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SOLAR/1017-79/14

Solar Energy System Performance Evaluation

FACILITIES DEVELOPMENT GAS CO.
MULTIFAMILY CONDOMINIUM

San Diedo, California
September 1978 Through March 1979

U.S. Department of Energy

National Solar Heating and
Cooling Demonstration Program

National Solar Data Program

NOTICE

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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

FACILITIES DEVELOPMENT GAS COMPANY
SAN DIEGO, CALIFORNIA

SEPTEMBER 1978 THROUGH MARCH 1979

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CONSERVATION AND SOLAR APPLICATION
UNDER CONTRACT EG-77-C-01-4049
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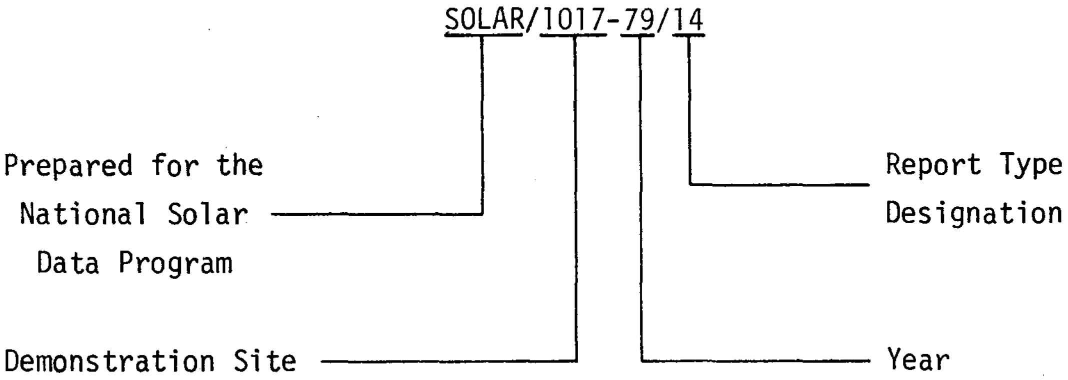
NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under specific format. For example, this report for the Facilities Development Gas Company project site is designated as SOLAR/1017-79/14. The elements of this designation are explained in the following illustration.



- Demonstration Site Number:

  Each project site has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

- Report Type Designation:

  This number identifies the type of report, e.g.,

  - Monthly Performance Reports are designated by the numbers 01 (for January) through 12 (for December).
  - Solar Energy System Performance Evaluations are designated by the number 14.

- Solar Project Descriptions are designated by the number 50.

- Solar Project Cost Reports are designated by the number 60.

These reports are disseminated through the U. S. Department of Energy Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

1. FOREWORD

The National Program for Solar Heating and Cooling is being conducted by the Department of Energy under the Solar Heating and Cooling Demonstration Act of 1974. The overall goal of this activity is to accelerate the establishment of a viable solar energy industry and to stimulate its growth to achieve a substantial reduction in nonrenewable energy resource consumption through widespread applications of solar heating and cooling technology.

Information gathered through the Demonstration Program is disseminated in a series of site-specific reports. These reports are issued as appropriate and may include such topics as:

- Solar Project Description
- Design/Construction Report
- Project Costs
- Maintenance and Reliability
- Operational Experience
- Monthly Performance
- System Performance Evaluation

The International Business Machines (IBM) Corporation is contributing to the overall goal of the Demonstration Act by monitoring, analyzing, and reporting the thermal performance of solar energy systems through analysis of measurements obtained by the National Solar Data Program.

The Solar Energy System Performance Evaluation Report is a product of the National Solar Data Program. Reports are issued periodically to document the results of analysis of specific solar energy system operational performance. This report includes system description, operational characteristics and capabilities, and an evaluation of actual versus expected performance. The Monthly Performance Report, which is the basis for the System Performance Evaluation Report, is published on a regular basis. Each parameter presented in these reports as characteristic of system performance represents over 8,000 discrete measurements obtained each month by the National Solar Data Network (NSDN). Documents referenced in this report are listed in Section 6, "References." Numbers shown in brackets refer to reference numbers in Section 6. All other documents issued by the National Solar Data Program for the Facilities Development Gas Company solar energy system are listed in Section 7, "Bibliography."

This Solar Energy System Performance Evaluation Report presents the results of a thermal performance analysis of the Facilities Development Gas Company solar energy system. The analysis covers operation of the system from September 1978 through March 1979. The Facilities Development Gas Company solar energy system provides domestic hot water preheating to a 31-unit apartment building located in San Diego, California. Section 2 presents a summary of the overall system results. A system description is contained in Section 3. Analysis of the system thermal performance was accomplished using a system energy balance technique described in Section 4. Section 5 presents a detailed assessment of the individual subsystems applicable to the site.

The measurement data for the reporting period were collected by the NSDN [1]. System performance data are provided through the NSDN via an IBM-developed Central Data Processing System (CDPS) [2]. The CDPS supports the collection and analysis of solar data acquired from instrumented systems located throughout the country. This data is processed daily and summarized into monthly performance reports. These monthly reports form a common basis for system evaluation and are the source of the performance data used in this report.

2. SUMMARY AND CONCLUSIONS

This section provides an operational summary of the performance of the solar energy system installed at the Facilities Development Gas Company site, located in San Diego, California for the period September 1978 through March 1979. This solar energy system is designed to support the domestic hot water load. A detailed description of the Facilities Development Gas Company solar energy system operation is presented in Section 3.

2.1 Performance Summary

The solar energy site was occupied from September 1978 through March 1979, and the solar energy system operated continuously during this reporting period. When compared with expected system thermal performance as derived from a modified f-chart analysis (see Sections 5 and 5.2 for details), the system performed approximately as expected. During the reporting period the total incident solar energy was 162.33 million Btu, of which 70.63 million Btu were collected by the solar energy system. It achieved a collector efficiency of 48 percent. Although the measured amount of solar energy delivered to the DHW load (56.78 million Btu) was about 12 percent less than the expected value, solar energy satisfied 23 percent of the DHW requirements which was one percentage point more than the expected value. The solar energy system provided an electrical energy savings of 55.28 million Btu.

A total of 162.33 million Btu of incident solar energy was measured in the plane of the collector array during the reporting period. At times when the collector array was operating there were 146.41 million Btu incident on the array. The measured average daily incident solar energy per unit area in the plane of the collector array was 1476 million Btu/ft^2/day, which is 14 percent below the long-term daily average of 1718 million Btu/ft^2/day for the 7-month reporting period.

2.2 Conclusions

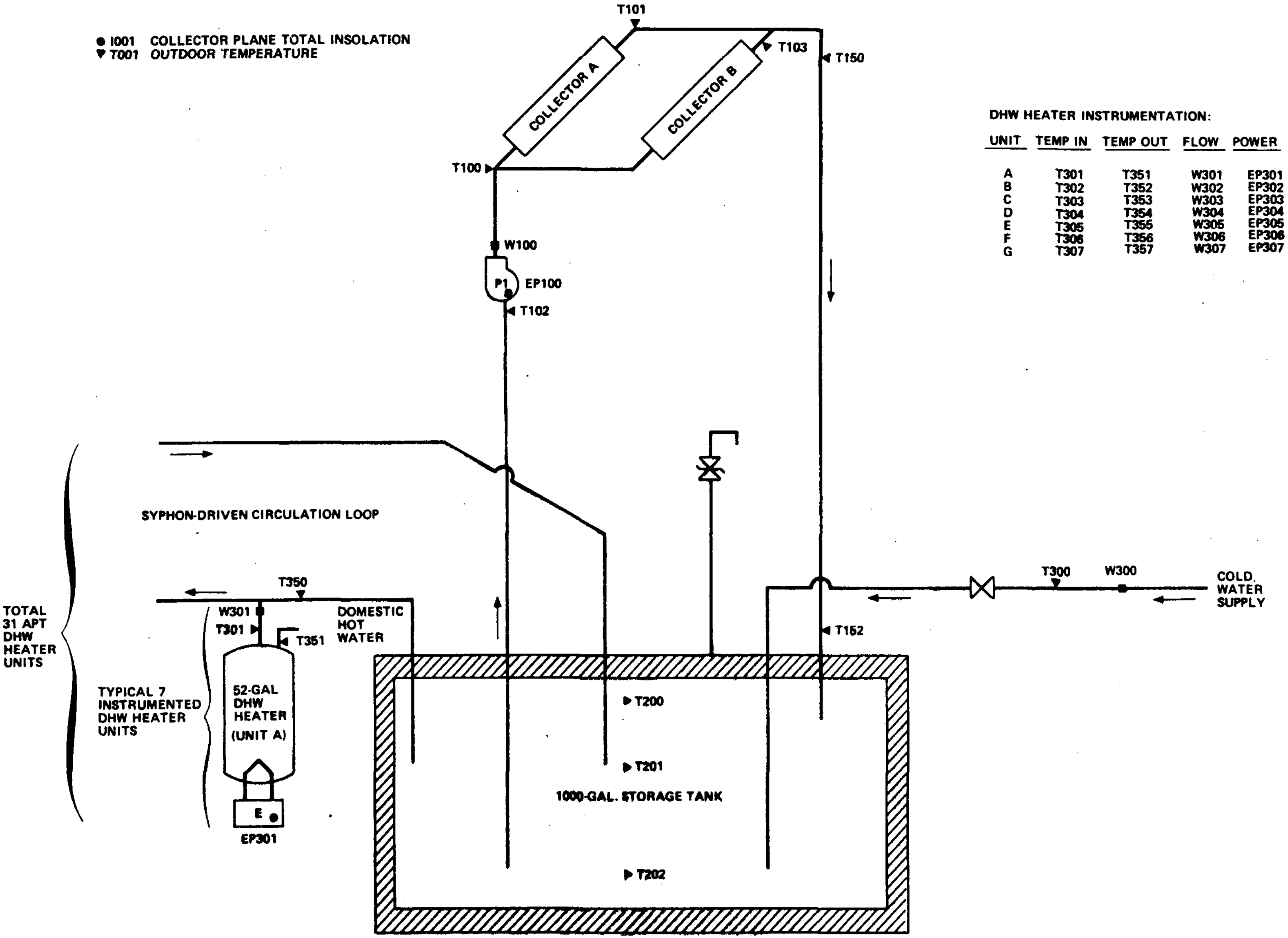
During the reporting period, the solar energy system operated normally and performed approximately as expected. In the solar energy system performance evaluation of the site, the collected solar energy, the collector loop operating energy, energy delivered to storage, solar energy used, and hot water consumed were derived from overall solar energy system parameters. The auxiliary electrical energy used (representing the entire building) was extrapolated from the average of the 7 instrumented apartment units (since only 7 of the 31 apartments were instrumented). The hot water load and the average value of the hot water temperature supplied to the building were not determined because of inadequate instrumentation. Installation of improved instrumentation has been scheduled by Boeing.

3. SYSTEM DESCRIPTION

The Facilities Development Gas Company site is a three-story, multifamily condominium consisting of 31 units in San Diego, California. Solar energy is used for preheating domestic hot water (DHW) for the complex. The solar energy system has an array of flat-plate collectors with a gross area of 520 square feet. The array faces south at an angle of 42 degrees to the horizontal. Potable water is the transfer medium that delivers solar energy from the collector array to storage. Solar energy is stored underground in an insulated 1000-gallon glass-lined tank. Preheated water from the storage tank is supplied, on demand, to 31 conventional 52-gallon DHW tanks. When solar energy is insufficient to satisfy the hot water load, two electrical heating elements, energized separately within the individual DHW tanks, provide auxiliary energy for water heating. The system, shown schematically in Figure 3-1, has two modes of solar operation.

Mode 1 - Collector-to-Storage: This mode activates when the water temperature in the collectors is 9°F higher than the temperature of the storage tank. Water is pumped through the collectors and circulates back to storage until the temperature difference is 3°F or less.

Mode 2 - Storage-to-DHW Tank: This mode activates when there is a demand for hot water replenishment by the individual DHW tank. Water from storage circulates by thermosiphoning action through a supply service loop to the individual DHW tanks and returns through a service line to storage. The water in each DHW tank is maintained at an average temperature which is thermostatically controlled. When required, additional energy is supplied by an auxiliary electrical heating element.



DHW HEATER INSTRUMENTATION:

UNIT	TEMP IN	TEMP OUT	FLOW	POWER
A	T301	T351	W301	EP301
B	T302	T352	W302	EP302
C	T303	T353	W303	EP303
D	T304	T354	W304	EP304
E	T305	T355	W305	EP305
F	T306	T356	W306	EP306
G	T307	T357	W307	EP307

FIGURE 3-1. SOLAR ENERGY SYSTEM SCHEMATIC
FACILITIES DEVELOPMENT GAS COMPANY

4. PERFORMANCE EVALUATION TECHNIQUES

The performance of the Facilities Development Gas Company solar energy system is evaluated by calculating a set of primary performance factors which are based on those proposed in the intergovernmental agency report "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program" [3]. These performance factors quantify the thermal performance of the system by measuring the amount of energies that are being transferred between the components of the system. The performance of the system can then be evaluated based on the efficiency of the system in transferring these energies. All performance factors and their definitions are listed in Appendix A.

Data from monitoring instrumentation located at key points within the solar energy system are collected by the National Solar Data Network. This data is first formed into factors showing the hourly performance of each system component, either by summation or averaging techniques, as appropriate. The hourly factors then serve as a basis for calculating the daily and monthly performance of each component subsystem. The performance factor equations for this site are listed in Appendix B.

Each month, as appropriate, a summary of overall performance of the Facilities Development Gas Company site and a detailed subsystem analysis are published. These monthly reports for the period covered by this Solar Energy System Performance Evaluation (September 1978 through March 1979) are available from the Technical Information Center, Oak Ridge, Tennessee 37830.

In addition, data are included in this report for which monthly reports are not available. This data is included with the intention of making this report as comprehensive as possible. Months for which no published monthly reports exist are shown in parentheses in the tables and figures. In the tables and figures in this report, an asterisk indicates that the value is not available for that month; N.A. indicates that the value is not applicable for this site.

5. PERFORMANCE ASSESSMENT

The performance of the Facilities Development Gas Company solar energy system has been evaluated for the September 1978 through March 1979 time period. Two perspectives were taken in this assessment. The first views the overall system in which the total solar energy collected, the system load, the measured values for solar energy used, and system solar fraction are presented. Where applicable, the expected values for solar energy used and system solar fraction are also shown. The expected values have been derived from a modified f-chart analysis which uses measured weather and subsystem loads as input. f-chart is the designation of a performance estimation technique used for designing solar heating systems. It was developed by the Solar Energy Laboratory, University of Wisconsin-Madison. The system model used in the analysis is based on manufacturer's data and other known system parameters. In addition, the solar energy system coefficient of performance (COP) at both the system and subsystem level has been presented.

The second view presents a more in-depth look at the performance of individual subsystems. Details relating to the performance of the collector array and storage subsystems are presented first, followed by details pertaining to the domestic hot water (DHW) subsystem. Included in this section are all parameters pertinent to the operation of each individual subsystem.

In addition to the overall system and subsystem analysis, this report also describes the equivalent energy savings contributed by the solar energy system. The overall system and individual subsystem energy savings are presented in Section 5.5.

The performance assessment of any solar energy system is highly dependent on the prevailing weather conditions at the site during the period of performance. The original design of the system is generally based on the long-term averages for available insolation and temperature. Deviations from these long-term averages can significantly affect the performance of the system. Therefore, before beginning the discussion of actual system performance, a presentation of the measured and long-term averages for critical weather parameters has been provided.

5.1 Weather Conditions

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the Facilities Development Gas Company site during the reporting period are presented in Table 5-1. Also presented in Table 5-1 are the corresponding long-term average monthly values of the measured weather parameters. These data are taken from Reference Monthly Environmental Data for Systems in the National Solar Data Network [4]. A complete yearly listing of these values for the site is given in Appendix C.

During the reporting period, September 1978 through March 1979, the average daily total incident solar energy on the collector array was 1476 Btu per square foot per day. This was below the estimated average daily solar radiation for this geographical area during the reporting period of 1718 Btu per square foot per day for a south-facing plane with a tilt of 42 degrees to the horizontal. The average ambient temperature during the reporting period was 58°F as compared with the long-term average for September through March of 61°F.

Monthly values of heating and cooling degree-days are derived from daily values of ambient temperature. Heating degree-days and cooling degree-days are computed as the difference between daily average temperature and 65°F. For example, if a day's average temperature was 60°F, then five heating degree-days are accumulated. Similarly, if a day's average temperature was 80°F, then 15 cooling degree-days are accumulated. The total number of heating and cooling degree-days is summed monthly.

TABLE 5-1. WEATHER CONDITIONS
FACILITIES DEVELOPMENT GAS COMPANY

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA[1] (Btu/Ft^2)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
SEPT	1575	1840	70	70	0	16	154	163
(OCT)	1443	1797	67	66	6	43	63	77
(NOV)	1451	1649	57	61	229	140	0	14
(DEC)	1407	1521	51	51	418	257	0	0
JAN	1143	1571	53	55	364	314	0	10
FEB	1719	1757	53	57	326	237	0	0
MAR	1595	1892	57	58	258	219	0	0
TOTAL					1601	1226	217	264
AVERAGE	1476	1718	58	61	229	175	31	38

[1] In collector array plane and azimuth, unless otherwise indicated in Section 5.1.

5.2 System Thermal Performance

The thermal performance of a solar energy system is a function of the total solar energy collected and applied to the system load. The total system load is the sum of the useful energy delivered to the loads (excluding losses in the system), both solar and auxiliary thermal energies. The portion of the total load provided by solar energy is defined as the solar fraction of the load.

The thermal performance of the Facilities Development Gas Company solar energy system is presented in Table 5-2. This performance assessment is based on the seven month period from September 1978 to March 1979. During the reporting period, a total of 70.63 million Btu of solar energy was collected and the total system load was not determined because of instrumentation problems. The measured amount of solar energy delivered to the load subsystem was 56.78 million Btu or 7.52 million Btu less than the expected value. The measured system solar fraction was 23 percent as compared to an expected value of 26 percent.

Figure 5-1 illustrates the flow of solar energy from the point of collection to the various points of consumption and loss for the reporting period. The numerical values account for the quantity of energy corresponding with the transport, operation, and function of each major element in the Facilities Development Gas Company solar energy system for the total reporting period. Transport loss from storage to the DHW load was not measured. DHW load was not determined.

Solar energy distribution flowcharts for each month of the reporting period are presented in Appendix D.

Table 5-3 summarizes solar energy distribution and provides a percentage breakdown. For the period September 1978 through March 1979, the load subsystem consumed 80 percent of the energy collected. Appendix E contains the monthly solar energy percentage distributions.

TABLE 5-2. SYSTEM THERMAL PERFORMANCE SUMMARY
FACILITIES DEVELOPMENT GAS COMPANY

MONTH	SOLAR ENERGY COLLECTED (Million Btu)	SYSTEM LOAD (Million Btu)	SOLAR ENERGY USED (Million Btu)		SOLAR FRACTION (%)	
			EXPECTED	MEASURED	EXPECTED	MEASURED
SEPT	10.22	*	8.3	7.59	55	51
(OCT)	10.12	*	8.1	8.09	45	45
(NOV)	9.78	*	8.2	7.42	41	37
(DEC)	9.68	*	9.6	6.98	20	14
JAN	7.52	*	7.2	6.41	15	13
FEB	11.16	*	11.4	9.16	26	21
MAR	12.15	*	11.5	11.13	20	20
TOTAL	70.63	*	64.3	56.78		
AVERAGE	10.09	*	9.19	8.11	26	23

* - Denotes unavailable data

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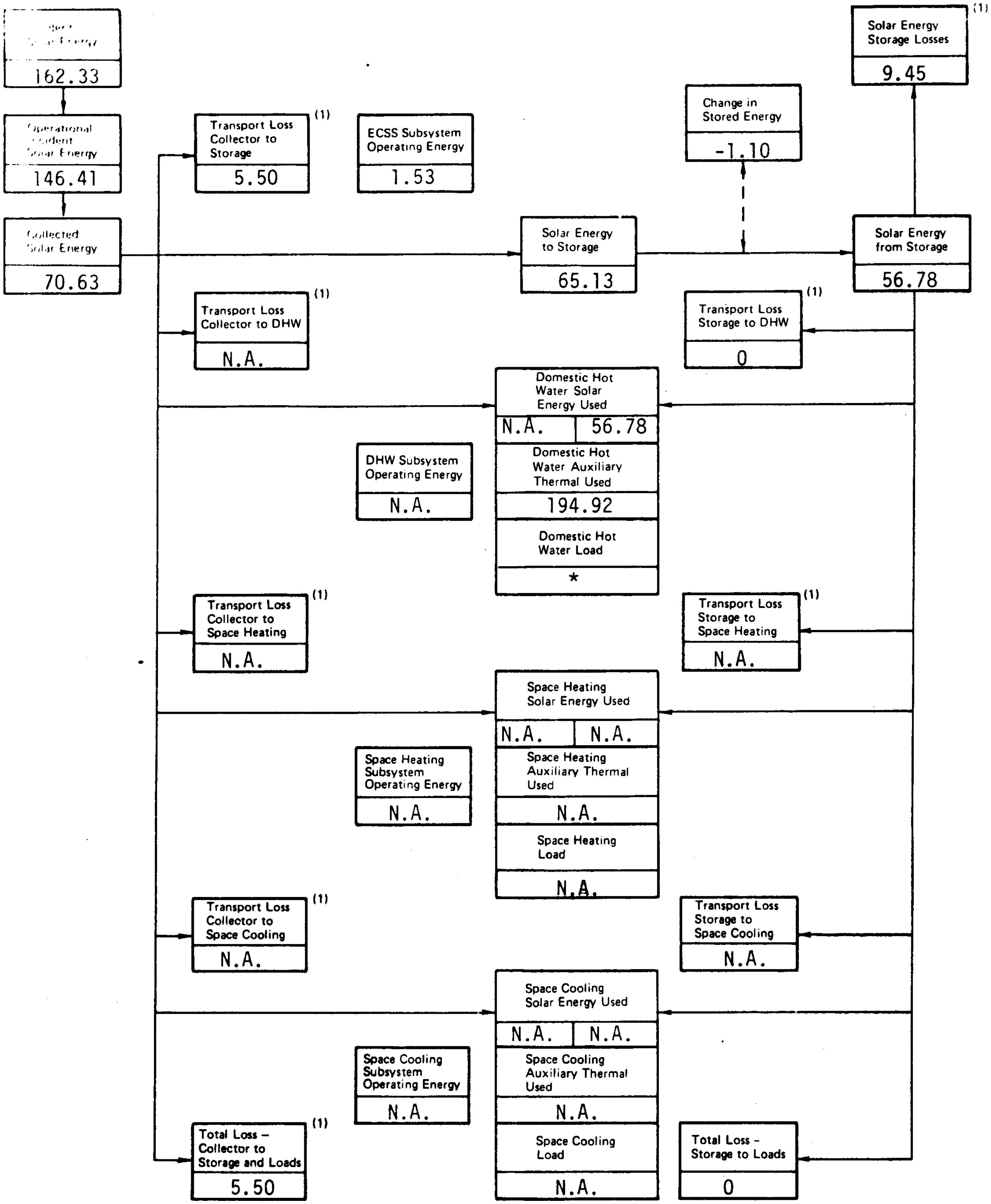
FIGURE 5-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART SUMMARY
FACILITIES DEVELOPMENT GAS COMPANY



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

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TABLE 5-3. SOLAR ENERGY DISTRIBUTION - SUMMARY - SEPTEMBER 1978 THROUGH MARCH 1979

FACILITIES DEVELOPMENT GAS COMPANY

- 70.63 million Btu TOTAL SOLAR ENERGY COLLECTED
  100%
  - 56.78 million Btu SOLAR ENERGY TO LOADS
    80%
    - 56.78 million Btu SOLAR ENERGY TO DHW SUBSYSTEM
      80%
    - N.A. million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
      %
    - N.A. million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
      %
  - 14.95 million Btu SOLAR ENERGY LOSSES
    21%
    - 9.45 million Btu SOLAR ENERGY LOSS FROM STORAGE
      13%
    - 5.50 million Btu SOLAR ENERGY LOSS IN TRANSPORT
      8%
      - 5.50 million Btu COLLECTOR TO STORAGE LOSS
        8%
      - N.A. million Btu COLLECTOR TO LOAD LOSS
        %
        - N.A. million Btu COLLECTOR TO DHW LOSS
          %
        - N.A. million Btu COLLECTOR TO SPACE HEATING LOSS
          %
        - N.A. million Btu COLLECTOR TO SPACE COOLING LOSS
          %
      - N.A. million Btu STORAGE TO LOAD LOSS
        %
        - N.A. million Btu STORAGE TO DHW LOSS
          %
        - N.A. million Btu STORAGE TO SPACE HEATING LOSS
          %
        - N.A. million Btu STORAGE TO SPACE COOLING LOSS
          %
  - -1.10 million Btu SOLAR ENERGY STORAGE CHANGE
    -1%

N.A. - Denotes not applicable data

The solar energy coefficient of performance (COP) is indicated in Table 5-4. The COP simply provides a numerical value for the relationship of solar energy collected or transported or used and the energy required to perform the transition. The greater the COP value, the more efficient the subsystem. The solar energy system at the Facility Development Gas Company site functioned at a weighted average COP value of 37.11 for the reporting period September 1978 through March 1979.

5.3 Subsystem Performance

The Facilities Development Gas Company solar energy installation may be divided into two subsystems:

1. Collector and Storage
2. Domestic Hot Water (DHW)

Each subsystem is evaluated and analyzed by the techniques defined in Section 4 to produce the monthly performance reports. This section presents the results of integrating the monthly data available on the two subsystems for the period September 1978 through March 1979.

5.3.1 Collector Array and Storage Subsystem

5.3.1.1 Collector Array

Collector array performance for the Facilities Development Gas Company site is presented in Table 5-5. The total incident solar radiation on the collector array for the period September 1978 through March 1979 was 162.33 million Btu. During the period the collector loop was operating the total insolation amounted to 146.41 million Btu. The total collected solar energy for the period was 70.63 million Btu, resulting in a collector array efficiency of 44 percent, based on total incident insolation. Solar energy delivered from the collector array to storage was 65.13 million Btu. Energy loss during

TABLE 5-4. SOLAR ENERGY SYSTEM COEFFICIENT OF PERFORMANCE FACILITIES DEVELOPMENT GAS COMPANY

MONTH	SOLAR ENERGY SYSTEM COP	COLLECTOR ARRAY SUBSYSTEM SOLAR COP	DOMESTIC HOT WATER SUBSYSTEM SOLAR COP	SPACE HEATING SUBSYSTEM SOLAR COP	SPACE COOLING SUBSYSTEM SOLAR COP
SEPT	34.50	46.50	*	N.A.	N.A.
(OCT)	36.77	46.00	*	N.A.	N.A.
(NOV)	33.73	44.45	*	N.A.	N.A.
(DEC)	30.35	42.09	*	N.A.	N.A.
JAN	35.61	41.78	*	N.A.	N.A.
FEB	39.83	48.52	*	N.A.	N.A.
MAR	48.39	52.83	*	N.A.	N.A.
WEIGHTED AVERAGE	37.11	46.16	*	N.A.	N.A.

S002

* - Denotes unavailable data
N.A. - Denotes not applicable data

TABLE 5-5. COLLECTOR ARRAY PERFORMANCE FACILITIES DEVELOPMENT GAS COMPANY

MONTH	INCIDENT SOLAR ENERGY (Million Btu)	COLLECTED SOLAR ENERGY (Million Btu)	COLLECTOR ARRAY EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY (Million Btu)	OPERATIONAL COLLECTOR ARRAY EFFICIENCY (%)
SEPT	24.57	10.22	42	22.11	46
(OCT)	23.27	10.12	44	21.23	48
(NOV)	22.63	9.78	43	20.61	47
(DEC)	22.69	9.68	43	20.82	46
JAN	18.43	7.52	41	15.65	48
FEB	25.03	11.16	45	22.83	49
MAR	25.71	12.15	47	23.16	52
TOTAL	162.33	70.63		146.41	
AVERAGE	23.19	10.09	44	20.92	48

S002

transfer from the collector array to storage was 5.50 million Btu. This loss represented 8 percent of the energy collected. Operating energy required by the collector loop was 1.53 million Btu.

Collector array efficiency has been computed from two bases. The first assumes that the efficiency is based upon all available solar energy. This approach makes the operation of the control system part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum; therefore, the energy is not collected. In this approach, collector array performance is described by comparing the collected solar energy to the incident solar energy. The ratio of these two energies represents the collector array efficiency which may be expressed as

$$\eta_c = Q_s/Q_i$$

where: η_c = collector array efficiency

Q_s = collected solar energy

Q_i = incident solar energy

The monthly efficiency computed by this method is listed in the column entitled "Collector Array Efficiency" in Table 5-5.

The second approach assumes the efficiency is based upon the incident solar energy only during the periods of collection.

Evaluating collector efficiency using operational incident energy and compensating for the difference between gross collector array area and the gross collector area yield operational collector efficiency. Operational collector efficiency, η_{co}, is computed as follows:

$$\eta_{co} = Q_s/(Q_{oi} \times \frac{A_p}{A_a})$$

where: Q_s = collected solar energy

Q_{oi} = operational incident energy

A_p = gross collector area (product of the number of collectors and the total envelope area of one unit)

A_a = gross collector array area (total area perpendicular to the solar flux vector, including all mounting, connecting and transport hardware

Note: The ratio $\frac{A_p}{A_a}$ is typically 1.0 for most collector array configurations.

The monthly efficiency computed by this method is listed in the column entitled "Operational Collector Array Efficiency" in Table 5-5. This latter efficiency term is not the same as collector efficiency as represented by the ASHRAE Standard 93-77 [5]. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 5-5.

5.3.1.2 <u>Storage</u>

Storage performance data for the Facilities Development Gas Company site for the reporting period is shown in Table 5-6. Results of analysis of solar energy losses during transport and storage are shown in Table 5-7. This table contains an evaluation of solar energy transport losses as a fraction of energy transported to subsystems.

TABLE 5-6. STORAGE PERFORMANCE
FACILITIES DEVELOPMENT GAS COMPANY Y

MONTH	ENERGY TO STORAGE (Million Btu)	ENERGY FROM STORAGE (Million Btu)	CHANGE IN STORED ENERGY (Million Btu)	STORAGE EFFICIENCY (%)	STORAGE AVERAGE TEMPERATURE (°F)	EFFECTIVE STORAGE HEAT LOSS COEFFICIENT (Btu/Hr -- °F)
SEPT	9.61	7.59	-0.03	79	112	N.A.
(OCT)	9.58	8.09	-0.13	83	109	N.A.
(NOV)	9.29	7.42	-0.13	79	102	N.A.
(DEC)	9.18	6.98	0.12	77	91	N.A.
JAN	6.86	6.41	-0.46	87	90	N.A.
FEB	9.79	9.16	-0.16	92	95	N.A.
MAR	10.82	11.13	-0.31	100	89	N.A.
TOTAL	65.13	56.78	-1.10			
AVERAGE	9.30	8.11	-0.16	86	98	N.A.

N.A. - Denotes not applicable data

S002

TABLE 5-7. SOLAR ENERGY LOSSES – STORAGE AND TRANSPORT
FACILITIES DEVELOPMENT GAS COMPANY

	MONTH							
	SEPT	(OCT)	(NOV)	(DEC)	JAN	FEB	MAR	TOTAL
1. SOLAR ENERGY (SE) COLLECTED MINUS SE DIRECTLY TO LOADS (million Btu)	10.22	10.12	9.78	9.68	7.52	11.16	12.15	70.63
2. SE TO STORAGE (million Btu)	9.61	9.58	9.29	9.18	6.86	9.79	10.82	65.13
3. LOSS – COLLECTOR TO STORAGE (%) $\frac{1-2}{1}$	6	5	5	5	9	12	11	8
4. CHANGE IN STORED ENERGY (million Btu)	-0.03	-0.13	-0.13	+0.12	-0.46	-0.16	-0.31	-1.10
5. SOLAR ENERGY – STORAGE TO DHW SUBSYSTEM (million Btu)	7.59	8.09	7.42	6.98	6.41	9.16	11.13	56.78
6. SOLAR ENERGY – STORAGE TO SPACE HEATING SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
7. SOLAR ENERGY – STORAGE TO SPACE COOLING SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
8. LOSS FROM STORAGE (%) $\frac{2-(4+5+6+7)}{2}$	21	17	22	23	13	8	0	14
9. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million Btu)	7.59	8.09	7.42	6.98	6.41	9.16	11.13	56.78
10. LOSS – STORAGE TO HWSE (%) $\frac{5-9}{5}$	0	0	0	0	0	0	0	0
11. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
12. LOSS – STORAGE TO HSE (%) $\frac{6-11}{6}$	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

N.A. - Denotes not applicable data

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During the reporting period, total solar energy delivered to storage was 65.13 million Btu. There were 56.78 million Btu delivered from storage to the DHW subsystem. Energy loss from storage was 9.45 million Btu. This loss represented 14 percent of the energy delivered to storage. The storage efficiency was 86 percent: This is calculated as the ratio of the sum of the energy removed from storage and the change in stored energy, to the energy delivered to storage. The average storage temperature for the period was 98°F.

Storage subsystem performance is evaluated by comparison of energy to storage, energy from storage and the change in stored energy. The ratio of the sum of energy from storage and the change in stored energy, to the energy to storage is defined as storage efficiency, η_s. This relationship is expressed in the equation

$$\eta_s = (\Delta Q + Q_{so})/Q_{si}$$

where:

ΔQ = change in stored energy. This is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value)

Q_{so} = energy from storage. This is the amount of energy extracted by the load subsystem from the primary storage medium

Q_{si} = energy to storage. This is the amount of energy (both solar and auxiliary) delivered to the primary storage medium

5.3.2 Domestic Hot Water (DHW) Subsystem

The DHW subsystem performance for the Facilities Development Gas Company site for the reporting period is shown in Table 5-8. The DHW subsystem consumed 56.78 million Btu of solar energy and 194.92 million Btu of auxiliary electrical energy to satisfy an undetermined hot water load. The solar fraction of this load was 23 percent. The DHW flowmeters at the seven instrumented apartments were not adequate for determination of DHW load and hot water temperature when flow was occuring.

The performance of the DHW subsystem is described by comparing the amount of solar energy supplied to the subsystem with the total energy required by the subsystem. The total energy required by the subsystem consists of both solar and auxiliary thermal energy. The DHW load is defined as the amount of energy required to raise the mass of water delivered by the DHW subsystem between the temperature at which it entered the subsystem and its delivery temperature. The DHW solar fraction is defined as the portion of the DHW load which is supported by solar energy.

5.4 Operating Energy

Measured values of the Facilities Development Gas Company solar energy system and subsystem operating energy for the reporting period are presented in Table 5-9. A total of 1.53 million Btu of operating energy was consumed by the entire system during the reporting period.

Operating energy for a solar energy system is defined as the amount of electrical energy required to support the subsystems without affecting their thermal state.

Total system operating energy for the Facilities Development Gas Company site is the energy required to support the energy collection and storage subsystem (ECCS). With reference to the system schematic Figure 3-1, the ECCS operating energy includes electrical energy required to operate pump EP100 in the

TABLE 5-8. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE FACILITIES DEVELOPMENT GAS COMPANY

MONTH	DOMESTIC HOT WATER LOAD (Million Btu)	ENERGY CONSUMED (Million Btu)				SOLAR FRACTION (%)
		SOLAR	AUXILIARY THERMAL	AUXILIARY		
				ELECTRICAL	FOSSIL	
SEPT	*	7.59	7.41	7.41	N.A.	51
OCT	*	8.09	9.74	9.74	N.A.	45
NOV	*	7.42	12.50	12.50	N.A.	37
DEC	*	6.98	41.64	41.64	N.A.	14
JAN	*	6.41	42.39	42.39	N.A.	13
FEB	*	9.16	35.40	35.40	N.A.	21
MAR	*	11.13	45.84	45.84	N.A.	20
TOTAL	*	56.78	194.92	194.92		
AVERAGE	*	8.11	27.85	27.85		23

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* - Denotes unavailable data
N.A. - Denotes not applicable data

TABLE 5-9 . OPERATING ENERGY
FACILITIES DEVELOPMENT GAS COMPANY

MONTH	ENERGY COLLECTION AND STORAGE OPERATING ENERGY (Million Btu)	DOMESTIC HOT WATER OPERATING ENERGY (Million Btu)	SPACE HEATING OPERATING ENERGY (Million Btu)	SPACE COOLING OPERATING ENERGY (Million Btu)	TOTAL SYSTEM OPERATING ENERGY (Million Btu)
SEPT	0.22	N.A.	N.A.	N.A.	0.22
(OCT)	0.22	N.A.	N.A.	N.A.	0.22
(NOV)	0.22	N.A.	N.A.	N.A.	0.22
(DEC)	0.23	N.A.	N.A.	N.A.	0.23
JAN	0.18	N.A.	N.A.	N.A.	0.18
FEB	0.23	N.A.	N.A.	N.A.	0.23
MAR	0.23	N.A.	N.A.	N.A.	0.23
TOTAL	1.53	N.A.	N.A.	N.A.	1.53
AVERAGE	0.22	N.A.	N.A.	N.A.	0.22

N.A. - Denotes not applicable data

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collector/storage loop. The DHW subsystem required no operating energy, since it is a thermal siphoning system.

5.5 Energy Savings

Energy savings for the Facilities Development Gas Company site for the reporting period are presented in Table 5-10. For this period the net electrical energy savings for the site were 55.28 million Btu, for a monthly average of 7.90 million Btu. An electrical energy expense of 1.53 million Btu was incurred during the reporting period for the operation of the solar energy transportation pump.

Solar energy system savings are realized whenever energy provided by the solar energy system is used to meet system demands which would otherwise be met by auxiliary energy sources. The operating energy required to provide solar energy to the load subsystems is subtracted from the solar energy contribution to determine net savings.

The auxiliary source at the Facilities Development Gas Company site consists of 31 DHW tanks, one in each apartment. These units are maintained at thermostatically controlled temperatures with electrical auxiliary energy when needed.

TABLE 5-10. ENERGY SAVINGS FACILITIES DEVELOPMENT GAS COMPANY

MONTH	SOLAR ENERGY USED (Million Btu)	SOLAR ENERGY SAVINGS ATTRIBUTED TO (Million Btu)						SOLAR OPERATING ENERGY (Million Btu)	ENERGY SAVINGS (Million Btu)	
		SPACE HEATING		DOMESTIC HOT WATER		SPACE COOLING				
		ELECTRICAL	FOSSIL FUEL	ELECTRICAL	FOSSIL FUEL	ELECTRICAL	FOSSIL FUEL		ELECTRICAL	FOSSIL FUEL
SEPT	7.59	N.A.	N.A.	7.59	N.A.	N.A.	N.A.	0.22	7.37	N.A.
(OCT)	8.09	N.A.	N.A.	8.09	N.A.	N.A.	N.A.	0.22	7.88	N.A.
(NOV)	7.42	N.A.	N.A.	7.42	N.A.	N.A.	N.A.	0.22	7.21	N.A.
(DEC)	6.98	N.A.	N.A.	6.98	N.A.	N.A.	N.A.	0.23	6.75	N.A.
JAN	6.41	N.A.	N.A.	6.41	N.A.	N.A.	N.A.	0.18	6.23	N.A.
FEB	9.16	N.A.	N.A.	9.16	N.A.	N.A.	N.A.	0.23	8.94	N.A.
MAR	11.13	N.A.	N.A.	11.13	N.A.	N.A.	N.A.	0.23	10.90	N.A.
TOTAL	56.78	N.A.	N.A.	56.78	N.A.	N.A.	N.A.	1.53	55.28	N.A.
AVERAGE	8.11	N.A.	N.A.	8.11	N.A.	N.A.	N.A.	0.22	7.90	N.A.

N.A. - Denotes not applicable data

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Copies of these reports may be obtained from Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

APPENDIX A

DEFINITIONS OF PERFORMANCE FACTORS AND SOLAR TERMS

COLLECTOR ARRAY PERFORMANCE

The collector array performance is characterized by the amount of solar energy collected with respect to the energy available to be collected.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.
- OPERATIONAL INCIDENT ENERGY (SEOP) is the amount of solar energy incident on the collector array during the time that the collector loop is active (attempting to collect energy).
- COLLECTED SOLAR ENERGY (SECA) is the thermal energy removed from the collector array by the energy transport medium.
- COLLECTOR ARRAY EFFICIENCY (CAREF) is the ratio of the energy collected to the total solar energy incident on the collector array. It should be emphasized that this efficiency factor is for the collector array, and available energy includes the energy incident on the array when the collector loop is inactive. This efficiency must not be confused with the more common collector efficiency figures which are determined from instantaneous test data obtained during steady-state operation of a single collector unit. These efficiency figures are often provided by collector manufacturers or presented in technical journals to characterize the functional capability of a particular collector design. In general, the collector panel maximum efficiency factor will be significantly higher than the collector array efficiency reported here.

STORAGE PERFORMANCE

The storage performance is characterized by the relationships among the energy delivered to storage, removed from storage, and the subsequent change in the amount of stored energy.

- ENERGY TO STORAGE (STEI) is the amount of energy, both solar and auxiliary, delivered to the primary storage medium.
- ENERGY FROM STORAGE (STEO) is the amount of energy extracted by the load subsystems from the primary storage medium.

- o CHANGE IN STORED ENERGY (STECH) is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value).

- o STORAGE AVERAGE TEMPERATURE (TST) is the mass-weighted average temperature of the primary storage medium.

- o STORAGE EFFICIENCY (STEFF) is the ratio of the sum of the energy removed from storage and the change in stored energy to the energy delivered to storage.

ENERGY COLLECTION AND STORAGE SUBSYSTEM

The Energy Collection and Storage Subsystem (ECSS) is composed of the collector array, the primary storage medium, the transport loops between these, and other components in the system design which are necessary to mechanize the collector and storage equipment.

- o INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- o AMBIENT TEMPERATURE (TA) is the average temperature of the outdoor environment at the site.

- o ENERGY TO LOADS (SEL) is the total thermal energy transported from the ECSS to all load subsystems.

- o AUXILIARY THERMAL ENERGY TO ECSS (CSAUX) is the total auxiliary energy supplied to the ECSS, including auxiliary energy added to the storage tank, heating devices on the collectors for freeze-protection, etc.

- o ECSS OPERATING ENERGY (CSOPE) is the critical operating energy required to support the ECSS heat transfer loops.

HOT WATER SUBSYSTEM

The hot water subsystem is characterized by a complete accounting of the energy flow into and from the subsystem, as well as an accounting of internal energy. The energy into the subsystem is composed of auxiliary fossil fuel, and electrical auxiliary thermal energy, and the operating energy for the subsystem.

- o HOT WATER LOAD (HWL) is the amount of energy required to heat the amount of hot water demanded at the site from the incoming temperature to the desired outlet temperature.

- SOLAR FRACTION OF LOAD (HWSFR) is the percentage of the load demand which is supported by solar energy.
- SOLAR ENERGY USED (HWSE) is the amount of solar energy supplied to the hot water subsystem.
- OPERATING ENERGY (HWOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the subsystem.
- AUXILIARY THERMAL USED (HWAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid, or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.
- AUXILIARY FOSSIL FUEL (HWAF) is the amount of fossil fuel energy supplied directly to the subsystem.
- ELECTRICAL ENERGY SAVINGS (HWSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.
- FOSSIL FUEL SAVINGS (HWSVF) is the estimated difference between the fossil fuel energy requirements of the alternative conventional system (carrying the full load) and the actual fossil fuel energy requirements of the subsystem.

SPACE HEATING SUBSYSTEM

The space heating subsystem is characterized by performance factors accounting for the complete energy flow into the subsystem. The average building temperature is tabulated to indicate the relative performance of the subsystem in satisfying the space heating load and in controlling the temperature of the conditioned space.

- SPACE HEATING LOAD (HL) is the sensible energy added to the air in the building.
- SOLAR FRACTION OF LOAD (HSFR) is the fraction of the sensible energy added to the air in the building derived from the solar energy system.
- SOLAR ENERGY USED (HSE) is the amount of solar energy supplied to the space heating subsystem.

- OPERATING ENERGY (HOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the system.
- AUXILIARY THERMAL USED (HAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.
- AUXILIARY ELECTRICAL FUEL (HAE) is the amount of electrical energy supplied directly to the subsystem.
- ELECTRICAL ENERGY SAVINGS (HSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.
- BUILDING TEMPERATURE (TB) is the average heated space dry bulb temperature.

APPENDIX B

SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS

FACILITIES DEVELOPMENT GAS COMPANY

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance calculations on the system and its major subsystems. These calculations are based on physical measurement data taken from each sensor every 320 seconds. This data is then mathematically combined to determine the hourly, daily, and monthly performance of the system. This appendix describes the general computational methods and the specific energy balance equations used for this site.

Data samples from the system measurements are integrated to provide discrete approximations of the continuous functions which characterize the system's dynamic behavior. This integration is performed by summation of the product of the measured rate of the appropriate performance parameters and the sampling interval over the total time period of interest.

There are several general forms of integration equations which are applied to each site. These general forms are exemplified as follows: The total solar energy available to the collector array is given by

$$\text{SOLAR ENERGY AVAILABLE} = (1/60)\ \Sigma\ [\text{I001} \times \text{AREA}] \times \Delta\tau$$

where I001 is the solar radiation measurement provided by the pyranometer in Btu per square foot per hour, AREA is the area of the collector array in square feet, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given typically by

$$\text{COLLECTED SOLAR ENERGY} = \Sigma\ [\text{W100} \times \text{CP} \times \text{RHO} \times (\text{T150} - \text{T100})] \times \Delta\tau$$

Where W100 is the flow rate of the heat transfer fluid in gal/min, CP and RHO are the specific heat and density, and T100 and T150 are the temperatures of the fluid before and after passing through the heat exchanging component. Frequently this temperature diffierece is referred to as simply TD100. The product W100 x RHO is often combined and represented as M100.

For electrical power, a general example is

$$\text{ECSS OPERATING ENERGY} = (3413/60)\ \Sigma\ [\text{EP100}] \times \Delta\tau$$

where EP100 is the power required by electrical equipment in kilowatts and the two factors (1/60) and 3413 correct the data to Btu/min.

These equations are comparable to those specified in "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program." This document was prepared by an interagency committee of the Government, and presents guidelines for thermal performance evaluation.

Performance factors are computed for each hour of the day. Each integration process, therfore, is performed over a period of one hour. Since long-term performance data is desired, it is necessary to build these hourly performance factors to daily values. This is accomplished, for energy parameters, by summing the 24 hourly values. For temperatures, the hourly values are averaged. Certain special factors, such as efficiencies, require appropriate handling to properly weight each hourly sample for the daily value computation. Similar procedures are required to convert daily values to monthly values.

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

NOTE: SENSOR IDENTIFICATION (MEASUREMENT) NUMBERS REFERENCE SYSTEM SCHEMATIC FIGURE 3-1

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \Sigma\ T001 \times \Delta\tau$$

DAYTIME AMBIENT TEMPERATURE (°F)

$$TDA = (1/360) \times \Sigma\ T001 \times \Delta\tau$$

FOR $\pm$ 3 HOURS FROM SOLAR NOON

SUPPLY WATER TEMPERATURE (°F)

$$TSW = (1/60) \times \Sigma\ T001 \times \Delta\tau$$

FOR T300 MEASURED WHILE WATER IS FLOWING TO LOADS

HOT WATER AVERAGE TEMPERATURE

$$THWAVG = (THW1 + THW2 + THW3 + THW4 + THW5 + THW6 + THW7)/7$$

WHERE THW1 = T351, MEASURED WHILE WATER IS FLOWING FROM UNIT 1

$$THW = (1/60) \times \Sigma\ THWAVG \times \Delta\tau$$

INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2)

$$SE = (1/60) \times \Sigma\ I001 \times \Delta\tau$$

INCIDENT SOLAR ENERGY

$$SEA = (1/60) \times \Sigma\ [I001 \times CLAREA] \times \Delta\tau$$

OPERATIONAL INCIDENT SOLAR ENERGY

$$SEOP = (1/60) \times \Sigma\ [I001 \times CLAREA] \times \Delta\tau$$

WHILE THE COLLECTOR PUMP IS CIRCULATING FLUID

COLLECTED SOLAR ENERGY

$$SEC = \Sigma\ [M100 \times HWD(T150, T100) \times \Delta\tau$$

WHERE M100 IS THE COLLECTOR FLUID MASS FLOW RATE AND HWD IS A FUNCTION CALCULATING CHANGE IN FLUID ENTHALPY OVER THE RANGE T150-T100.

COLLECTED SOLAR ENERGY PER UNIT AREA

$$SECA = \Sigma\ [M100 \times HWD(T150,\ T100)/CLAREA] \times \Delta\tau$$

STORAGE TEMPERATURE (°F)

$$TST = (1/60) \times \Sigma\ [T200 + T201 + T202)/3] \times \Delta\tau$$

ENERGY TO STORAGE

$$STEI = \Sigma\ [M100 \times HWD(T152,\ T102)] \times \Delta\tau$$

ENERGY FROM STORAGE

$$STEO = \Sigma\ [M300 \times HWD(T350,\ T300)] \times \Delta\tau$$

ECSS OPERATING ENERGY

$$CSOPE = (56.88) \times \Sigma EP100 \times \Delta\tau$$

HOT WATER USED (GALLONS)

$$HWCSM = \Sigma\ WD300 \times \Delta\tau$$

WHERE WD300 IS THE TIME DERIVATIVE OF THE TOTALIZING FLOWMETER

HOT WATER LOAD

$$HWL = \Sigma\ [M300 \times HWD(THWAVG,\ T300)] \times \Delta\tau$$

AUXILIARY ELECTRICAL ENERGY COMPUTATIONS

The Facilities Development Gas Company auxiliary electrical load is a combination of the loads of 31 individual domestic hot water tanks, of which 7 are currently instrumented. Load computations are estimates, treating the 31 tanks as a single composite tank. Auxiliary electrical energy is calculated by the following equation:

$$HWAE = \sum_{i=1}^{N} (\Sigma\ EP \times \Delta\tau) \times (\text{Number of Apartments}/N)$$

Where N = Number of instrumented apartments

EPX = EP measurement for individual instrumented apartments

COLLECTOR ARRAY EFFICIENCY

$$CAREF = SECA/SEA$$

CHANGE IN STORED ENERGY

$$STECH = STOCAP \times (TST \times RHO \times CP - TST_p \times RHO_p \times CP_p)$$

WHERE THE SUBSCRIPT $_p$ INDICATES VALUES TAKEN FROM A PREVIOUS REFERENCE HOUR

STORAGE EFFICIENCY

STEFF = (STECH + STEO)/STEI

ENERGY DELIVERED TO LOAD FROM ECSS

CSEA = STEO

SOLAR ENERGY TO LOAD

SEL = STEO

ECSS SOLAR CONVERSION EFFICIENCY

CSCEF = SEL/SEA

HOT WATER AUXILIARY THERMAL ENERGY

HWAT = HWAE

HOT WATER SOLAR ENERGY

HWSE = STEO

HOT WATER SOLAR FRACTION

HWSFR = HWSE/(HWSE + HWAT)

HOT WATER ELECTRICAL SAVINGS

HWSVE = HWSE

SYSTEM LOAD

SYSL = HWL

SYSTEM SOLAR FRACTION

SFR = HWSFR

SYSTEM PERFORMANCE FACTOR

SYSPF = SYSL/[(HWAE + CSOPE) x 3.33]

AUXILIARY ELECTRICAL ENERGY

AXE + HWAE

AUXILIARY THERMAL ENERGY

AXT = HWAE

SYSTEM OPERATING ENERGY

SYSOPE = CSOPE

TOTAL ENERGY CONSUMED

TECSM = AXE + SYSOPE + SECA

TOTAL ELECTRICAL SAVINGS

TSVE = HWSVE - CSOPE

APPENDIX C

LONG-TERM AVERAGE WEATHER CONDITIONS

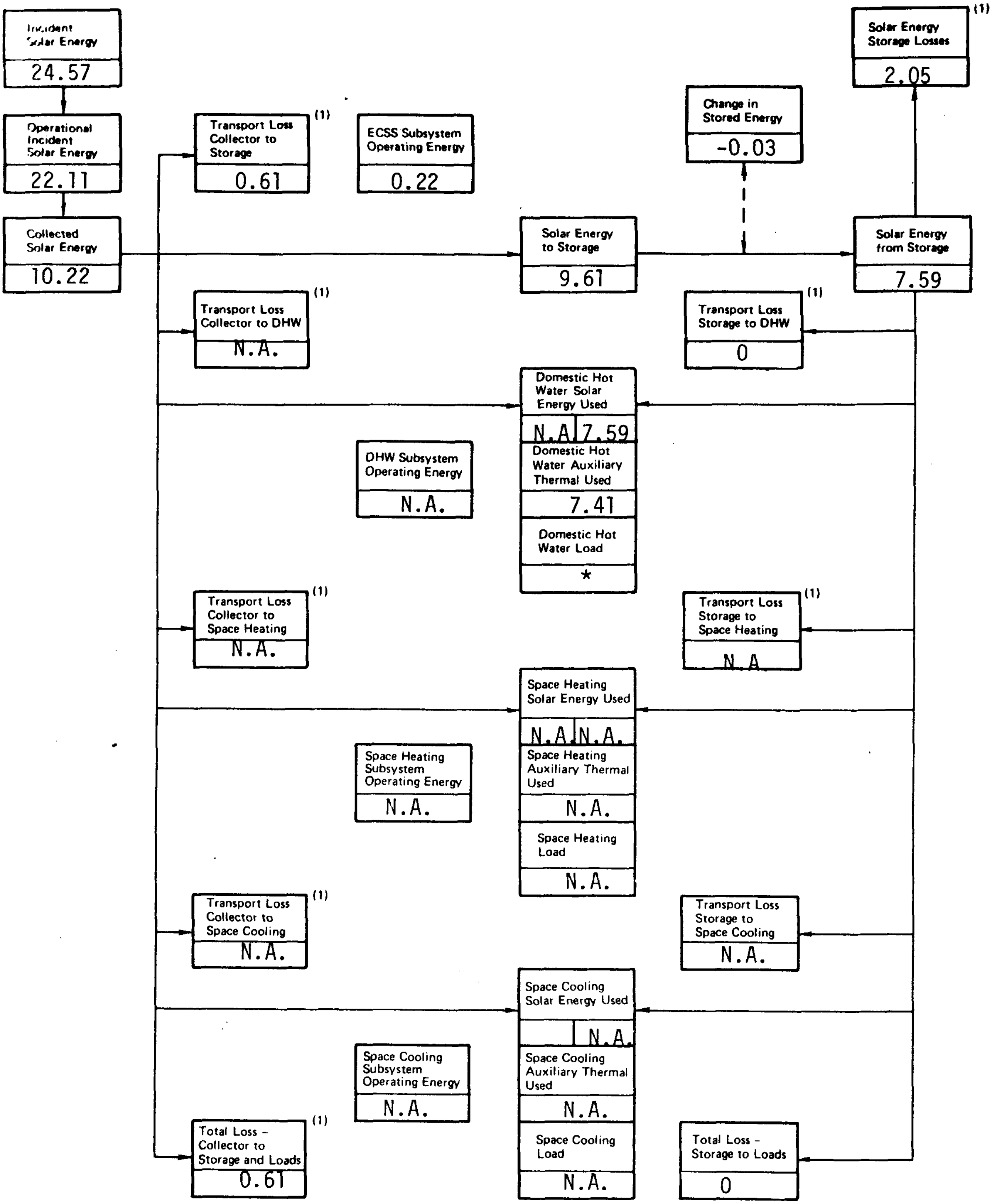
This appendix contains a table which lists the long-term average weather conditions for each month of the year for this site.

```
SITE:  'FACILITIES DEV           61.          LOCATION:  SAN DIEGO    CA

ANALYST:   M. FU                              FDRIVE NO.:   22.

COLLECTOR TILT:   42.00 (DEGREES)             COLLECTOR AZIMUTH:    0.0  (DEGREES)

LATITUDE:    32.67 (DEGREES)                  RUN DATE:  6/04/79


           *         *         *         *         *         *         *         *
  MONTH    *  HOBAR  *   HBAR  *   KBAR  *   RBAR  *   SBAR  *   HDD   *   CDD   *   TBAR
           *         *         *         *         *         *         *         *
**************************************************************************************************
           *         *         *         *         *         *         *         *
JAN        *   1716. *   977.  * 0.56944 *  1.608  *  1571.  *     314 *      10 *     55.
           *         *         *         *         *         *         *         *
FEB        *   2143. *  1268.  * 0.59174 *  1.385  *  1757.  *     237 *       0 *     57.
           *         *         *         *         *         *         *         *
MAR        *   2665. *  1633.  * 0.61286 *  1.158  *  1892.  *     219 *       0 *     58.
           *         *         *         *         *         *         *         *
APR        *   3168. *  1936.  * 0.61101 *  0.958  *  1855.  *     144 *      15 *     61.
           *         *         *         *         *         *         *         *
MAY        *   3490. *  2002.  * 0.57365 *  0.837  *  1676.  *      79 *      26 *     63.
           *         *         *         *         *         *         *         *
JUN        *   3609. *  2061.  * 0.57110 *  0.789  *  1626.  *      52 *      67 *     66.
           *         *         *         *         *         *         *         *
JUL        *   3541. *  2186.  * 0.61741 *  0.805  *  1761.  *       6 *     149 *     70.
           *         *         *         *         *         *         *         *
AUG        *   3284. *  2057.  * 0.62650 *  0.902  *  1857.  *       0 *     201 *     71.
           *         *         *         *         *         *         *         *
SEP        *   2841. *  1718.  * 0.60482 *  1.071  *  1840.  *      16 *     163 *     70.
           *         *         *         *         *         *         *         *
OCT        *   2292. *  1375.  * 0.60007 *  1.307  *  1797.  *      43 *      77 *     66.
           *         *         *         *         *         *         *         *
NOV        *   1813. *  1062.  * 0.58554 *  1.553  *  1649.  *     140 *      14 *     61.
           *         *         *         *         *         *         *         *
DEC        *   1594. *   903.  * 0.56673 *  1.684  *  1521.  *     257 *       0 *     57.
           *         *         *         *         *         *         *


LEGEND:

  HOBAR ==>  MONTHLY AVERAGE DAILY EXTRATERRESTRIAL RADIATION (IDEAL) IN BTU/DAY-FT2.
  HBAR  ==>  MONTHLY AVERAGE DAILY RADIATION (ACTUAL) IN BTU/DAY-FT2.
  KBAR  ==>  RATIO OF HBAR TO HOBAR.
  RBAR  ==>  RATIO OF MONTHLY AVERAGE DAILY RADIATION ON TILTED SURFACE TO THAT ON A
             HORIZONTAL SURFACE FOR EACH MONTH (I.E., MULTIPLIER OBTAINED BY TILTING).
  SBAR  ==>  MONTHLY AVERAGE DAILY RADIATION ON A TILTED SURFACE (I.E., RBAR * HBAR) IN BTU/DAY-FT2.
  HDD   ==>  NUMBER OF HEATING DEGREE DAYS PER MONTH.
  CDD   ==>  NUMBER OF COOLING DEGREE DAYS PER MONTH.
  TBAR  ==>  AVERAGE AMBIENT TEMPERATURE IN DEGREES FAHRENHEIT.
```

APPENDIX D

MONTHLY SOLAR ENERGY DISTRIBUTION FLOWCHARTS

The flowcharts in this appendix depict the quantity of solar energy corresponding to each major component or characteristic of the Facilities Development Gas Company solar energy system for 7 months of the reporting period. Each monthly flowchart represents a solar energy balance as the total input equals the total output.



* Denotes Unavailable Data

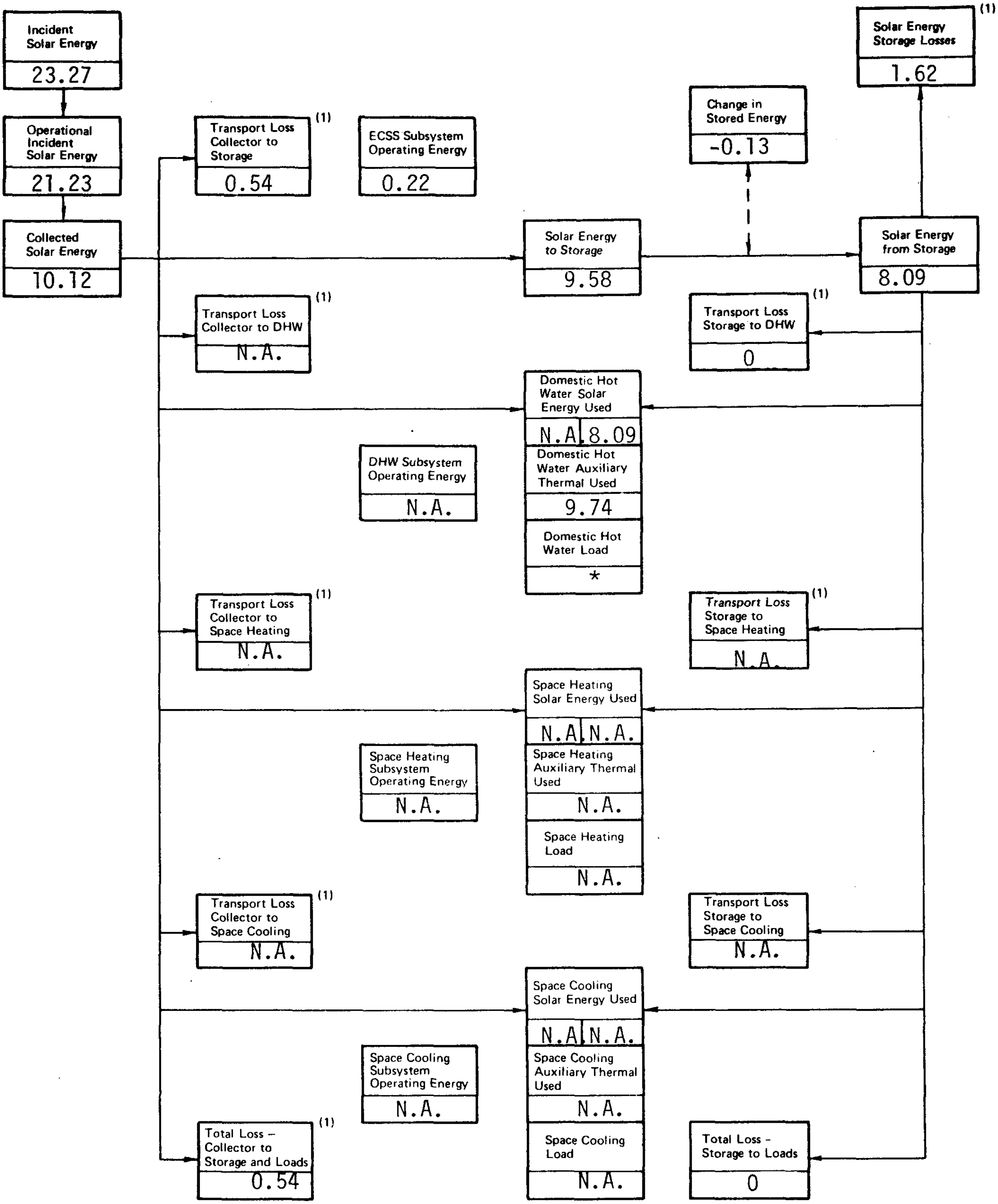
N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - SEPTEMBER 1978

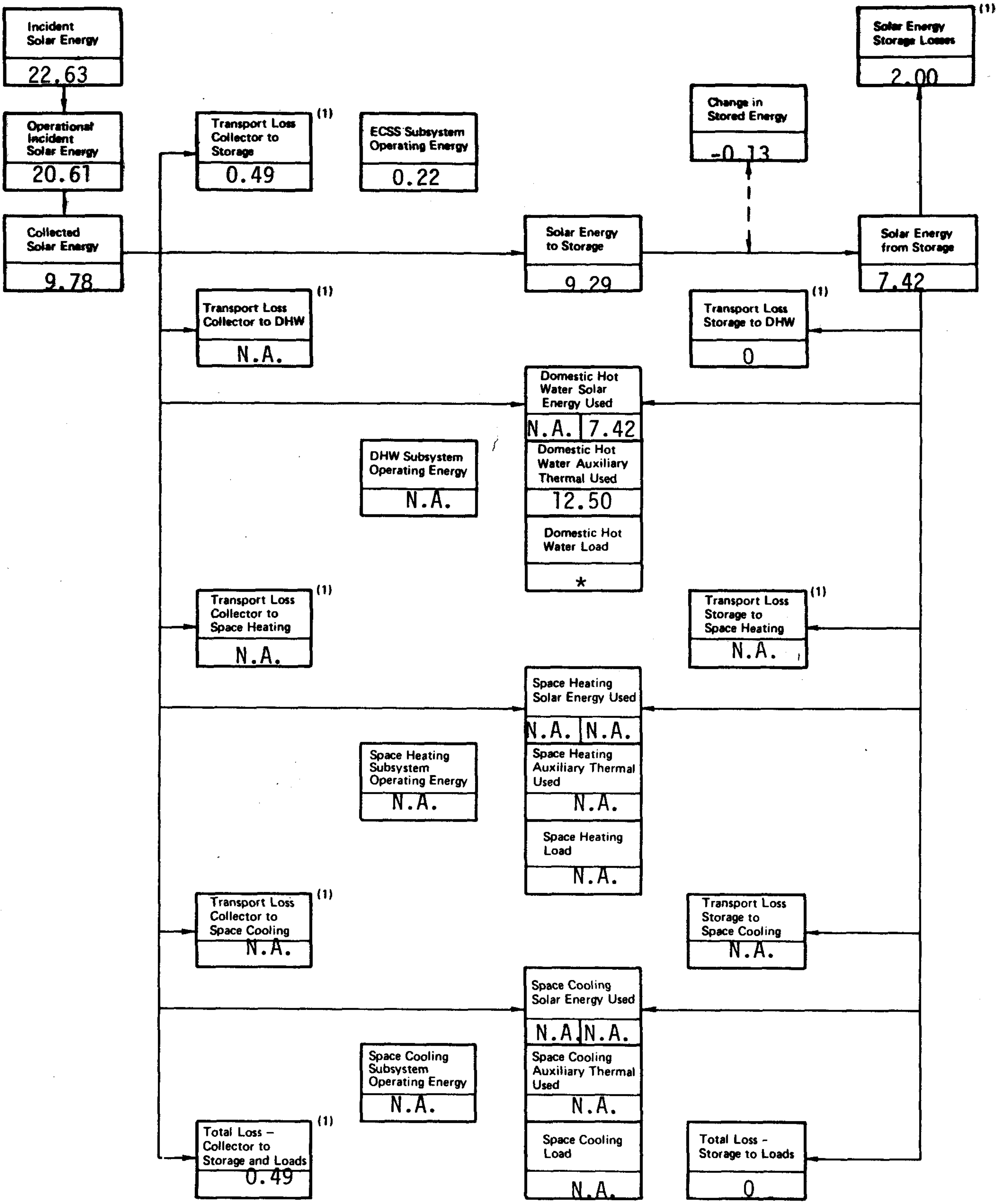
FACILITIES DEVELOPMENT GAS COMPANY



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

FIGURE D-2. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - OCTOBER 1978

FACILITIES DEVELOPMENT GAS COMPANY



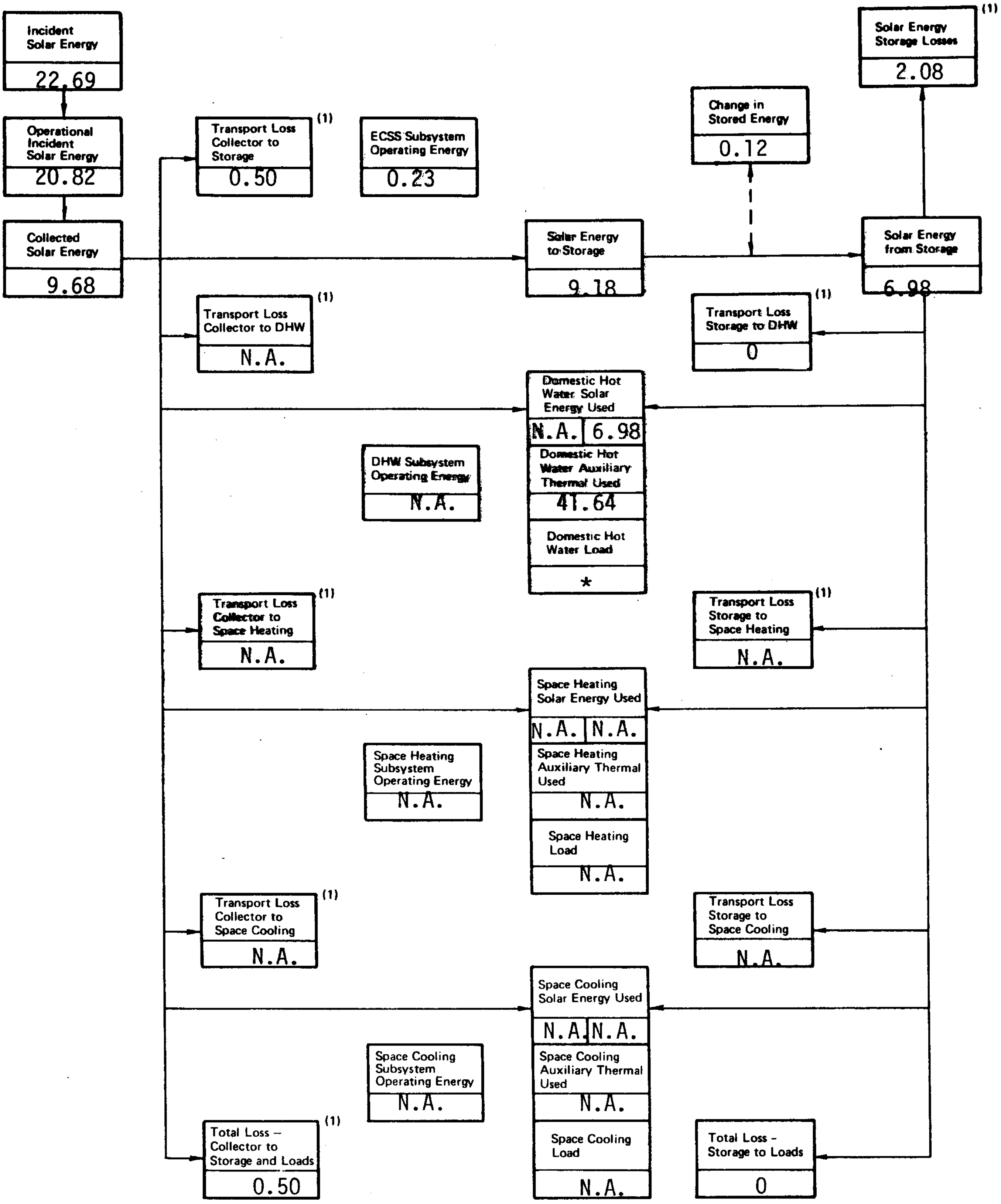
* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

FIGURE D-3. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - NOVEMBER 1978

FACILITIES DEVELOPMENT GAS COMPANY

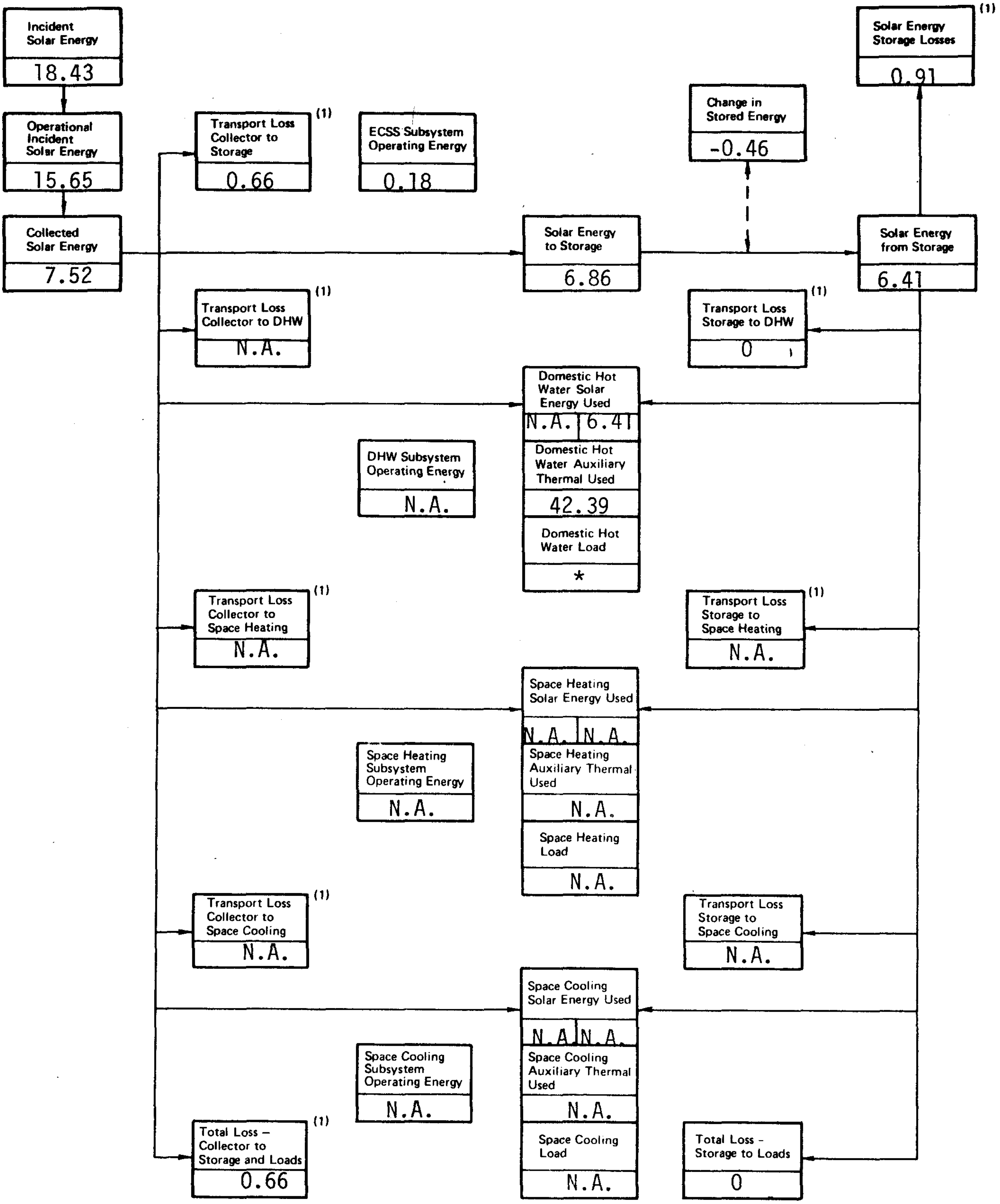


* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

FIGURE D-4. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - DECEMBER 1978
FACILITIES DEVELOPMENT GAS COMPANY



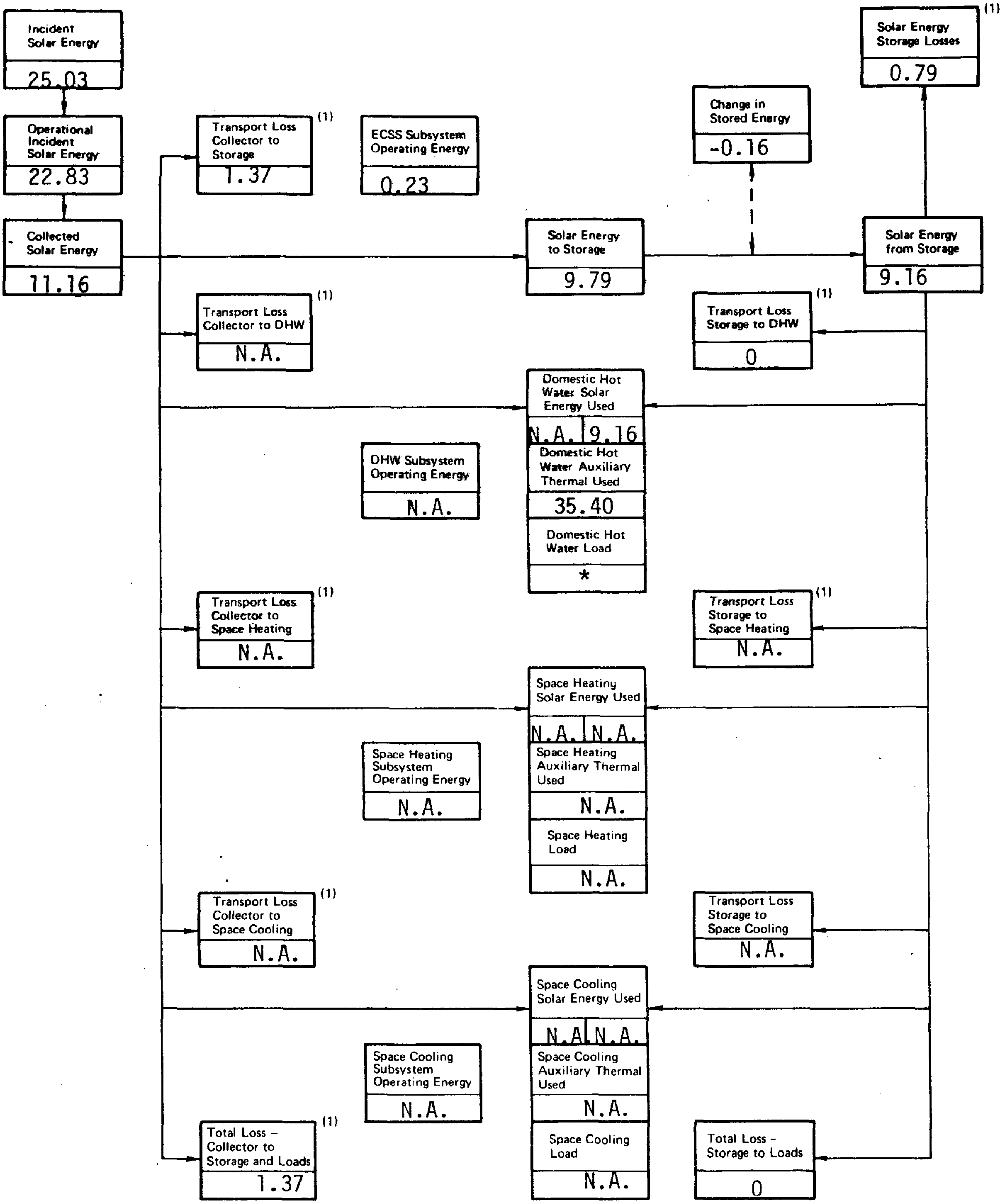
* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

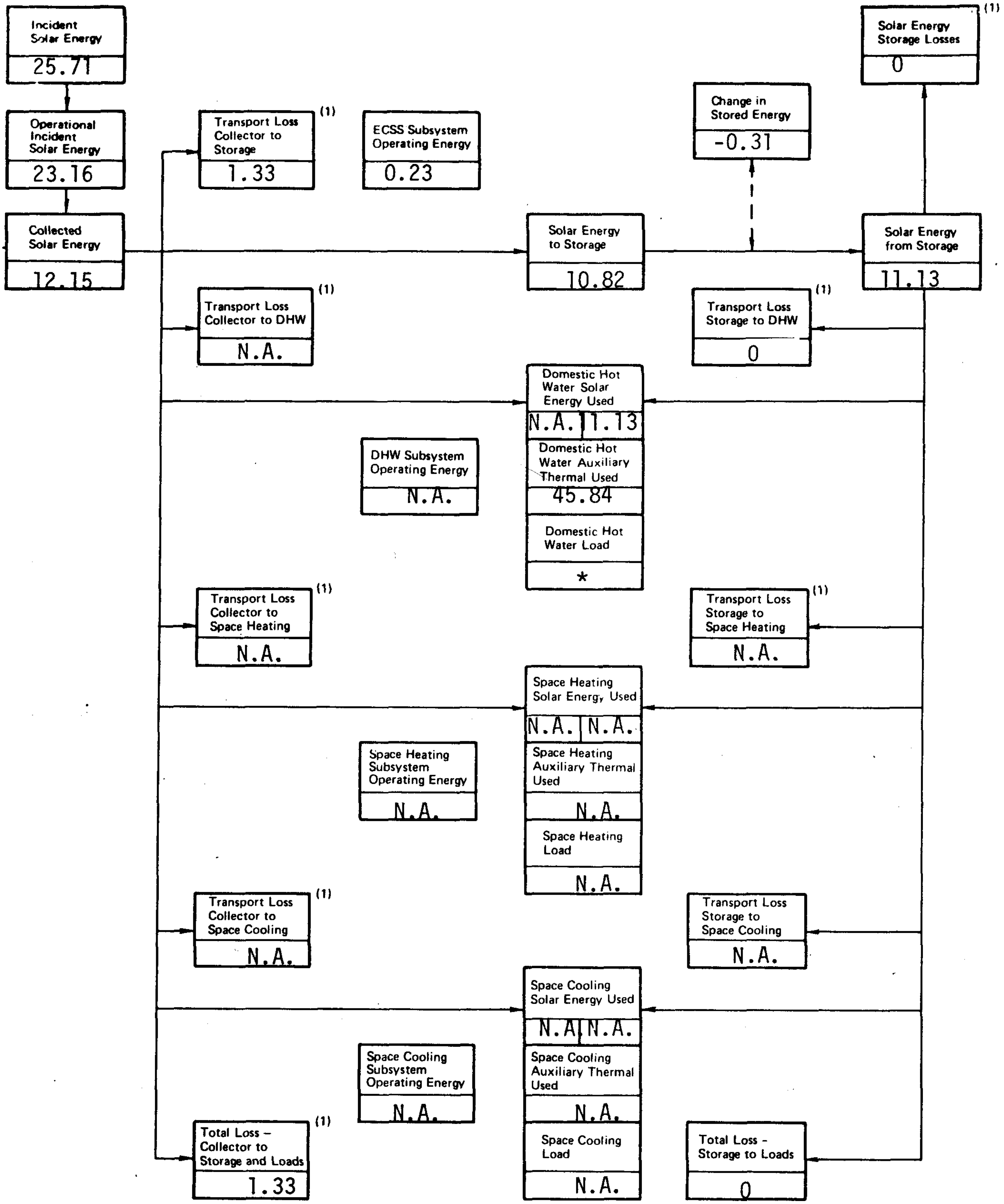
FIGURE D-5. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - JANUARY 1979
FACILITIES DEVELOPMENT GAS COMPANY



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-6. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - FEBRUARY 1979
FACILITIES DEVELOPMENT GAS COMPANY



* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-7. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - MARCH 1979
FACILITIES DEVELOPMENT GAS COMPANY

APPENDIX E

MONTHLY SOLAR ENERGY DISTRIBUTIONS

The data tables provided in this appendix present an indication of solar energy distribution, intentional and unintentional, in the Facilities Development Gas Company solar energy system. Tables are provided for 7 months of the reporting period.

TABLE E-1. SOLAR ENERGY DISTRIBUTION SEPTEMBER 1978
FACILITIES DEVELOPMENT GAS COMPANY

- $\frac{10.22}{100\%}$ million Btu TOTAL SOLAR ENERGY COLLECTED
  - $\frac{7.59}{74\%}$ million Btu SOLAR ENERGY TO LOADS
    - $\frac{7.59}{74\%}$ million Btu SOLAR ENERGY TO DHW SUBSYSTEM
    - $\frac{\text{N.A.}}{\%}$ million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - $\frac{\text{N.A.}}{\%}$ million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - $\frac{2.66}{26\ \%}$ million Btu SOLAR ENERGY LOSSES
    - $\frac{2.05}{20\%}$ million Btu SOLAR ENERGY LOSS FROM STORAGE
    - $\frac{0.61}{6\%}$ million Btu SOLAR ENERGY LOSS IN TRANSPORT
      - $\frac{0.61}{6\%}$ million Btu COLLECTOR TO STORAGE LOSS
      - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO LOAD LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO DHW LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO SPACE HEATING LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO SPACE COOLING LOSS
      - $\frac{*}{\%}$ million Btu STORAGE TO LOAD LOSS
        - $\frac{*}{\%}$ million Btu STORAGE TO DHW LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO SPACE HEATING LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO SPACE COOLING LOSS
  - $\frac{-0.03}{0\%}$ million Btu SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data
N.A. - Denotes not applicable data

TABLE E-2. SOLAR ENERGY DISTRIBUTION OCTOBER 1978
FACILITIES DEVELOPMENT GAS COMPANY

- 10.12 / 100% million Btu TOTAL SOLAR ENERGY COLLECTED
  - 8.09 / 80% million Btu SOLAR ENERGY TO LOADS
    - 8.09 / 80% million Btu SOLAR ENERGY TO DHW SUBSYSTEM
    - N.A. / % million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - N.A. / % million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - 2.16 / 21% million Btu SOLAR ENERGY LOSSES
    - 1.62 / 16% million Btu SOLAR ENERGY LOSS FROM STORAGE
    - 0.54 / 5% million Btu SOLAR ENERGY LOSS IN TRANSPORT
      - 0.54 / 5% million Btu COLLECTOR TO STORAGE LOSS
      - N.A. / % million Btu COLLECTOR TO LOAD LOSS
        - N.A. / % million Btu COLLECTOR TO DHW LOSS
        - N.A. / % million Btu COLLECTOR TO SPACE HEATING LOSS
        - N.A. / % million Btu COLLECTOR TO SPACE COOLING LOSS
      - N.A. / % million Btu STORAGE TO LOAD LOSS
        - N.A. / % million Btu STORAGE TO DHW LOSS
        - N.A. / % million Btu STORAGE TO SPACE HEATING LOSS
        - N.A. / % million Btu STORAGE TO SPACE COOLING LOSS
  - -0.13 / -1% million Btu SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

TABLE E-3. SOLAR ENERGY DISTRIBUTION NOVEMBER 1978
FACILITIES DEVELOPMENT GAS COMPANY

- 9.78 million Btu TOTAL SOLAR ENERGY COLLECTED
  100%
  - 7.42 million Btu SOLAR ENERGY TO LOADS
    76%
    - 7.42 million Btu SOLAR ENERGY TO DHW SUBSYSTEM
      76%
    - N.A. million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
      %
    - N.A. million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
      %
  - 2.49 million Btu SOLAR ENERGY LOSSES
    25%
    - 2.00 million Btu SOLAR ENERGY LOSS FROM STORAGE
      20%
    - 0.49 million Btu SOLAR ENERGY LOSS IN TRANSPORT
      5%
      - 0.49 million Btu COLLECTOR TO STORAGE LOSS
        5%
      - N.A. million Btu COLLECTOR TO LOAD LOSS
        %
        - N.A. million Btu COLLECTOR TO DHW LOSS
          %
        - N.A. million Btu COLLECTOR TO SPACE HEATING LOSS
          %
        - N.A. million Btu COLLECTOR TO SPACE COOLING LOSS
          %
      - N.A. million Btu STORAGE TO LOAD LOSS
        %
        - N.A. million Btu STORAGE TO DHW LOSS
          %
        - N.A. million Btu STORAGE TO SPACE HEATING LOSS
          %
        - N.A. million Btu STORAGE TO SPACE COOLING LOSS
          %
  - -0.13 million Btu SOLAR ENERGY STORAGE CHANGE
    -1%

N.A. - Denotes not applicable data

TABLE E-4. SOLAR ENERGY DISTRIBUTION DECEMBER 1978
FACILITIES DEVELOPMENT GAS COMPANY

- $\frac{9.68}{100\%}$ million Btu TOTAL SOLAR ENERGY COLLECTED
    - $\frac{6.98}{72\%}$ million Btu SOLAR ENERGY TO LOADS
        - $\frac{6.98}{72\%}$ million Btu SOLAR ENERGY TO DHW SUBSYSTEM
        - $\frac{\text{N.A.}}{\%}$ million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
        - $\frac{\text{N.A.}}{\%}$ million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
    - $\frac{2.58}{27\%}$ million Btu SOLAR ENERGY LOSSES
        - $\frac{2.08}{22\%}$ million Btu SOLAR ENERGY LOSS FROM STORAGE
        - $\frac{0.50}{5\%}$ million Btu SOLAR ENERGY LOSS IN TRANSPORT
            - $\frac{0.50}{5\%}$ million Btu COLLECTOR TO STORAGE LOSS
            - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO LOAD LOSS
                - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO DHW LOSS
                - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO SPACE HEATING LOSS
                - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO SPACE COOLING LOSS
            - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO LOAD LOSS
                - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO DHW LOSS
                - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO SPACE HEATING LOSS
                - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO SPACE COOLING LOSS
    - $\frac{0.12}{1\%}$ million Btu SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

TABLE E-5. SOLAR ENERGY DISTRIBUTION JANUARY 1979
FACILITIES DEVELOPMENT GAS COMPANY

- 7.52 / 100% million Btu TOTAL SOLAR ENERGY COLLECTED
  - 6.41 / 85% million Btu SOLAR ENERGY TO LOADS
    - 6.41 / 85% million Btu SOLAR ENERGY TO DHW SUBSYSTEM
    - N.A. / % million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - N.A. / % million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - 1.57 / 21% million Btu SOLAR ENERGY LOSSES
    - 0.91 / 12% million Btu SOLAR ENERGY LOSS FROM STORAGE
    - 0.66 / 9% million Btu SOLAR ENERGY LOSS IN TRANSPORT
      - 0.66 / 9% million Btu COLLECTOR TO STORAGE LOSS
      - N.A. / % million Btu COLLECTOR TO LOAD LOSS
        - N.A. / % million Btu COLLECTOR TO DHW LOSS
        - N.A. / % million Btu COLLECTOR TO SPACE HEATING LOSS
        - N.A. / % million Btu COLLECTOR TO SPACE COOLING LOSS
      - N.A. / % million Btu STORAGE TO LOAD LOSS
        - N.A. / % million Btu STORAGE TO DHW LOSS
        - N.A. / % million Btu STORAGE TO SPACE HEATING LOSS
        - N.A. / % million Btu STORAGE TO SPACE COOLING LOSS
  - -0.46 / -6% million Btu SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

TABLE E-6. SOLAR ENERGY DISTRIBUTION FEBRUARY 1979
FACILITIES DEVELOPMENT GAS COMPANY

- $\frac{11.16}{100\%}$ million Btu TOTAL SOLAR ENERGY COLLECTED
  - $\frac{9.16}{82\%}$ million Btu SOLAR ENERGY TO LOADS
    - $\frac{9.16}{82\%}$ million Btu SOLAR ENERGY TO DHW SUBSYSTEM
    - $\frac{\text{N.A.}}{\%}$ million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - $\frac{\text{N.A.}}{\%}$ million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - $\frac{2.16}{19\%}$ million Btu SOLAR ENERGY LOSSES
    - $\frac{0.79}{7\%}$ million Btu SOLAR ENERGY LOSS FROM STORAGE
    - $\frac{1.37}{12\%}$ million Btu SOLAR ENERGY LOSS IN TRANSPORT
      - $\frac{1.37}{12\%}$ million Btu COLLECTOR TO STORAGE LOSS
      - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO LOAD LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO DHW LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO SPACE HEATING LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO SPACE COOLING LOSS
      - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO LOAD LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO DHW LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO SPACE HEATING LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO SPACE COOLING LOSS
  - $\frac{-0.16}{-1\%}$ million Btu SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

TABLE E-7. SOLAR ENERGY DISTRIBUTION MARCH 1979
FACILITIES DEVELOPMENT GAS COMPANY

- $\frac{12.15}{100\%}$ million Btu TOTAL SOLAR ENERGY COLLECTED
  - $\frac{11.13}{92\ \%}$ million Btu SOLAR ENERGY TO LOADS
    - $\frac{11.13}{92\ \%}$ million Btu SOLAR ENERGY TO DHW SUBSYSTEM
    - $\frac{\text{N.A.}}{\%}$ million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - $\frac{\text{N.A.}}{\%}$ million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - $\frac{1.33}{11\ \%}$ million Btu SOLAR ENERGY LOSSES
    - $\frac{0}{\%}$ million Btu SOLAR ENERGY LOSS FROM STORAGE
    - $\frac{1.33}{11\ \%}$ million Btu SOLAR ENERGY LOSS IN TRANSPORT
      - $\frac{1.33}{11\%}$ million Btu COLLECTOR TO STORAGE LOSS
      - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO LOAD LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO DHW LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO SPACE HEATING LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu COLLECTOR TO SPACE COOLING LOSS
      - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO LOAD LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO DHW LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO SPACE HEATING LOSS
        - $\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO SPACE COOLING LOSS
  - $\frac{-0.31}{-3\%}$ million Btu SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data