%. November, January and February required more heating and supplied less sunshine than normal resulting in much less solar heating than would normally be expected. December and March however seemed to be normal in heating demand and % sunshine, but while December provided the expected solar contribution, March fell below the expected values. Figure 7a is a graph of daily heating requirements and solar heating supplied for March. Plotted together in Figure 7b are the percent of possible sunshine and mid-morning storage tank temperatures. These graphs indicate that storage was depleted early in March when heating demands were highest and skies were overcast accounting in part for the low solar utilization in March.

4.1.1 System Problems

Figures 5 through 7 illustrate the problem of phasing solar availability and space heating requirements in maximizing solar heat utilization. But problems and potential problems associated with the operation and performance of this system have also been observed. Although apparently not yet serious, they warrant special attention.

Condensation. As can be seen in Figure 1 several collectors have varying amounts of condensation. Improper installation resulted in the top side weep holes of the lower row of collectors being exposed to water run-off from the upper row of collectors. The water entering the weep holes reduces the performance of the collectors by condensing on the inside of the glazing effectively blocking solar input and by reducing the insulating value of the collector insulation. The resulting decrease in collector efficiency in wet weather could in part account for the apparent discrepancy in normal performance in December when the collectors were dry and the poorer performance in March after rains had dampened the insulation.

Vapor-lock. The system did experience a brief interval when the collector fluid failed to circulate even though the pump appeared to be operating properly. It is believed that a vapor lock in the pump caused the stoppage resulting in loss of collector fluid, since the collectors overheated and activated the relief valve. This was a one time occurrence and has not yet reoccurred.

Residue on Collector Glazing. During the first year of operation the collectors have become speckled with what appears to be sap from trees upwind and across the street. The extent of reduction in collector performance due to this residue has yet to be determined.

Rust in Storage Tank. The epoxy lining of the 1500 gallon steel tank failed, allowing the inside of the storage tank to rust and pit. A new epoxy lining, more suitable to high temperatures, was applied in late September, 1978.

4.2 CURRENT SHORT TERM TESTING

4.2.1 Additional Summer Cooling Load Due to Solar Operation

The entire system can be left operational during the summer to provide domestic hot water heating. Because the system is above ground and in the house, even though in an insulated room, it will cause some additional cooling load on the house. The relative magnitude of this additional load was determined by comparing the electrical energy consumption of the air conditioning compressor with no solar operation and storage depleted, to the compressor energy requirements when the system was operational with storage temperatures between 140°F and 170°F. Figure 8 shows the manufacturer's performance curves for several cooling load profiles. Plotting the test values on the performance curve indicates that the house baseline cooling load without solar operation is 11,750 BTU/degree-day and that with the solar system operating the house cooling load is raised to approximately 12,700 BTU/degree-day. This represents slightly over an 8% increase in cooling load and cooling cost which in some cases would more than offset the benefit of solar heated domestic hot water. More insulation between thermal storage and the house is needed for effective summer operation.

4.2.2 Collector Performance

Figure 9 shows the Lennox collector performance curve and the experimental performance data for the collectors before and after a one week stagnation period. The increase in performance after stagnation is probably due to the drying out of the dampened collector insulation. Even after drying, the performance of the collectors still falls short of the Lennox curve. A collector test in mid-winter last year showed the collectors to be operating closer to the Lennox curve. The reasons for the present decrease in performance has not been fully established, but it is likely to be due to a combination of large summer sun-collector incident angle, residue on collectors and possibly some collector degradation.

4.2.3 Systems Operation

Overheating storage water can be a problem during summertime operation when solar availability is high and demand is low. Although the system is not automated for night time heat rejection, the system can be manually turned on at night to reject heat from storage through the solar panels to the night air. This method was used to keep the storage water temperature below 170°F.

Table 3 summarizes the results of the short term testing.

4.2.4 Thermistor Stability Studies

A periodic temperature probe calibration program has been undertaken to assure the accuracy of both absolute and differential temperature measurements and provide stability information on the thermistors.[4]

4.3 COMPUTER ANALYSIS

A SOLCOST (Solar Energy Design Program for Non-Thermal Specialists) program [8] was run on the Gilcrease Hills Solar Home to produce life cycle cost analyses under various economic conditions. In general the solar system was not deemed economical for a 20 year life span at 6.9% fuel escalation rate when compared with the cost of gas heating but was marginally economical when referenced to the cost of electrical resistance heating.

5. PROJECTED TEST PROGRAM

The basic program for this winter consists of determining the house energy budget, recording local climatological data and performing short term tests on components and system.

5.1 HOUSE ENERGY BUDGET

An hourly account of the energy budget of the house will include the following:

(1) Available solar energy
(2) Space heating from collectors
(3) Space heating from storage
(4) Space heating from gas
(5) Usable stored thermal energy
(6) DHW solar preheating
(7) DHW heating from gas
(8) Electrical energy required by solar.

5.2 CLIMATOLOGICAL DATA

Certain climatological data will be recorded and correlated with the performance data to produce normalized solar system performance information. The local climatological variables to be recorded are:

(1) Average ambient air temperature
(2) Average insolation
(3) Percent diffuse radiation
(4) Average wind speed
(5) Average wind direction.

5.3 SHORT TERM TESTING

Along with the energy budget and climatological data short term performance data will be recorded. Some of projected short term tests will be:

(1) Collector performance vs. heat exchanger operation
(2) Reduction of collector efficiency due to dirt on panel glazing
(3) System performance vs. storage water stratification
(4) System performance vs. storage capacity
(5) Optimization of control unit operation
(6) Thermal loss measurements of storage tank, room and fluid lines
(7) Thermal response of house.

6. REFERENCES

(1) W. P. Moran and G. E. Kouba, "A Microprocessor Based Solar Monitoring System", pg. 183, PROC. DOE CONF. ON PERFORMANCE MONITORING TECHNIQUES FOR EVALUATION OF SOLAR HEATING AND COOLING SYSTEMS, Washington, D.C., April 3-4, 1978.

(2) W. P. Moran, "A Microprocessor Controlled Flow, Flow Rate, Real and Elapse Time Measuring System", pg. 237, PROC. DOE CONF. ON PERFORMANCE MONITORING TECHNIQUES FOR EVALUATION OF SOLAR HEATING AND COOLING SYSTEMS, Washington, D.C., April 3-4, 1978.

(3) G. E. Kouba, "A Microprocessor Compatible Temperature Measuring System", pg. 191, PROC. DOE CONF. ON PERFORMANCE MONITORING TECHNIQUES FOR EVALUATION OF SOLAR HEATING AND COOLING SYSTEMS, Washington, D.C., April 3-4, 1978.

(4) G. E. Kouba, "Long Term Stability of a Linearized Thermistor Circuit", PROC. UMR-DNR CONF. ON ENERGY, October 10-12, 1978.

(5) W. P. Moran, "Toward a Methodology for Analyzing Solar Performance Data", PROC. UMR-DNR CONF. ON ENERGY, October 10-12, 1978.

(6) N. Lior, "Instrumentation Principles for Solar Heating Performance Measurements", PROC. DOE CONF. ON PERFORMANCE MONITORING TECHNIQUES FOR EVALUATION OF SOLAR HEATING AND COOLING SYSTEMS, Washington, D.C., April 3-4, 1978.

(7) Correspondence from the National Bureau of Standards concerning the Round Robin Collector Test Program.

(8) SOLCOST, Solar Energy Design Program for Non-Thermal Specialists, prepared by Martin Marietta Aerospace for ERDA Solar Heating and Cooling Branch, Dec., 1977.

7. BIOGRAPHIES

GENE E. KOUBA received the B. S. and M. S. degrees in Mechanical Engineering at Oklahoma State University in 1972 and 1974 respectively. The title of the master's thesis was "Modeling Inflows Into Stratified Lakes With Vertical Scale Distortion" and was funded by the Oklahoma Water Resources Research Institute. Presently Kouba is a Research Associate for the Solar Energy Research Laboratory at The University of Tulsa. He is a co-principal investigator of the Solar Home Energy Evaluation Project.

WILLIAM P. MORAN received the B. S. in Physics from the University of Notre Dame in 1962 and the Ph.D. in Theoretical Physics form the University of Rochester in 1967. He has been with The University of Tulsa since that time in the Physics Department program in Engineering Physics. He was a NASA-ASEE Fellow in 1974 and 1975 working on systems design projects in national energy planning and energy conservation. He was an ERDA-ASEE Fellow in 1976 on a study of education and training needs for energy technologies. Moran is also the principal investigator for the Comprehensive Community Energy Management Plan for the City of Tulsa, funded by Argonne National Laboratories and U. S. Department of Energy.

BRUCE V. KETCHAM came to Oklahoma thirty years ago from Connecticut where he received an Engineering degree from Yale University. He has divided his time between the University of Oklahoma (17 years) and the University of Tulsa (13 years) where he has served both schools as a professor, Head of Aerospace Engineering Department and in various research capacities. Professor Ketcham is now Directo of Solar Energy Projects at the Universit of Tulsa, a position he has held for the past two years. Previous to this, he had been Director of Research at the University of Tulsa. He also holds the title of Professor of Resources Engineering and teaches both graduate and undergraduate courses in Solar Energy as well as directing the University's Solar Energy Laboratory.

FIGURE 1. PHOTOGRAPH OF SOLAR HOUSE

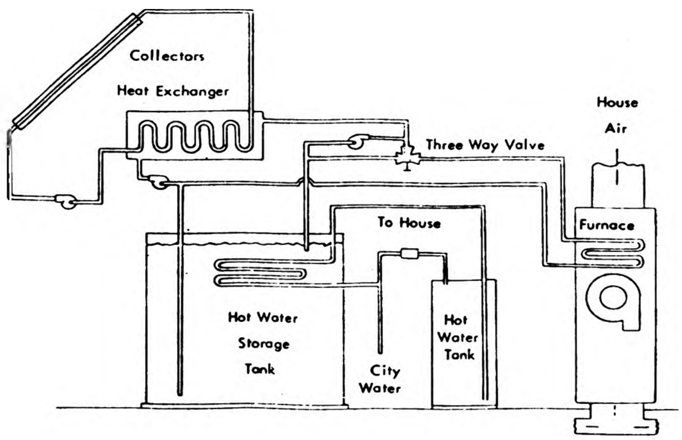

FIGURE 2. SCHEMATIC OF SOLAR SYSTEM

TABLE 1. SOLAR HEATING EQUIPMENT AND COSTS

ITEM	MANUFACTURER	COST
(1) 24 Collectors	Lennox @ $18/ft^2	$ 6,480
(2) 1500 gal Storage tank (steel with epoxy lining)	American Tank and Construction Company of Tulsa	800
(3) Expansion tank		100
(4) Furnace hydronic coil		180
(5) DHW preheat coil		250
(6) Heat Exchanger	Bell & Gossett	375
(7) 2 1/6 hp water pumps	Bell & Gossett @ $150	300
(8) 1 1/2 hp collector fluid pump	Bell & Gossett	100
(9) 1 3-way valve	Honeywell	35
(10) 1 Tempering valve		25
(11) 1 Relief valve	Bell & Gossett	18
(12) 1 System control panel	Honeywell	400
(13) 15 gal Collector anti-freeze fluid	Union Carbide	50
(14) Pipe insulation		300
(15) Storage tank insulation		200
(16) Copper tubing plumbing		240
(17) Installation-collector panels		300
(18) Installation-control system		250
(19) Installation-plumbing-coils		800
(20) Installation-insulation		250
	Total Cost	$11,453

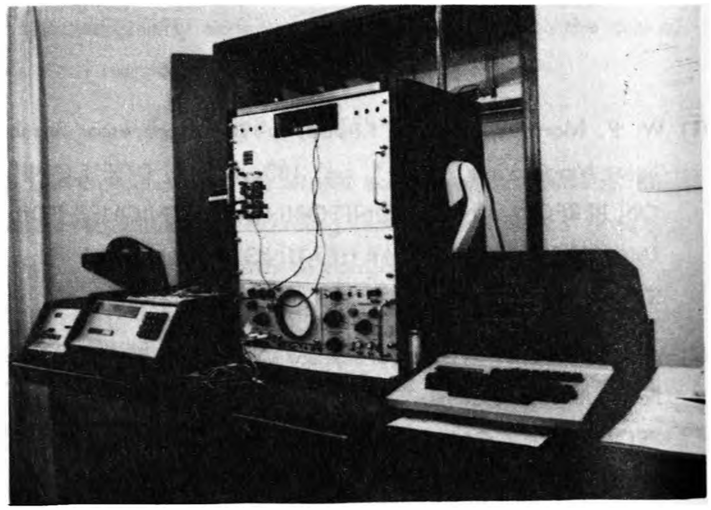

FIGURE 3. PHOTOGRAPH OF DATA ACQUISITION SYSTEM

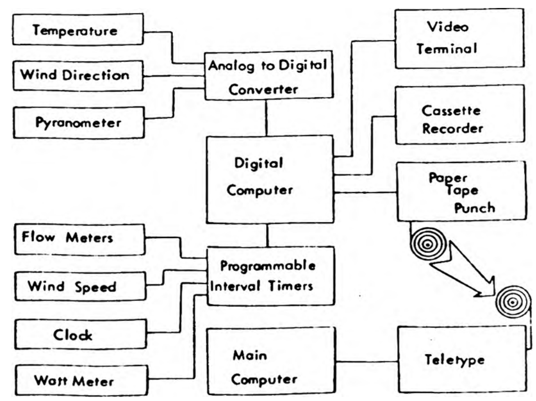

FIGURE 4. DIAGRAM OF DATA ACQUISITION SYSTEM

TABLE 2. DATA ACQUISITION SYSTEM COMPONENTS AND PRICES

Item	
Heath Components	
H8 Digital Computer	375
24 K Static Memory	630
Parallel Interface	150
Serial I/O & Cassette Interface	125
H9 Video Terminal	550
H10 Paper Tape Punch/Reader	350
Cassette Recorder	60
Extended Basic Program Language	10
Manuals	25
Subtotal	$2275
Datel Sinetrac 800 A/D Converter	550
Intel 8253 Programmable Interval Timers @ $18	64
ASR-33 Teletype and Acoustic Coupler	1200
Sensors:	
30 Linearized Thermistor Probes @ $20 (includes thermistor, electronics and hardware)	600
2 - 1" Halliburton Turbine Flowmeters	500
1 - 3/8" Halliburton Turbine Flowmeter	300
Texas Electronics Wind Speed Transmitter (TD-1102-2) and Wind Direction Indication (TD-104-P)	600
Eppley 8-48 Black and White Pyranometer	550
Datametrics Air Flow Meter (800 VTP)	625
Total	$7264

Duncan Watt-hour Meter provided by Public Service Company of Oklahoma

Singer Gas Meters provided by Oklahoma Natural Gas Company

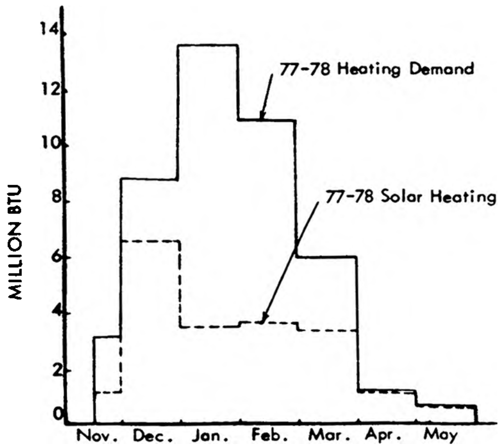

FIGURE 5a. MONTHLY SPACE HEATING REQUIREMENTS AND THE SOLAR HEATING CONTRIBUTION DETERMINED FROM THE GAS REQUIREMENTS FOR A HEAT LOSS FACTOR OF 11,000 BTU/D.D.

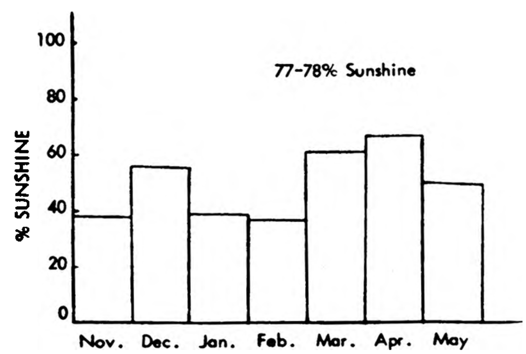

FIGURE 5b. MONTHLY PERCENT OF POSSIBLE SUNSHINE FOR 77-78 HEATING SEASON FOR TULSA

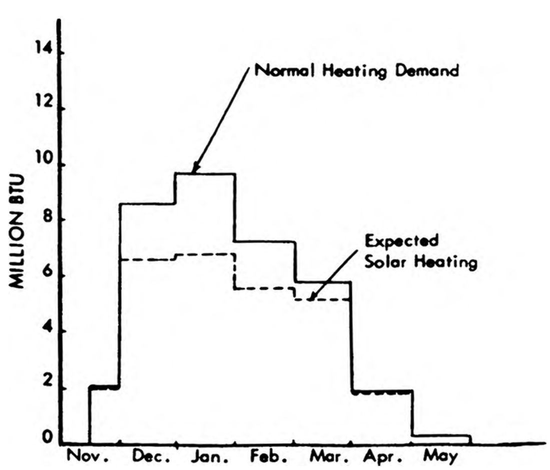

FIGURE 6a. NORMAL MONTHLY SPACE HEATING REQUIREMENTS AND EXPECTED MONTHLY SOLAR HEATING CONTRIBUTION BASED ON A HEAT LOSS FACTOR OF 11,000 BTU/D.D.

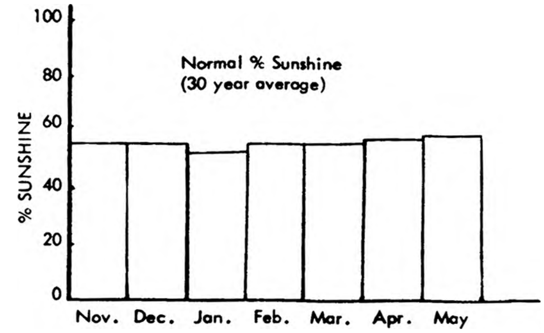

FIGURE 6b. NORMAL MONTHLY PERCENT OF POSSIBLE SUNSHINE FOR TULSA

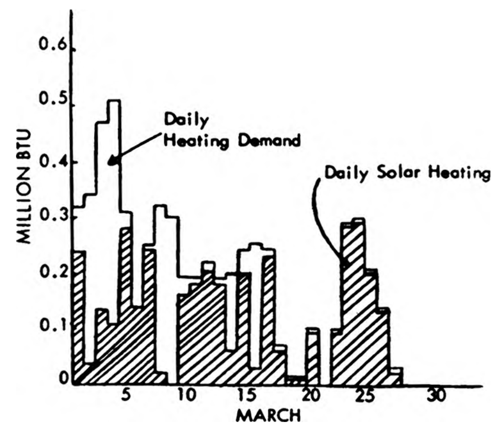

FIGURE 7a. DAILY SPACE HEATING REQUIREMENTS AND SOLAR HEATING CONTRIBUTION FOR MARCH 1977

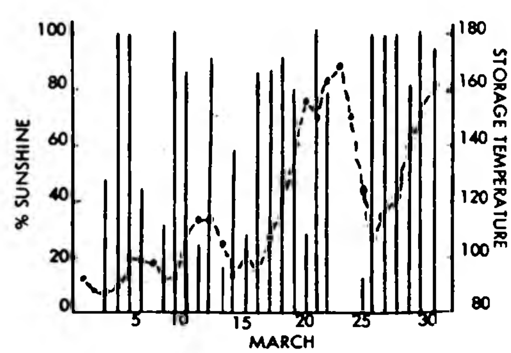

FIGURE 7b. DAILY PERCENT OF POSSIBLE SUNSHINE (BARS) AND MID-MORNING STORAGE WATER TEMPERATURE (DOTS) FOR MARCH 1977

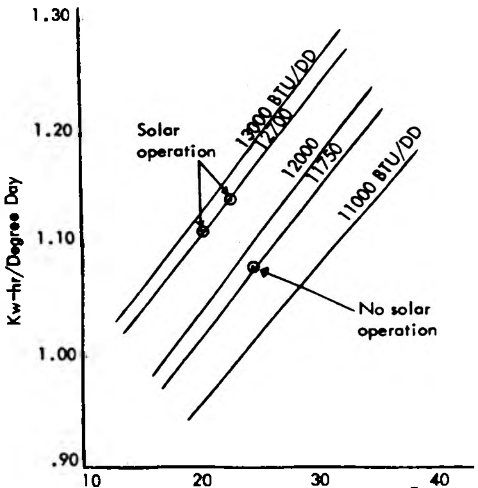

FIGURE 8. COMPRESSOR PERFORMANCE CURVE FOR LENNOX HS9-411 CONDENSING UNIT. EACH PLOTTED POINT WAS DETERMINED FROM COMPRESSOR ENERGY REQUIREMENTS AND AVERAGE OUTDOOR TEMPERATURE FOR ONE WEEK

TABLE 3. SHORT TERM TEST RESULTS

TEST	RESULTS
(1) House Cooling Load	
without solar operation, storage < 90°F	11,750 BTU/DD
with solar operation, 140°F < storage temp < 160°F	12,700 BTU/DD
(2) Collector Time Constant	11 minutes
(3) Collector Performance	% of Lennox value
mid-winter - dry panels	96
spring and summer - damp panels	50 - 65
summer after stagnation - dry panels	73
(4) Coefficient of Performance	
summer time heat collection - peak value	40
- system startup	12
- system shut down	6
nighttime heat rejection, storage temperature 165°F to 140°F, ambient air temperature 78°F	15
(5) Heat Exchanger (collector loop)	
effectiveness at equal heat capacities on both sides of heat exchanger	0.43
(6) Preheat Coal (DHW)	

Flowrate (gpm)	Effectiveness
.5	0.90
1.0	0.84
2.0	0.70
4.0	0.45

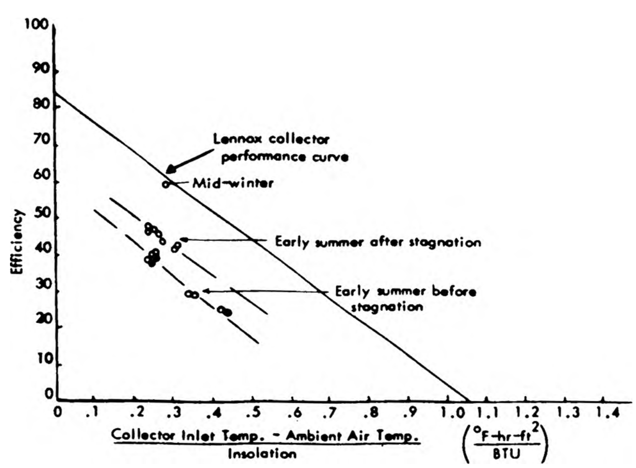

FIGURE 9. COLLECTOR PERFORMANCE CHART. THE SOLID LINE IS THE PERFORMANCE CURVE FOR THE LENNOX LSC 18-1S SINGLE GLAZED COLLECTOR. THE DATA POINTS RESULTED FROM CLEAR SKY MID-DAY TESTING UNDER VARIOUS CIRCUMSTANCES THAT INDICATE THE PRESENT AND POSSIBLY PERMANENT DEGRADATION OF THE COLLECTORS.