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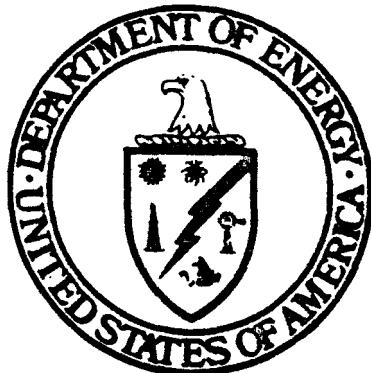
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SOLAR/1002-79/14

Solar Energy System Performance Evaluation

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**WASHINGTON NATURAL GAS CO.
SINGLE-FAMILY RESIDENCE
Kirkland, Washington
January 1979 Through March 1979**



U.S. Department of Energy

**National Solar Heating and
Cooling Demonstration Program**

National Solar Data Program

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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

WASHINGTON NATURAL GAS COMPANY
KIRKLAND, WASHINGTON

JANUARY 1979 THROUGH MARCH 1979

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UNDER CONTRACT EG-77-C-01-4049
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TABLE OF CONTENTS

	<u>Page</u>
1. FOREWORD	1-1
2. SUMMARY AND CONCLUSIONS.	2-1
2.1 Performance Summary	2-1
2.2 Conclusions	2-2
3. SYSTEM DESCRIPTION	3-1
4. PERFORMANCE EVALUATION TECHNIQUES	4-1
5. PERFORMANCE ASSESSMENT	5-1
5.1 Weather Conditions	5-2
5.2 System Thermal Performance	5-4
5.3 Subsystem Performance	5-9
5.3.1 Collector Array and Storage Subsystem.	5-9
5.3.1.1 Collector Array	5-9
5.3.1.2 Storage	5-12
5.3.2 Domestic Hot Water (DHW) Subsystem	5-15
5.3.3 Space Heating Subsystem	5-17
5.4 Operating Energy.	5-17
5.5 Energy Savings	5-20
6. REFERENCES	6-1
7. BIBLIOGRAPHY	7-1
APPENDIX A DEFINITIONS OF PERFORMANCE FACTORS AND SOLAR TERMS	A-1
APPENDIX B SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS	B-1
APPENDIX C LONG-TERM AVERAGE WEATHER CONDITIONS	C-1
APPENDIX D MONTHLY SOLAR ENERGY DISTRIBUTION FLOWCHARTS	D-1
APPENDIX E MONTHLY SOLAR ENERGY DISTRIBUTIONS	E-1

LIST OF ILLUSTRATIONS

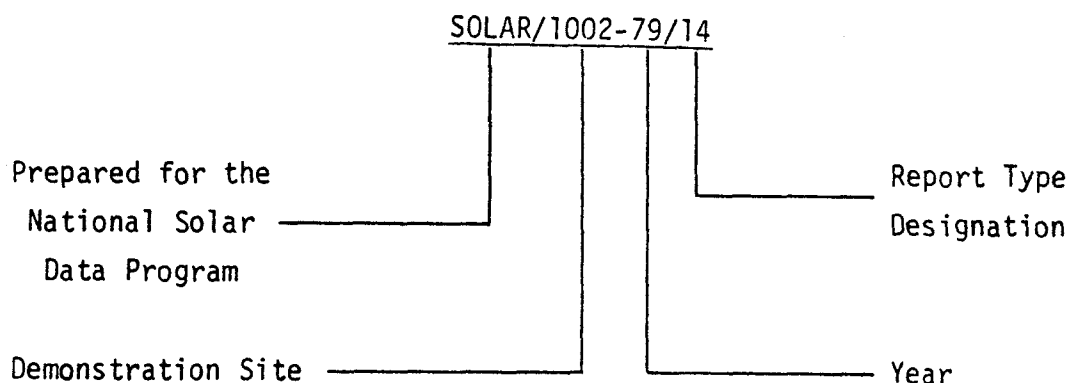
FIGURES	TITLE	PAGE
3-1	Solar Energy System Schematic	3-2
5-1	Solar Energy Distribution Flowchart - Summary	5-6
D-1	Solar Energy Distribution Flowchart - January 1979	D-2
D-2	Solar Energy Distribution Flowchart - February 1979	D-3
D-3	Solar Energy Distribution Flowchart - March 1979	D-4

LIST OF TABLES

TABLES	TITLE	PAGE
5-1	Weather Conditions	5-3
5-2	System Thermal Performance Summary	5-5
5-3	Solar Energy Distribution Summary	5-7
5-4	Solar Energy System Coefficient of Performance	5-8
5-5	Collector Array Performance	5-10
5-6	Storage Performance	5-13
5-7	Solar Energy Losses - Storage and Transport	5-14
5-8	Domestic Hot Water Subsystem Performance	5-16
5-9	Space Heating Subsystem Performance	5-18
5-10	Operating Energy	5-19
5-11	Energy Savings	5-21
E-1	Solar Energy Distribution - January 1979	E-2
E-2	Solar Energy Distribution - February 1979	E-3
E-3	Solar Energy Distribution - March 1979	E-4

NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under specific format. For example, this report for the Washington Natural Gas Company project site is designated as SOLAR/1002-79/14. The elements of this designation are explained in the following illustration.



o Demonstration Site Number:

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

o 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 in order 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:

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

The International Business Machines 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 Solar Energy 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 Washington Natural 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 Washington Natural Gas Company solar energy system. The analysis covers operation of the system from January 1979 through March 1979. The Washington Natural Gas Company solar energy system provides domestic hot water (DHW) and space heating to a single-family dwelling located in Kirkland, Washington. 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 a summary of the performance of the solar energy system installed at Washington Natural Gas Company, located in Kirkland, Washington for the period January 1979 through March 1979. This solar energy system is designed to support the space heating and DHW loads. A detailed description of Washington Natural Gas Company solar energy system operation is presented in Section 3.

2.1 Performance Summary

The solar energy site was occupied from January 1979 through March 1979 and the solar energy system was operational during this reporting period. The total incident solar energy was 37.22 million Btu, of which 10.81 million Btu were collected by the solar energy system. Solar energy satisfied 31 percent of the DHW requirements and 14 percent of the space heating requirements. The solar energy system incurred an electrical expense of 1.54 million Btu and a fossil fuel savings of 6.16 million Btu.

During the period from January 1979 through March 1979 the system operated without any major interruptions. The solar energy system performed somewhat poorer than expected to the extent that the amount of solar energy used to satisfy the loads was less than expected: for January the actual solar fraction was 11 percent versus an expected solar fraction of 25 percent, for February the actual solar fraction was 18 percent versus an expected solar fraction of 8 percent, and for March the actual solar fraction was 35 percent versus an estimated 72 percent.

For all three months the actual collected solar energy exceeded the estimated solar energy collected. January actual was 3.59 million Btu versus an estimated 1.34 million Btu, February actual was 1.97 million Btu versus an estimated 0.34 million Btu, and the March actual was 5.25 million Btu versus an estimated 3.50 million Btu.

This site was designed with south-facing windows to allow a passive solar contribution to the space heating load. This passive contribution is not measurable with the installed instrumentation and the drapes for these windows were not installed until the spring of 1979. Therefore, although there was some passive space heating, there was also some loss of heat through these windows during periods of low insolation and at night.

2.2 Conclusions

In January 1979, Boeing completed its air flow survey of the complete system using newly installed air-flow sensors. An air-flow sensor is normally placed in the ductwork at a location where it will sense the average velocity of the air going through the duct. This procedure is good for all air-flow sensors with the exception of W200, which must measure the air flow entering rock storage when energy is being taken out of storage and the air flow leaving rock storage when energy is being put into storage. Because the air flow in this duct is bidirectional, depending upon whether the air is entering or leaving storage, and because of bends in the ductwork, the point of average velocity is not the same for air entering storage as it is for air leaving storage. Therefore, the air-flow sensor was placed at the average velocity point for air entering storage and software modifications are made to the sensor readings to determine the average velocity of the air leaving rock storage.

This solar energy system was designed so that a portion of the return air from conditioned space goes through rock storage in both the storage-to-space-heating mode and in the auxiliary space-heating mode. Under normal circumstances this is desirable, since rock storage is usually warmer than the return air and the return air is preheated prior to its entering the auxiliary heater. However, during the month of February the weather was extremely harsh; very cold temperatures and very low insolation resulted in an unusual situation: rock storage became colder than the return air from conditioned space. This situation resulted in having the auxiliary heat source supplying heat to rock storage as well as to the conditioned space which increased the amount of fossil fuel used over and above that which would have been required to just heat the conditioned space.

During the months of January and March the solar energy system collected more energy than expected, but it consumed less energy than expected. This is due to the way the control system sequences the air handler and the auxiliary heating system. Regardless of the amount of energy in rock storage, the auxiliary heating system is turned on no more than five minutes after the air handler is turned on. This does not give the storage subsystem enough time to satisfy the space heating needs. This also causes the solar fraction of the space heating subsystem to be lower than expected.

3. SYSTEM DESCRIPTION

The Washington Natural Gas Company site is a single-family residence in Kirkland, Washington. The home has approximately 2607 square feet of conditioned space. Solar energy is used for space heating the home and preheating domestic hot water (DHW). The solar energy system has an array of flat-plate collectors with a gross area of 591 square feet. The array faces south at an angle of 57 degrees to the horizontal. Air is the transfer medium that delivers solar energy from the collector array to storage and to the space heating and hot water loads. Solar energy is stored underground in a 273-cubic-foot bin containing 27,300 pounds of smooth stones. The bin has two inches of styrofoam insulation. Preheated city water is stored in an 80-gallon preheat storage tank and supplied, on demand, to a conventional 50-gallon DHW tank. When solar energy is insufficient to satisfy the space heating load, a gas furnace provides auxiliary energy for space heating. Similarly, a gas-fired unit in the DHW tank provides auxiliary energy for water heating. The system, shown schematically in Figure 3-1, has four modes of solar operation.

Mode 1 - Collector-to-Storage: This mode activates when there is no demand for space heating, and the temperature of the collector outlet exceeds that of the solar energy storage bin as measured by the control system sensors. Air circulates from the collector, through the air-to-liquid heat exchanger, through the air-handling unit and then through the solar energy storage bin to the collector. This mode exists as long as the temperature of the storage bin does not exceed 140°F.

Mode 2 - Storage-to-Space Heating: This mode activates when space heating is required, the solar insolation is insufficient to furnish the required energy from the collector, and the temperature of the solar energy storage bin is higher than 90°F, as indicated by the control system sensors. Air circulates from the solar energy storage bin, through the air-handling unit and gas furnace, then returns to the storage bin, bypassing the collectors.

Mode 3 - Collector-to-DHW Tank: This mode activates during the summer when the collector outlet temperature is higher than the temperature of the water

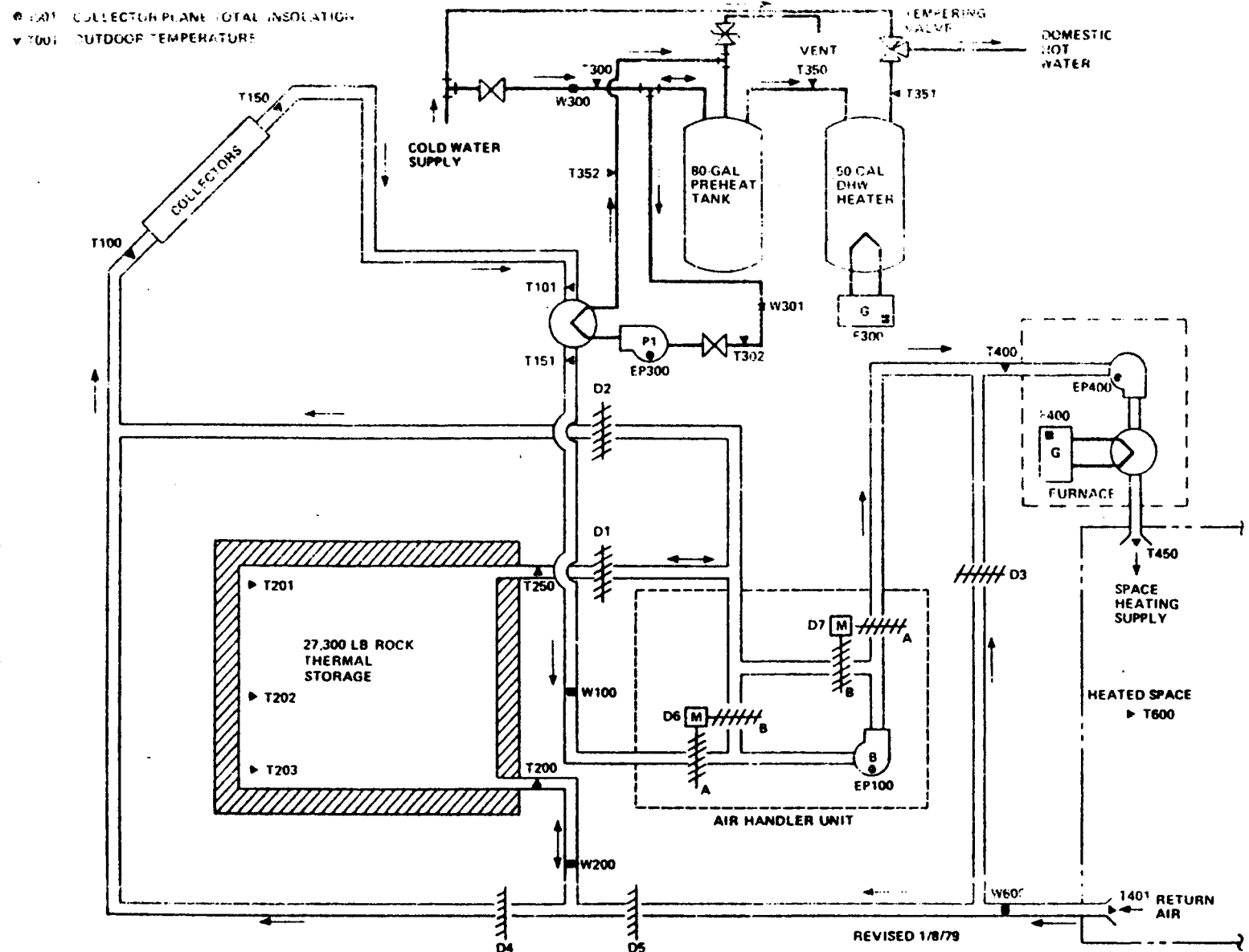


FIGURE 3-1. SOLAR ENERGY SYSTEM SCHEMATIC

WASHINGTON NATURAL GAS COMPANY

in the preheat tank as indicated by the control system sensors. Air circulates from the collector, through the air-to-liquid heat exchanger and the air-handling unit, and returns to the collectors, bypassing the solar energy storage bin. Domestic water preheating also occurs in modes 1 and 4.

Mode 4 - Collector-to-Space Heating: This mode activates when the collector is operating and the plenum temperature at the top of storage, as indicated by the control system sensors, is higher than the minimum value suitable for supplying heat to the house. Heated air is circulated through the house by the air-handling unit before being returned to the collector.

4. PERFORMANCE EVALUATION TECHNIQUES

The performance of the Washington Natural 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 the calculation of 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 Washington Natural Gas Company site and a detailed subsystem analysis is published. These monthly reports for the period covered by this System Performance Evaluation January 1979 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. 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 Washington Natural Gas Company solar energy system has been evaluated for the January 1979 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. The f-chart is a performance estimation technique used for designing solar heating systems. It was developed by the Solar Energy Laboratory, University of Wisconsin - Madison. The system mode 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 space heating and domestic hot water (DHW) subsystems. 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 Washington Natural 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.

From January 1979 through March 1979 the average daily total incident solar energy on the collector array was 690 Btu per square foot per day. This was below the estimated average daily solar radiation for this geographical area during the reporting period of 769 Btu per square foot per day for a south-facing plane with a tilt of 57 degrees to the horizontal. The average ambient temperature during January 1979 through March 1979 was 42°F as compared with the long-term average for January through March of 41°F. The number of heating degree-days for the same period (based on a 65°F reference) was 675, as compared with the summation of the long-term averages of 705. The number of cooling degree-days for the same period (based on a 65°F reference) was zero, as compared with the summation of the long-term averages of zero.

Monthly values of heating and cooling degree-days are derived from daily values of ambient temperature. They are useful indications of the system heating and cooling loads. 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
WASHINGTON NATURAL 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
JAN	591	465	36	38	899	831	0	0
FEB	410	771	42	42	629	636	0	0
MAR	1,070	1,070	49	44	496	648	0	0
TOTAL					2,024	2,115	0	0
AVERAGE	690	769	42	41	675	705	0	0

(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 Washington Natural Gas Company solar energy system is presented in Table 5-2. This performance assessment is based on the 3-month period from January 1979 to March 1979. During the reporting period, a total of 10.81 million Btu of solar energy was collected and the total system load was 20.56 million Btu. The measured amount of solar energy delivered to the load subsystems was 3.69 million Btu or 1.49 million Btu less than the expected value. The measured system solar fraction was 21 percent as compared to an expected value of 35 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 Washington Natural Gas Company solar energy system for the total reporting period. 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 January 1979 through March 1979, the load subsystems consumed 33 percent of the energy collected and 67 percent was lost. Appendix E contains the monthly solar energy percentage distributions.

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

TABLE 5-2. SYSTEM THERMAL PERFORMANCE SUMMARY

WASHINGTON NATURAL GAS COMPANY

MONTH	SOLAR ENERGY COLLECTED (Million Btu)	SYSTEM LOAD (Million Btu)	SOLAR ENERGY USED (Million Btu)		SOLAR FRACTION (%)	
			EXPECTED	MEASURED	EXPECTED	MEASURED
JAN	3.59	11.64	1.34	1.25	25	11
FEB	1.97	4.19	0.34	0.73	8	18
MAR	5.25	4.84	3.50	1.71	72	35
TOTAL	10.81	20.56	5.18	3.69		
AVERAGE	3.60	6.85	1.73	1.23	35	21

WASHINGTON NATURAL GAS COMPANY



TABLE 5-3. SOLAR ENERGY DISTRIBUTION SUMMARY - JANUARY THROUGH MARCH 1979
WASHINGTON NATURAL GAS COMPANY

$\frac{10.81}{100\%}$ million Btu TOTAL SOLAR ENERGY COLLECTED

$\frac{3.60}{33\%}$ million Btu SOLAR ENERGY TO LOADS

$\frac{1.35}{12\%}$ million Btu SOLAR ENERGY TO DHW SUBSYSTEM

$\frac{2.25}{21\%}$ million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM

$\frac{\text{N.A.}}{\%}$ million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM

$\frac{7.09}{66\%}$ million Btu SOLAR ENERGY LOSSES

$\frac{3.91}{36\%}$ million Btu SOLAR ENERGY LOSS FROM STORAGE

$\frac{3.81}{30\%}$ million Btu SOLAR ENERGY LOSS IN TRANSPORT

$\frac{*}{\%}$ million Btu COLLECTOR TO STORAGE LOSS

$\frac{*}{\%}$ million Btu COLLECTOR TO LOAD LOSS

$\frac{*}{\%}$ million Btu COLLECTOR TO DHW LOSS

$\frac{*}{\%}$ 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

$\frac{\text{N.A.}}{\%}$ million Btu STORAGE TO DHW LOSS

$\frac{*}{\%}$ 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

* - Denotes unavailable data 5-7

N.A. - Denotes not applicable data

TABLE 5-4. SOLAR ENERGY SYSTEM COEFFICIENT OF PERFORMANCE
WASHINGTON NATURAL 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
JAN	1.69	5.89	18.50	15.60	N.A.
FEB	1.45	4.48	32.00	7.00	N.A.
MAR	3.42	12.50	16.50	26.25	N.A.
WEIGHTED AVERAGE	2.13	7.35	19.29	15.00	N.A.

N.A. - Denotes not applicable data

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 Washington Natural Gas Company functioned at a weighted average COP value of 2.13 for the reporting period January 1979 through March 1979.

5.3 Subsystem Performance

The Washington Natural Gas Company solar energy installation may be divided into three subsystems:

1. Collector Array and Storage
2. Domestic Hot Water
3. Space Heating

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

5.3.1 Collector Array and Storage Subsystem

5.3.1.1 Collector Array

Collector array performance for the Washington Natural Gas Company site is presented in Table 5-5. The total incident solar radiation on the collector array for the period January 1979 through March 1979 was 37.22 million Btu. During the period the collector loop was operating the total insolation amounted to 27.98 million Btu. The total collected solar energy for the period was 10.81 million Btu, resulting in a collector array efficiency of 29 percent, based on total incident insolation. Solar energy delivered from the collector array to storage was 6.19 million Btu. Operating energy required by the collector loop was 1.47 million Btu.

TABLE 5-5. COLLECTOR ARRAY PERFORMANCE
WASHINGTON NATURAL 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 (%)
JAN	10.83	3.59	33	8.63	42
FEB	6.78	1.97	29	4.44	44
MAR	19.61	5.25	27	14.91	35
TOTAL	37.22	10.81		27.98	
AVERAGE	12.41	3.60	29	9.33	39

5-10

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 during the periods of collection only.

Evaluation of collector efficiency using operational incident energy and compensating for the difference between gross collector array area and the gross collector area yields 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 Storage

Storage performance data for the Washington Natural 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.

During the reporting period, total solar energy delivered to storage was 6.19 million Btu. There were 2.16 million Btu delivered from storage to the space heating subsystem. Energy loss from storage was 3.91 million Btu. This loss

TABLE 5-6. STORAGE PERFORMANCE
WASHINGTON NATURAL GAS COMPANY

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)
JAN	2.20	0.74	0.15	40	73	N.A.
FEB	1.13	0.39	-0.06	29	70	N.A.
MAR	2.86	1.03	0.03	37	107	N.A.
TOTAL	6.19	2.16	0.12			
AVERAGE	2.06	0.72	0.04	35	83	N.A.

N.A. - Denotes not applicable data

S002

TABLE 5-7. SOLAR ENERGY LOSSES – STORAGE AND TRANSPORT
WASHINGTON NATURAL GAS COMPANY

	MONTH						
	JAN	FEB	MAR				TOTAL
1. SOLAR ENERGY (SE) COLLECTED MINUS SE DIRECTLY TO LOADS (million Btu)	*	*	*				*
2. SE TO STORAGE (million Btu)	2.20	1.13	2.86				6.19
3. LOSS – COLLECTOR TO STORAGE (%) $\frac{1-2}{1}$	*	*	*				*
4. CHANGE IN STORED ENERGY (million Btu)	0.15	-0.06	0.03				0.12
5. SOLAR ENERGY – STORAGE TO DHW SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.				N.A.
6. SOLAR ENERGY – STORAGE TO SPACE HEATING SUBSYSTEM (million Btu)	0.74	0.39	1.03				2.16
7. SOLAR ENERGY – STORAGE TO SPACE COOLING SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.				N.A.
8. LOSS FROM STORAGE (%) $\frac{2 - (4+5+6+7)}{2}$	60	71	63				63
9. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million Btu)	N.A.	N.A.	N.A.				N.A.
10. LOSS – STORAGE TO HWSE (%) $\frac{5-9}{5}$	N.A.	N.A.	N.A.				N.A.
11. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million Btu)	0.74	0.39	1.03				2.16
12. LOSS – STORAGE TO HSE (%) $\frac{6-11}{6}$	*	*	*				*

S002

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

represented 63 percent of the energy delivered to storage. The storage efficiency was 35 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 83°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 Washington Natural Gas Company site for the reporting period is shown in Table 5-8. The DHW subsystem consumed 1.35 million Btu of solar energy and 5.11 million Btu of auxiliary fossil fuel energy to satisfy a hot water load of 4.42 million Btu. The solar fraction of this load was 30 percent.

TABLE 5-8. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE
WASHINGTON NATURAL GAS COMPANY

MONTH	DOMESTIC HOT WATER LOAD (Million Btu)	ENERGY CONSUMED (Million Btu)				SOLAR FRACTION (%)
		SOLAR	AUXILIARY THERMAL	AUXILIARY		
				ELECTRICAL	FOSSIL	
JAN	1.64	0.37	1.26	N.A.	2.10	23
FEB	1.40	0.32	1.08	N.A.	1.81	23
MAR	1.38	0.66	0.72	N.A.	1.20	48
TOTAL	4.42	1.35	3.06	N.A.	5.11	
AVERAGE	1.47	0.45	1.02	N.A.	1.70	31

N.A. - Denotes not applicable data

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 energy 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.

5.3.3 Space Heating Subsystem

The space heating subsystem performance for the Washington Natural Gas Company site for the reporting period is shown in Table 5-9. The space heating subsystem consumed 2.25 million Btu of solar energy and 23.21 million Btu of auxiliary fossil fuel energy to satisfy a space heating load of 16.27 million Btu. The solar fraction of this load was 14 percent.

The performance of the space heating subsystem is described by comparing the amount of solar energy supplied to the subsystem with the energy required to satisfy the total space heating load. The energy required to satisfy the total load consists of both solar energy and auxiliary thermal energy. The ratio of solar energy supplied to the load to the total load is defined as the heating solar fraction.

5.4 Operating Energy

Measured values of the Washington Natural Gas Company solar energy system and subsystem operating energy for the reporting period are presented in Table 5-10. A total of 2.56 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.

TABLE 5-9. SPACE HEATING SUBSYSTEM PERFORMANCE
WASHINGTON NATURAL GAS COMPANY

MONTH	SPACE HEATING LOAD (Million Btu)	ENERGY CONSUMED (Million Btu)				SOLAR FRACTION (%)
		SOLAR	AUXILIARY THERMAL	AUXILIARY		
				ELECTRICAL	FOSSIL	
JAN	10.02	0.78	9.15	N.A.	15.24	9
FEB	2.79	0.42	2.37	N.A.	3.95	15
MAR	3.46	1.05	2.41	N.A.	4.02	30
TOTAL	16.27	2.25	13.93	N.A.	23.21	
AVERAGE	5.42	0.75	4.64	N.A.	7.74	14

N.A. - Denotes not applicable data

S002

TABLE 5-10. OPERATING ENERGY

WASHINGTON NATURAL 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)
JAN	0.61	0.02	0.52	N.A.	1.15
FEB	0.44	0.01	0.38	N.A.	0.83
MAR	0.42	0.04	0.12	N.A.	0.58
TOTAL	1.47	0.07	1.02	N.A.	2.56
AVERAGE	0.49	0.02	0.34	N.A.	0.85

N.A. - Denotes not applicable data

Total system operating energy for the Washington Natural Gas Company is the energy required to support the energy collection and storage subsystem (ECSS), the DHW subsystem and the space heating subsystem. With reference to the system schematic (Figure 3-1) the ECSS operating energy includes the blower (EP100), the DHW subsystem operating energy consists of pump P1 (EP300), and the space heating operating energy consists of the blower (EP400).

5.5 Energy Savings

Energy savings for the Washington Natural Gas Company site for the reporting period are presented in Table 5-11. For this period the total electrical energy expense was 1.54 million Btu, for a monthly average of 0.51 million Btu; total fossil fuel energy savings was 6.16 million Btu, for a monthly average of 2.05 million Btu.

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 Washington Natural Gas Company consists of a 125 million Btu per hour gas furnace and a 44 million Btu per hour gas hot water heater. The units are considered to be 60 percent efficient for computational purposes.

TABLE 5-11. ENERGY SAVINGS
WASHINGTON NATURAL GAS COMPANY

MONTH	SOLAR ENERGY USED (Million Btu)	SOLAR ENERGY SAVINGS ATTRIBUTED TO (Million Btu)						SOLAR OPER- ATING ENERGY (Million Btu)	ENERGY SAVINGS (Million Btu)	
		SPACE HEATING		DOMESTIC HOT WATER		SPACE COOLING			ELEC- TRICAL	FOSSIL FUEL
		ELEC- TRICAL	FOSSIL FUEL	ELEC- TRICAL	FOSSIL FUEL	ELEC- TRICAL	FOSSIL FUEL			
JAN	1.15	N.A.	1.45	-0.02	0.62	N.A.	N.A.	0.68	-0.64	2.08
FEB	0.74	N.A.	0.70	-0.01	0.53	N.A.	N.A.	0.51	-0.45	1.22
MAR	1.71	N.A.	1.75	-0.04	1.11	N.A.	N.A.	0.50	-0.45	2.86
TOTAL	3.60	N.A.	3.80	-0.07	2.26	N.A.	N.A.	1.69	-1.54	6.16
AVERAGE	1.20	N.A.	1.27	-0.02	0.75	N.A.	N.A.	0.56	-0.51	2.05

N.A. - Denotes not applicable data

S002

6. REFERENCES

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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.

- 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 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).
- o COLLECTED SOLAR ENERGY (SECA) is the thermal energy removed from the collector array by the energy transport medium.
- o 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.

- o ENERGY TO STORAGE (STEI) is the amount of energy, both solar and auxiliary, delivered to the primary storage medium.
- o 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.

- o SOLAR FRACTION OF LOAD (HWSFR) is the percentage of the load demand which is supported by solar energy.
- o SOLAR ENERGY USED (HWSE) is the amount of solar energy supplied to the hot water subsystem.
- o 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.
- o 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.
- o AUXILIARY FOSSIL FUEL (HWAF) is the amount of fossil fuel energy supplied directly to the subsystem.
- o 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.
- o 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.

- o SPACE HEATING LOAD (HL) is the sensible energy added to the air in the building.
- o 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.
- o SOLAR ENERGY USED (HSE) is the amount of solar energy supplied to the space heating subsystem.

- o 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.
- o 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.
- o AUXILIARY ELECTRICAL FUEL (HAE) is the amount of electrical energy supplied directly to the subsystem.
- o 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.
- o BUILDING TEMPERATURE (TB) is the average heated space dry bulb temperature.

APPENDIX B

SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS

WASHINGTON NATURAL 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

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

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

$$\text{COLLECTED SOLAR ENERGY} = \sum [M100 \times \Delta H] \times \Delta\tau$$

where M100 is the mass flow rate of the heat transfer fluid in lb_m/min and ΔH is the enthalpy change, in Btu/lb_m, of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is generally given by

$$\Delta H = \bar{C}_p \Delta T$$

where $\bar{C}_p$ is the average specific heat, in Btu/(lb_m-°F), of the heat transfer fluid and ΔT , in °F, is the temperature differential across the heat exchanging component.

For an air system ΔH is generally given by

$$\Delta H = H_a(T_{out}) - H_a(T_{in})$$

where $H_a(T)$ is the enthalpy, in Btu/lb_m, of the transport air evaluated at the inlet and outlet temperatures of the heat exchanging component.

$H_a(T)$ can have various forms, depending on whether or not the humidity ratio of the transport air remains constant as it passes through the heat exchanging component.

For electrical power, a general example is

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

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, therefore, 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)

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

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \Sigma T600 \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

FOR $\pm$ 3 HOURS FROM SOLAR NOON

HOT WATER LOAD (BTU)

$$HWL = \Sigma [M300 \times HWD (T351, T300) \times \Delta\tau]$$

SOLAR ENERGY TO DHW TANK (BTU)

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

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT²)

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

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = SE \times CLAREA$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

WHEN THE COLLECTOR LOOP IS ACTIVE

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = SEOP \times CLAREA$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma [M200 \times HRF \times (T250 - T200)] \times \Delta\tau$$

WHEN IN THE COLLECTOR-TO-STORAGE MODE

SOLAR ENERGY TO SPACE HEATING LOAD (BTU)

$$HSE = \Sigma [M100 \times HRF (T151 - T100) \times \Delta\tau] \quad \text{COLLECTOR-TO-SPACE-HEATING MODE}$$

$$HSE = \Sigma [M200 \times HRF \times (T250 - T200) \times \Delta\tau] \quad \text{STORAGE-TO-SPACE-HEATING MODE}$$

ENERGY FROM STORAGE TO SPACE HEATING LOAD (BTU)

$$STEO = \Sigma [M200 \times HRF \times (T250 - T200) \times \Delta\tau]$$

WHEN IN THE STORAGE-TO-SPACE HEATING MODE

AVERAGE TEMPERATURE OF STORAGE

$$TST = \Sigma [(T201 + T202 + T203)/180] \times \Delta\tau$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = 56.8833 \times \Sigma EP100 \times \Delta\tau$$

HOT WATER CONSUMED (GALLONS)

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

HOT WATER SUBSYSTEM OPERATING ENERGY (BTU)

$$HWOPE = 56.8833 \times \Sigma EP300 \times \Delta\tau$$

HOT WATER AUXILIARY THERMAL ENERGY (BTU)

$$HWAT = \Sigma [M300 \times HWD (T351, T350)] \times \Delta\tau$$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = 56.8833 \times \Sigma EP400 \times \Delta\tau$$

SERVICE HOT WATER TEMPERATURE (°F)

$$THW = [\Sigma (T351 \times M300) \times \Delta\tau] / [\Sigma M300 \times \Delta\tau]$$

SERVICE SUPPLY WATER TEMPERATURE (°F)

$$TSW = [\Sigma (T300 \times M300) \times \Delta\tau] / [\Sigma M300 \times \Delta\tau]$$

SPACE HEATING AUXILIARY THERMAL ENERGY (BTU)

$$HAT = \Sigma [M600 \times HRF \times (T450 - T400)] \times \Delta\tau$$

COLLECTED SOLAR ENERGY (BTU)

$$SEC = \Sigma [[M100 \times HRF \times (T150 - T100)] / CLAREA] \times \Delta\tau$$

SPACE HEATING AUXILIARY ENERGY (BTU)

$$HAF = \Sigma (HAT/0.6) \times \Delta\tau$$

CHANGE IN STORED ENERGY (BTU)

$$STECH = MASSR \times 0.2 \left[[(T201 + T202 + T203)/3] - [(T201_p + T202_p + T203_p)/3] \right]$$

WHERE THE SUBSCRIPT _p REFERS TO A PRIOR REFERENCE VALUE

ENERGY DELIVERED TO LOAD SUBSYSTEM FROM ECSS (BTU)

$$CSEO = HSE + HWSE$$

STORING EFFICIENCY

$$STEFF = (STECH + STEO)/STEI$$

ECSS SOLAR CONVERSION EFFICIENCY

$$CSCEF = SEL/SEA$$

HOT WATER AUXILIARY FOSSIL ENERGY (BTU)

$$HWAFF = \Sigma [HWAT/0.6] \times \Delta\tau$$

HOT WATER SOLAR FRACTION

$$HWTKAUX = TANKE \times (1 - HWSFRP/100) + HWAT$$

$$HWTKSE = TANKE \times HWSFRP/100 + HWSE$$

$$HWSFR = 100 \times HWTKSE/(HWTKSE + HWTKAUX)$$

HOT WATER ELECTRICAL ENERGY SAVINGS (BTU)

$$HWSVE = -56.8833 \times \Sigma EP300 \times \Delta\tau$$

HOT WATER SYSTEM FOSSIL ENERGY SAVINGS (BTU)

$$HWSVF = HWSE/0.6$$

SPACE HEATING SYSTEM FOSSIL ENERGY SAVINGS (BTU)

$$HSVF = HSE/0.6$$

SPACE HEATING LOAD (BTU)

$$HL = HSE + HAT$$

SPACE HEATING SYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HSVE = 0.0$$

SYSTEM LOAD

$$SYSL = HL + HWL$$

SOLAR ENERGY TO LOAD

$$SEL = HWSE + HSE$$

SPACE HEATING SOLAR FRACTION

$$HSFR = 100 \times (HSE/HL)$$

SOLAR FRACTION OF SYSTEM LOAD

$$SFR = [(HSE + HWSE)/(HL + HWL)] \times 100$$

AUXILIARY THERMAL ENERGY TO LOADS

$$AXT = HWAT + HAT$$

AUXILIARY FOSSIL ENERGY TO LOADS

$$AXF = HWAF + HAF$$

SYSTEM OPERATING ENERGY

$$SYSOPE = HWOPE + HOPE + CSOPE$$

TOTAL ENERGY CONSUMED

$$TECSM = SYSOPE + AXF + SECA$$

TOTAL ELECTRICAL ENERGY SAVINGS

$$TSVE = HWSVE + HSVE - CSOPE$$

TOTAL FOSSIL ENERGY SAVINGS

$$TSVF = HWSVF + HSVF$$

SYSTEM PERFORMANCE FACTOR

$$SYSPF = SYSL/(SYSOPE \times 3.33 + AXF)$$

COLLECTOR ARRAY EFFICIENCY

$$CAREF = SECA/SEA$$

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: WASH. NAT. GAS 64. LOCATION: SEATTLE WA
 ANALYST: C. MESSERLY FDHIVE NO.: 23.
 COLLECTOR TILT: 57.00 (DEGREES) COLLECTOR AZIMUTH: 0.0 (DEGREES)
 LATITUDE: 47.50 (DEGREES) RUN DATE: 6/04/79

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	924.	262.	0.28317	1.775	465.	831	0	38.
FEB	1407.	494.	0.35113	1.561	771.	636	0	42.
MAR	2074.	849.	0.40892	1.261	1070.	640	0	44.
APR	2820.	1294.	0.45891	0.997	1230.	409	0	49.
MAY	3388.	1714.	0.50605	0.839	1438.	313	0	55.
JUN	3635.	1803.	0.49602	0.776	1400.	167	11	60.
JUL	3509.	2249.	0.64086	0.801	1800.	80	85	65.
AUG	3039.	1615.	0.53146	0.933	1506.	82	45	64.
SEP	2341.	1147.	0.48977	1.179	1352.	176	8	60.
OCT	1601.	656.	0.40998	1.515	995.	397	0	52.
NOV	1036.	339.	0.32740	1.811	614.	612	0	45.
DEC	799.	210.	0.26290	1.819	382.	760	0	41.

LEGEND:

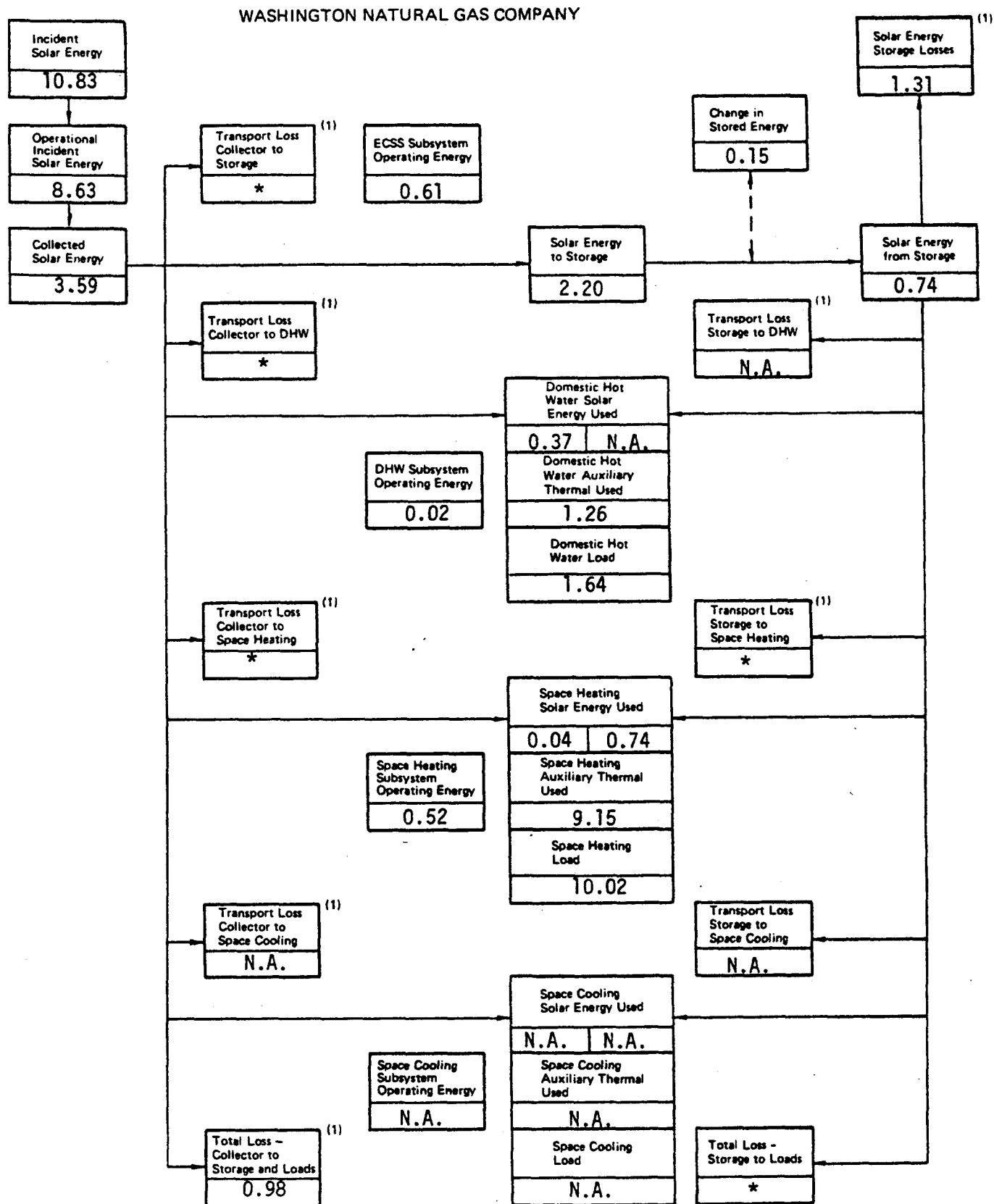
HOBAR ==> MONTHLY AVERAGE DAILY EXTRATERRESTRIAL RADIATION (IDEAL) IN BTU/DAY-FT2.
 HBAR ==> MONTHLY AVERAGE DAILY RADIATION (ACTUAL) IN BTU/DAY-FT2.
 KBAR ==> RATIO OF HBAR TO HOBAR.
 RBAR ==> RATIO OF MONTHLY AVERAGE DAILY RADIATION ON TILTED SURFACE TO THAT ON A HORIZONTAL SURFACE FOR EACH MONTH (I.E., MULTIPLIER OBTAINED BY TILTING).
 SBAR ==> MONTHLY AVERAGE DAILY RADIATION ON A TILTED SURFACE (I.E., HBAR * 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 Washington Natural Gas Company solar energy system for the 3-month reporting period. Each monthly flowchart represents a solar energy balance as the total input equals the total output.

FIGURE D-1. SOLAR ENERGY DISTRIBUTION FLOWCHART - JANUARY 1979



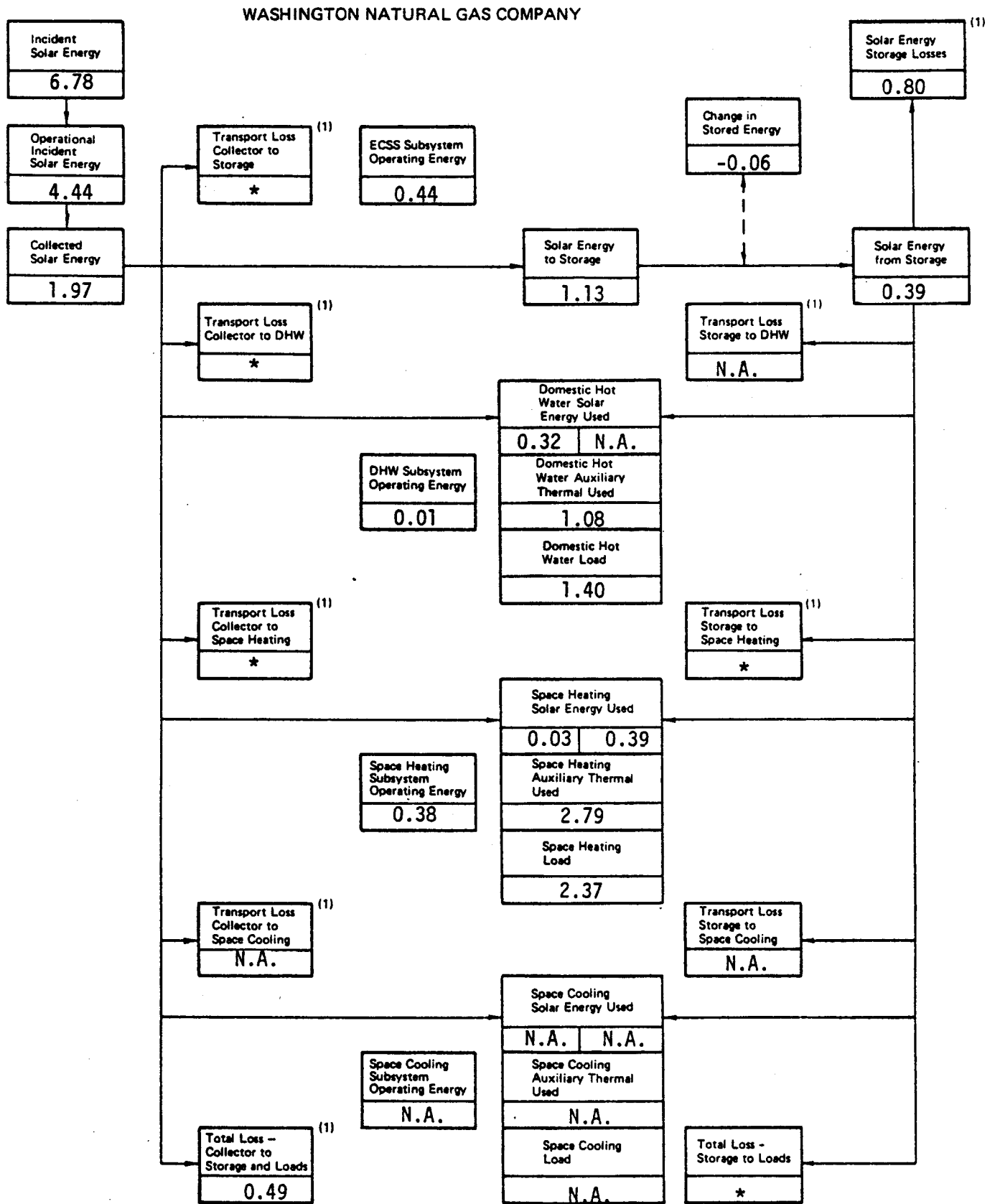
* Denotes Unavailable Data

N.A. denotes not applicable data

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

9002

FIGURE D-2. SOLAR ENERGY DISTRIBUTION FLOWCHART - FEBRUARY 1979



* Denotes Unavailable Data

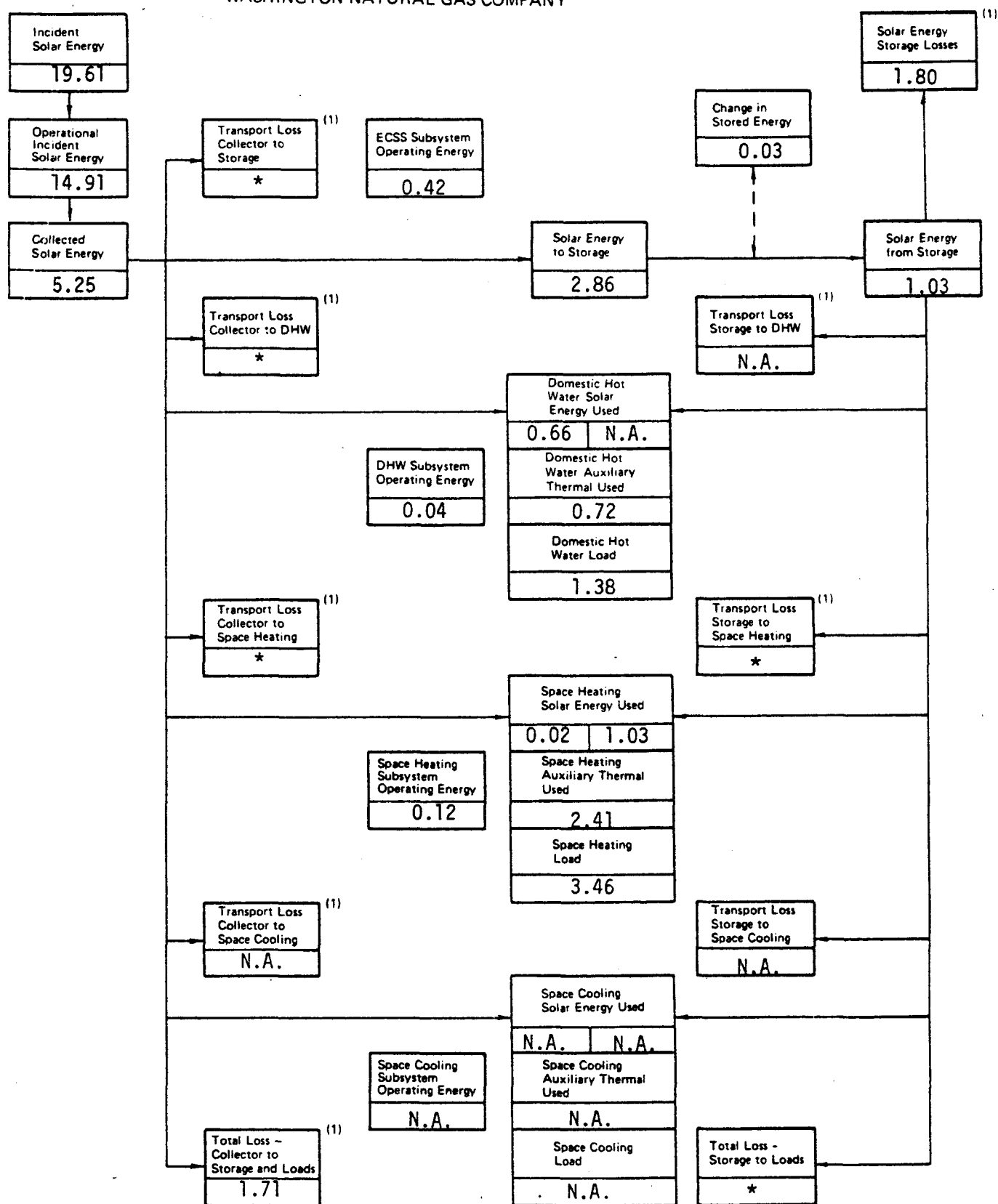
N.A. denotes not applicable data

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

5002

FIGURE D-3. SOLAR ENERGY DISTRIBUTION FLOWCHART - MARCH 1979

WASHINGTON NATURAL 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)

8002

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 Washington Natural Gas Company solar energy system. Tables are provided for the 3-month reporting period.

TABLE E-1. SOLAR ENERGY DISTRIBUTION - JANUARY 1979
WASHINGTON NATURAL GAS COMPANY

<u>3.59</u> 100%	million Btu	TOTAL SOLAR ENERGY COLLECTED
<u>1.15</u> 32 %	million Btu	SOLAR ENERGY TO LOADS
<u>0.37</u> 10 %	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
<u>0.78</u> 22 %	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
<u>N.A.</u> %	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
<u>2.29</u> 64 %	million Btu	SOLAR ENERGY LOSSES
<u>1.31</u> 37 %	million Btu	SOLAR ENERGY LOSS FROM STORAGE
<u>0.98</u> 27 %	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
<u>*</u> %	million Btu	COLLECTOR TO STORAGE LOSS
<u>*</u> %	million Btu	COLLECTOR TO LOAD LOSS
<u>*</u> %	million Btu	COLLECTOR TO DHW LOSS
<u>*</u> %	million Btu	COLLECTOR TO SPACE HEATING LOSS
<u>N.A.</u> %	million Btu	COLLECTOR TO SPACE COOLING LOSS
<u>*</u> %	million Btu	STORAGE TO LOAD LOSS
<u>N.A.</u> %	million Btu	STORAGE TO DHW LOSS
<u>*</u> %	million Btu	STORAGE TO SPACE HEATING LOSS
<u>N.A.</u> %	million Btu	STORAGE TO SPACE COOLING LOSS
<u>0.15</u> 4 %	million Btu	SOLAR ENERGY STORAGE CHANGE

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

TABLE E-2. SOLAR ENERGY DISTRIBUTION - FEBRUARY 1979
WASHINGTON NATURAL GAS COMPANY

<u>1.97</u> 100%	million Btu	TOTAL SOLAR ENERGY COLLECTED
<u>0.74</u> 37%	million Btu	SOLAR ENERGY TO LOADS
<u>0.32</u> 16%	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
<u>0.42</u> 21%	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
<u>N.A.</u> %	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
<u>1.29</u> 66%	million Btu	SOLAR ENERGY LOSSES
<u>0.80</u> 41%	million Btu	SOLAR ENERGY LOSS FROM STORAGE
<u>0.49</u> 25%	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
<u>*</u> %	million Btu	COLLECTOR TO STORAGE LOSS
<u>*</u> %	million Btu	COLLECTOR TO LOAD LOSS
<u>*</u> %	million Btu	COLLECTOR TO DHW LOSS
<u>*</u> %	million Btu	COLLECTOR TO SPACE HEATING LOSS
<u>N.A.</u> %	million Btu	COLLECTOR TO SPACE COOLING LOSS
<u>*</u> %	million Btu	STORAGE TO LOAD LOSS
<u>N.A.</u> %	million Btu	STORAGE TO DHW LOSS
<u>*</u> %	million Btu	STORAGE TO SPACE HEATING LOSS
<u>N.A.</u> %	million Btu	STORAGE TO SPACE COOLING LOSS
<u>-0.06</u> -3%	million Btu	SOLAR ENERGY STORAGE CHANGE

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

TABLE E-3. SOLAR ENERGY DISTRIBUTION - MARCH 1979
WASHINGTON NATURAL GAS COMPANY

$\frac{5.25}{100\%}$ million Btu TOTAL SOLAR ENERGY COLLECTED

$\frac{1.71}{32\%}$ million Btu SOLAR ENERGY TO LOADS

$\frac{0.66}{12\%}$ million Btu SOLAR ENERGY TO DHW SUBSYSTEM

$\frac{1.05}{20\%}$ million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM

$\frac{N.A.}{\%}$ million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM

$\frac{3.51}{67\%}$ million Btu SOLAR ENERGY LOSSES

$\frac{1.80}{34\%}$ million Btu SOLAR ENERGY LOSS FROM STORAGE

$\frac{1.71}{33\%}$ million Btu SOLAR ENERGY LOSS IN TRANSPORT

$\frac{*}{\%}$ million Btu COLLECTOR TO STORAGE LOSS

$\frac{*}{\%}$ million Btu COLLECTOR TO LOAD LOSS

$\frac{*}{\%}$ million Btu COLLECTOR TO DHW LOSS

$\frac{*}{\%}$ million Btu COLLECTOR TO SPACE HEATING LOSS

$\frac{N.A.}{\%}$ million Btu COLLECTOR TO SPACE COOLING LOSS

$\frac{*}{\%}$ million Btu STORAGE TO LOAD LOSS

$\frac{N.A.}{\%}$ million Btu STORAGE TO DHW LOSS

$\frac{*}{\%}$ million Btu STORAGE TO SPACE HEATING LOSS

$\frac{N.A.}{\%}$ million Btu STORAGE TO SPACE COOLING LOSS

$\frac{0.03}{1\%}$ million Btu SOLAR ENERGY STORAGE CHANGE

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