EFFICIENCY, F-CHART, AND HEATING LOAD ANALYSES
OF A SMALL RESIDENCE RETROFITTED
WITH AN AIR-MEDIUM SOLAR
HEATING SYSTEM

APPROVED:

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EFFICIENCY, F-CHART, AND HEATING LOAD ANALYSES OF A SMALL RESIDENCE RETROFITTED WITH AN AIR-MEDIUM SOLAR HEATING SYSTEM

by

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THESIS

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CHAPTER 1

INTRODUCTION

This thesis is the result of a 15-day test of a residential solar heating system. The system is of the air-medium type and is retrofitted into a small house located on the campus of The University of Texas at El Paso (UTEP). It was tested during the months of February and March, 1980.

Three separate studies were conducted on the UTEP solar house and system for the test period; these studies are the subjects of this thesis. The studies are:

1) A general evaluation of the performance of the system,
2) A test of the effectiveness of the "f-Chart" solar heating design method in estimating the thermal performance (1) of the system,
3) An evaluation of the accuracy of three heating load methods in estimating the heating requirements of the house.

The first study is of interest because the collectors in the system of the UTEP solar house are far from being oriented in an optimum manner for space heating. They are in fact oriented 57 degrees west of south at an angle of 48 degrees from the horizontal. This positioning was necessary because the orientation of the house did not permit a practical due-south arrangement. Statistical data on the performance of systems with such adverse collector positioning is not abundant. It is the purpose of this study to provide such data. The study presents the daily system efficiencies for the test period and percentages of optimum insolation available to the system.

The second study was chosen as a problem because the effectiveness of the f-Chart method in estimating the thermal performance of systems is not firmly established. This is due to the fact that the method, which relates thermal performance and system design parameters in an empirical

manner, is constructed around the results of many computer simulations of solar heating systems (1). Since computer simulations are only models of real systems, it is not known how well this method relates the design parameters with thermal performance in the many actual systems that can exist. This study attempts to verify this relationship for the particular system in the UTEP facility. This is accomplished through a simple comparison test of the f-Chart predicted and measured thermal performances of the system for the test period.

The third study is of interest because the accurate estimation of heating load for a residence is a necessary aspect in the design of any residential heating system. Through a comparison of the abilities of different methods to estimate loads, important observations can be made regarding the practicality of particular methods for residential applications. Also, it provides the opportunity to observe the effects of certain design variables on the accuracy of different methods. In this study, these aspects are investigated through the evaluation of three widely accepted heating load methods. These methods are:

1) A thermal response method developed by G. P. Mitalas (2),
2) The transfer function method recommended by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (3),
3) The degree-day method.

In the study, the methods are used to estimate the daily total heating loads of the UTEP solar house for the test period. The methods are assessed through a comparison of the methods' results with measured loads for the period.

CHAPTER 2

DESCRIPTION OF HOUSE, SYSTEM, AND MONITORING

House

The house used for this study is a small, single-story residence located at the corner of Rim and Hawthorne streets on the campus of The University of Texas at El Paso (see Figure 1). It is approximately 40 years old, has a living area of 1306 $ft.^2$, and is of fairly heavy construction. The exterior walls have a total thickness of 12 inches and are composed of mortared limestone dressed on the interior with 3 to 3 1/2 inches of cement-plaster. The windows are of the metal casement type, and they and the three exterior doors (not including the basement door) comprize about 15% of the exterior wall area.

The building has both an attic and a partial basement. The attic space is slightly ventilated, and the ceiling above the living area is framed. The framing is finished with plaster on sheet-rock lath and filled with about 3 inches of rock wool (approximately R-11).

The basement is comprized of two areas, a basement proper and a ventilated crawl-space openly connected to the former. The floor above both areas is joisted and supports a hardwood-fir deck. All joists are exposed except for a small area. This is in a 11' x 18' room, finished in plaster, that is isolated from the crawl-space. In the room, the joists are dressed with plaster on sheet-rock lath. This portion makes up about 16% of the total floor area.

The house was particularly favorable for use in a heating load analysis. Although it was being used as an office building during the test period, it was uninhabited most of the time. During the day, not more than two people occupied the house, and traffic into and out of the house was infrequent. During the night, there were no occupants. This situation permitted the load analysis to be performed with a minimal distortion of

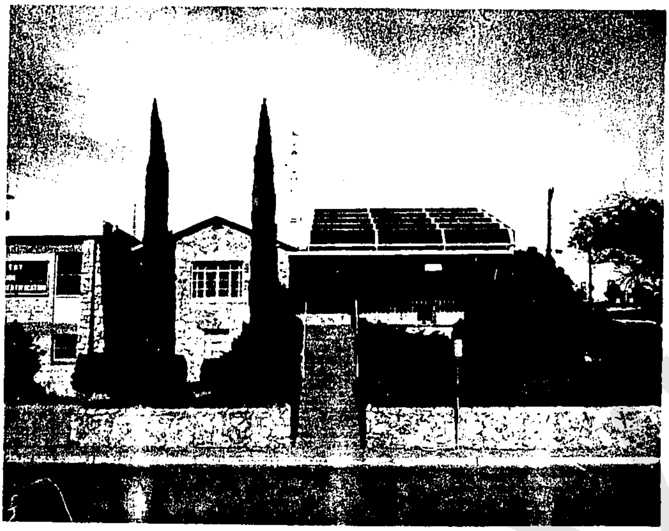

Figure 1a. View of House Looking Northeast

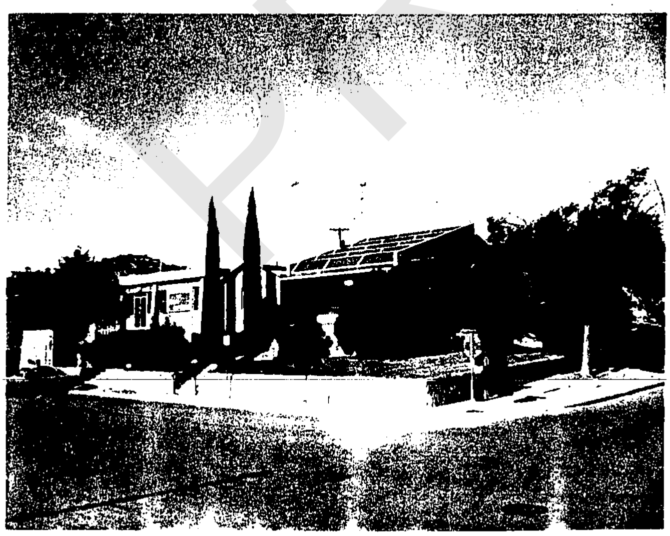

Figure 1b. View of House Looking North

Figure 1c. View of House Looking West

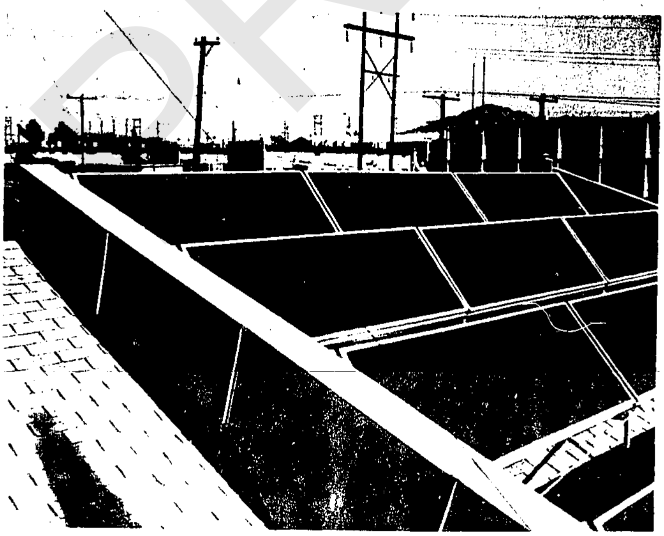

Figure 1d. View of Solar Collector Banks

results caused by unpredictable air changes and electrical appliances.

Solar Heating System

The solar heating system in the house is for space heating only and is integrated into the original central gas heating system. A schematic of the system is shown in Figure 2.

The system is of the air-medium type. Air is heated in five banks of three roof-mounted (Figure 1), Solar-Rey model 4101 and 4102 collectors, the total effective surface area of which is 333 $ft.^2$. The collectors are oriented 57 degrees west of south at an angle of 48 degrees from the horizontal. Ten-inch circular ducts carry air between the collectors and the heat storage unit located in the basement.

The heat storage unit is of double-walled plywood construction and is insulated with 6 inches of styrofoam. It is mounted on the concrete slab of the basement and contains approximately 118 $ft.^2$ of screen-sorted, washed river gravel 1 to 3 inches in size. Air routing to or from the unit is controlled with four Dayton model 2C904 motorized dampers located in the inlet and outlet ducts of the unit.

Two blowers move air through the system. The blowers operate together or independently, depending on the mode of operation. The blower which supplies air to the collectors, shown in the schematic as B1, is a Dietzen "Power-line" model 122B1C8H, in-line centrifugal type. The other, B2, is the original furnace blower that has been modified to compensate for the greater pressure drop that was anticipated across the pebble bed.

The system is designed to operate in any one of five modes. For purposes of reference throughout this thesis, these modes are defined as

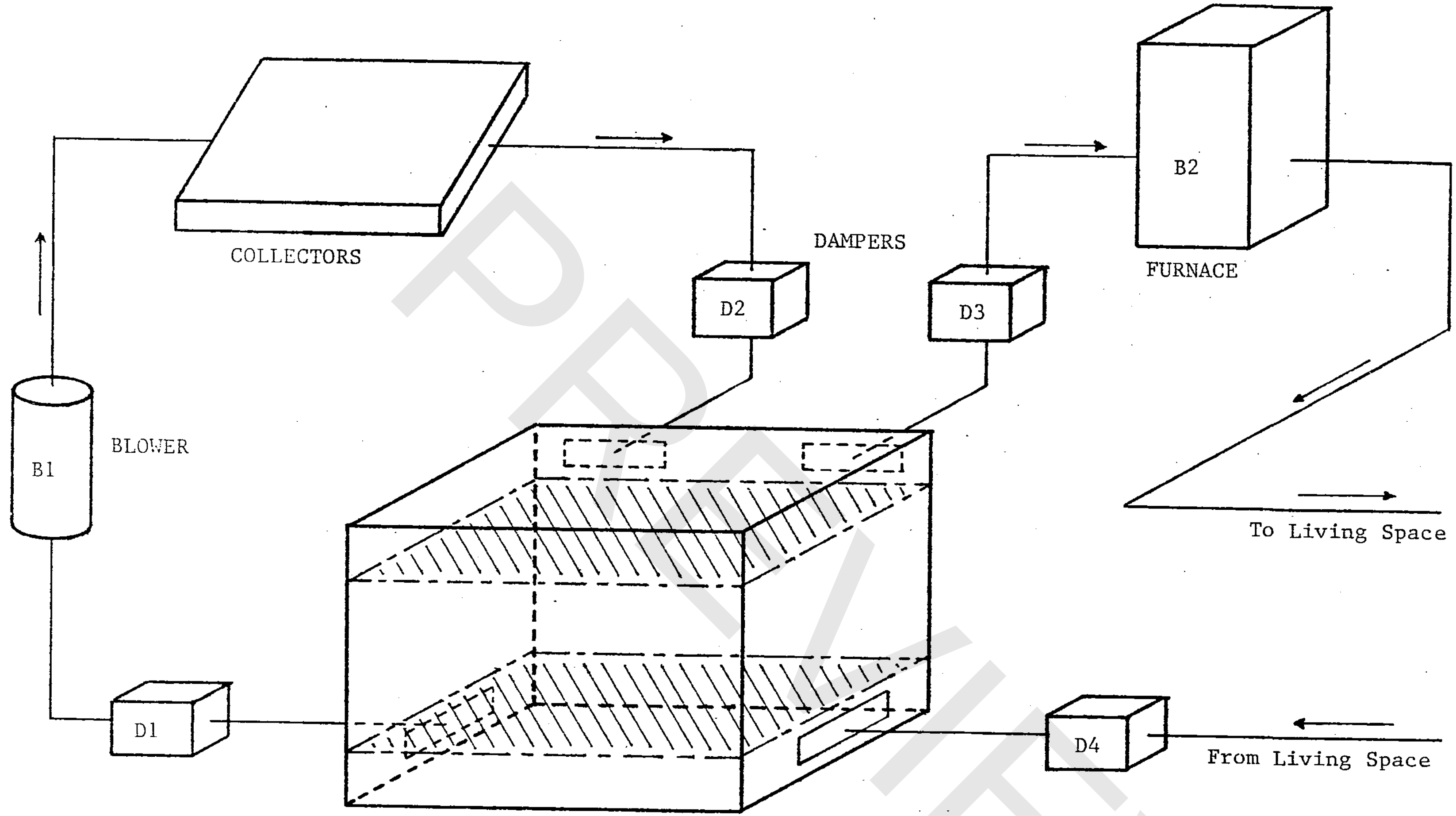

FIGURE 2
SCHEMATIC OF SOLAR HEATING SYSTEM

follows along with the blowers and dampers in operation:

1) Collection-storage: B1 on; D1 and D2 open; heat gathered from the collectors is stored in the storage unit.

2) Collection-heating: Both blowers on; all dampers open; heat gathered from the collectors by-passes storage and is used to heat the living space without supplementary heat from the furnace.

3) Collection-gas heating: Both blowers on; all dampers open; heat gathered from the collectors by-passes storage and is used to heat the living space along with supplementary heat from the furnace.

4) Storage-heating: B2 on; D3 and D4 open; stored heat is used to heat the living space.

5) Gas-heating: B2 on; D3 and D4 open; the living space is heated with the gas furnace only.

House and System Monitoring

To provide the necessary data for use in the performance, f-Chart, and heating load analyses, temperatures in both the house and appropriate points in the system were recorded, along with readings of solar insolation and windspeed. For the house, thermopiles were installed in the living space, attic, and basement-crawl-space. The outside temperature was measured with a shielded thermocouple placed in the weather tower on the roof. System temperatures were measured with thermocouples installed in the inlet and outlet ducts of the heat storage unit. The temperature in the storage unit was measured with four thermopiles buried 15 inches apart in the pebble bed. Figure 3 is the schematic of the temperature sensing circuitry.

Solar insolation data was collected using two Eppley model PSP

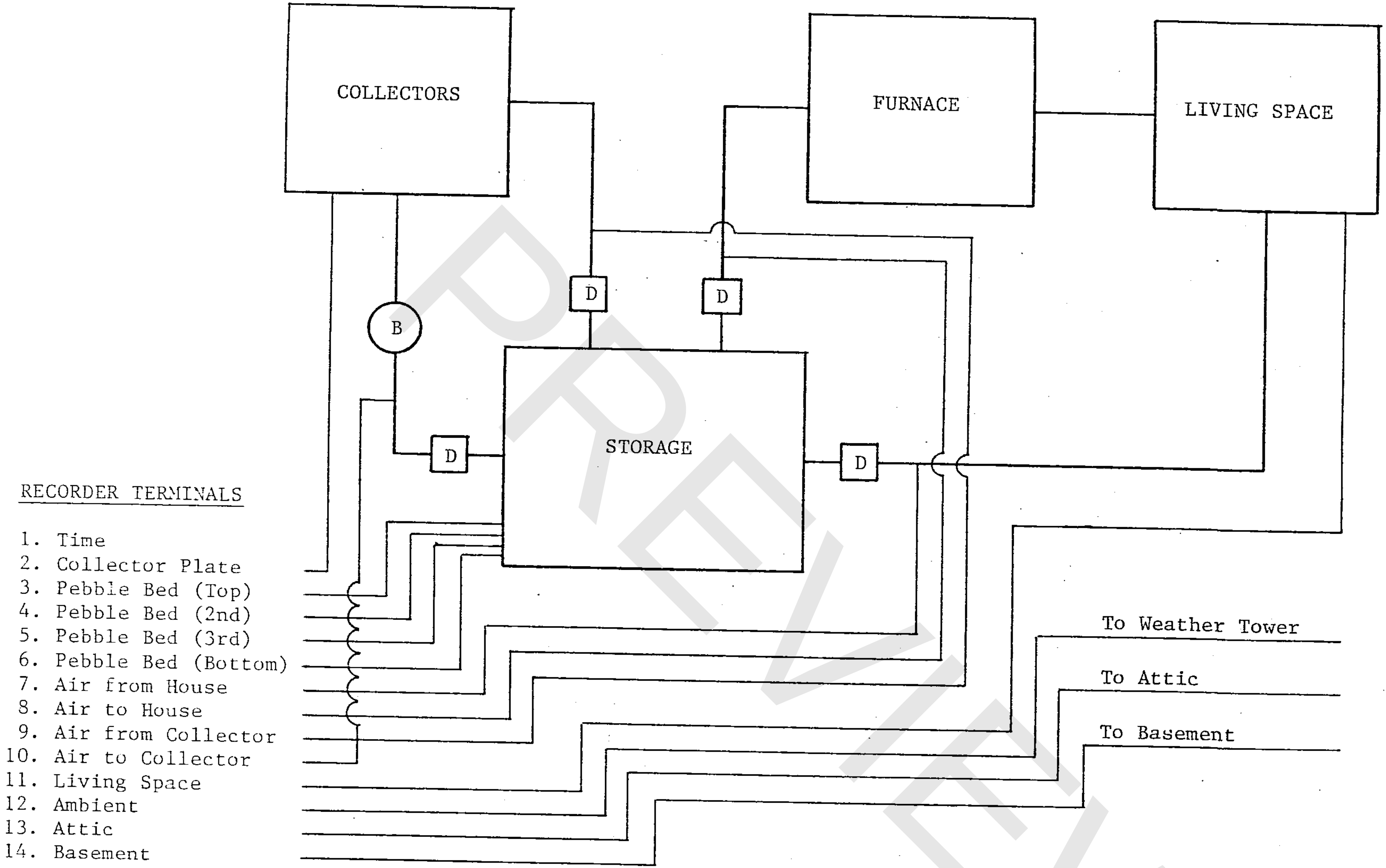

FIGURE 3
SCHEMATIC OF THERMOCOUPLE CIRCUITRY

pyranometers placed on the roof, one positioned at the horizontal and the other placed with the same orientation as the collectors. Windspeed was taken with a Weather Measure model MD103AC anemometer placed at the top of the weather tower.

All temperatures were recorded on a Kaye model DR-TCTF-ICDXX-117/60 digital recorder, programmed to record on the hour when the heating system was not operational. When the system was operating in any of its five modes, the recorder took data continuously at one-minute intervals. Solar and wind data were recorded on Honeywell model 194221-001-000-01 continuous strip recorders.

CHAPTER 3

MEASUREMENT OF AIR FLOW RATES, FURNACE EFFICIENCIES, AND HEAT TRANSFER RATES

The measured data for this study were gathered for three reasons:

1) To evaluate system efficiencies, heating loads, and the solar heating load fraction (thermal performance) for the test period,
2) To provide test-period averages of temperature and insolation for use in the f-Chart analysis,
3) To provide hourly values of temperature and wind speed for use in the heating load estimation methods.

The quantities listed in 2 and 3 are a direct application of the measured data. However, those in 1 had to be evaluated using three other quantities. These are:

1) Air flow rates in the system,
2) Furnace efficiencies for different flow conditions in the system,
3) Heat transfer rates in the system.

This chapter presents the details of how these three quantities were measured.

Air Flow Rates

Air flow rates in the system were established for three flow conditions (Figure 2):

1) Blower 1 operating alone,
2) Blower 2 operating alone,
3) Both blowers operating simultaneously.

The first condition was used to determine the flow rate to the collectors for the collection-storage mode. The second was for the determination of the flow rate to the living space for the storage-heating and gas-heating modes. The third was used to determine the rate to the living space for the collection-heating and collection-gas heating modes.

To determine the flow rates for the three flow conditions, duct pressure measurements were taken at two locations in the system (Figure 2):

1) Between Blower 1 and the storage unit,

2) Between the storage unit and the furnace.

At the first location, the fan static pressure (4) for flow condition 1 was measured. This was done using a Dwyer no. 11500400 micromanometer. The measured static pressure was used with the manufacturer's fan performance curve to establish the flow rate. At the second location, the velocity pressures for flow conditions 2 and 3 were measured. This was done using a Dover model AIR 79 Annubar and the Dwyer micromanometer. The velocity pressures were used to calculate air velocities for the two flow conditions. These velocities were multiplied by the duct area to determine the flow rates. The measured pressure differences and the resulting average flow rates for the three flow conditions are given below:

Blower in Operation	ΔP (in. w. g.)	Flow Rate (ft.^{3}/min.)
B1	0.497 (fan static pressure)	1315.4
B2	0.027 (vel. pressure)	896.4
B1 and B2	0.032 (vel. pressure)	978.0

Furnace Efficiencies

One aspect of the measurement of the heating load for the living space involves the measurement of the gas heating required. This measurement requires the efficiencies of the furnace be known for the two flow rates encountered during furnace operation. These rates have been given in the previous section for the gas-heating (B2) and collection-gas heating (B1 and B2) modes.

The furnace efficiency for a given flow rate was determined by measuring the inlet and outlet air temperatures of the furnace for an arbitrary furnace operation time. This was done on a minute-by-minute basis using the digital recorder. Using these temperatures and the flow rate, the heat transfer rates for each minute of furnace operation were calculated. These were then summed and divided by the product of the volume of gas burned and the local heating value of the fuel to yield the efficiency.

The above procedure was carried out three times for each flow rate to obtain an average efficiency. The rates and the respective average efficiencies are as follows:

Blower	Flow Rate (ft.^{3}/min.)	Average Efficiency
B2	896.4	81%
B1 and B2	978.0	97%

The result for the higher rate was considered too high for use in calculating auxiliary heating load for this thesis. Since the result for the lesser rate is a more reasonable value, it was used in all calculations. This had a minimal effect on the accuracy of the calculated loads, however, because the collection-gas heating mode, which uses the higher flow rate, rarely operated during the 15-day test period.

Heat Transfer Rates

Heat transfer rates within the system were determined from the minute-by-minute temperature record for the inlet and outlet ducts of the storage unit. The rates were calculated by first analyzing the 15-day temperature record to determine which of the five operational modes were

working at a particular time. This was done by scanning the record and noting subtle temperature changes within the ducts and storage unit. When all the modes and their durations were identified, the appropriate temperatures and flow rates were applied to the heat balance equation to obtain the heat rate for a given minute.