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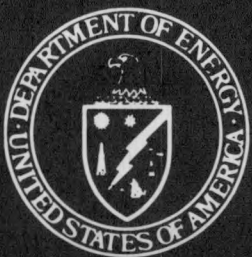
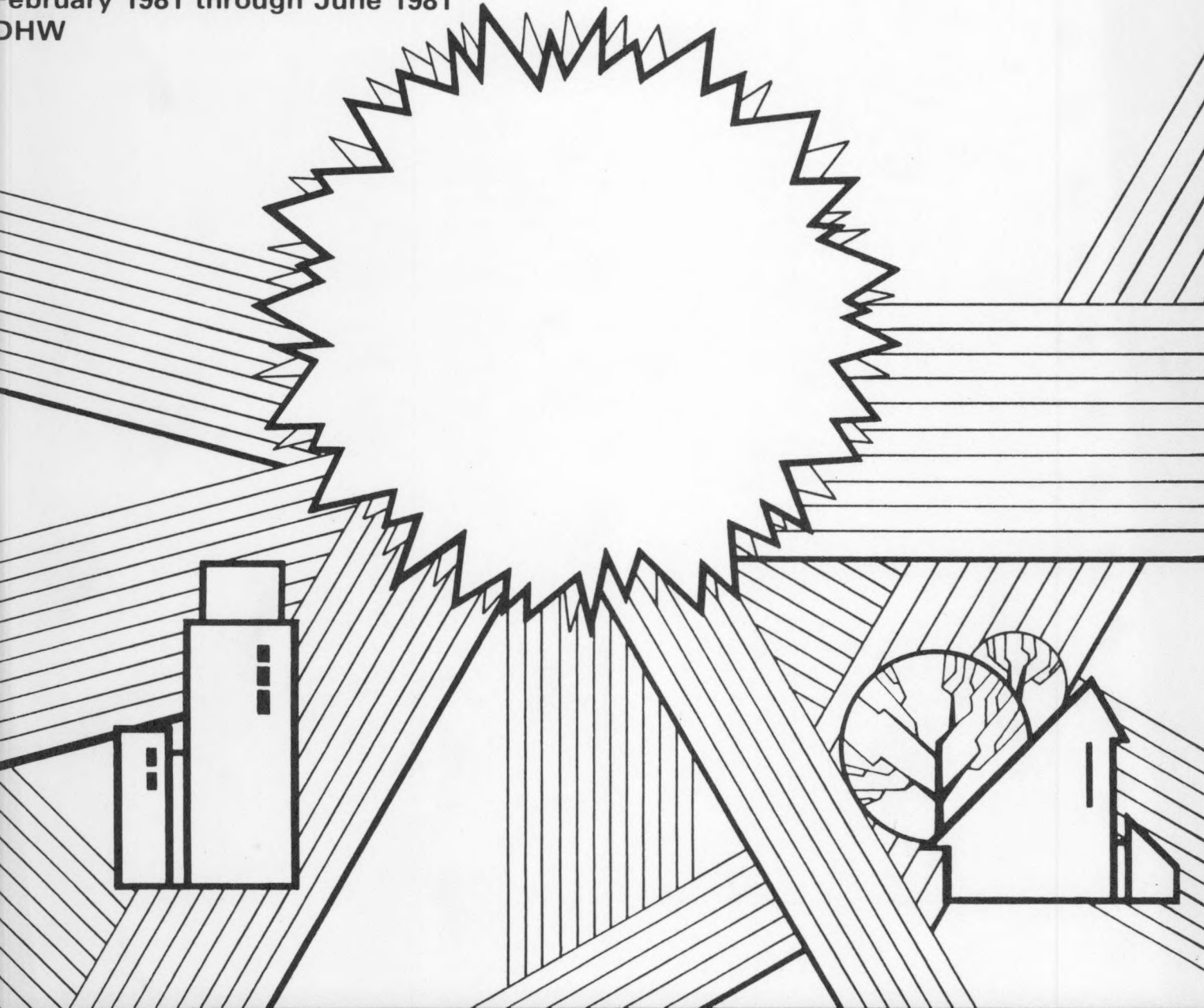
# **SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION**

**LOYOLA UNIVERSITY**

New Orleans, Louisiana

February 1981 through June 1981

DHW



**U.S. DEPARTMENT OF ENERGY**

**NATIONAL SOLAR DATA PROGRAM**

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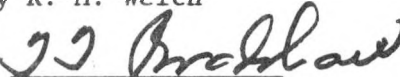
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LOYOLA UNIVERSITY  
NEW ORLEANS, LOUISIANA  
SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION  
FEBRUARY 1981 THROUGH JUNE 1981

Prepared by K. M. Welch

Approved:



T. T. Bradshaw  
Program Manager

Vitro Laboratories Division  
Automation Industries, Inc.  
14000 Georgia Avenue  
Silver Spring, Maryland 20910

The National Solar Data Network  
Department of Energy Contract Number DE-AC01-79CS30027  
Contract Management by:  
Argonne National Laboratory  
9700 South Cass Avenue  
Argonne, Illinois 60439

G. A. McGinnis, Project Manager

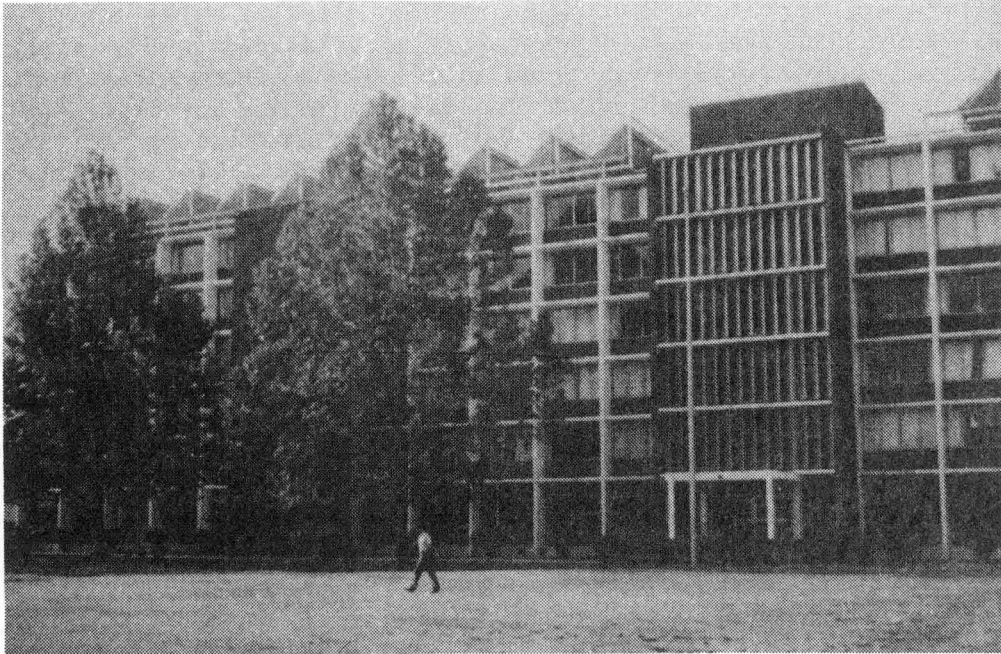
## FOREWORD

This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic hot water and annual performance reports are issued for such sites. In addition, Monthly Performance Reports, prior to 1981, are available for the solar systems in the network.

The National Solar Data Network consists of instrumented solar energy systems in buildings selected from among the 5,000 installations built (since early 1977) as part of the National Solar Heating and Cooling Demonstration Program. The overall purpose of this program is to assist in the development of solar technologies for buildings by providing data and information on the effectiveness of specific systems, the effectiveness of particular solar technologies, and the areas of potential improvement. Vitro Laboratories Division responsibility in the NSDN, under contract with the Department of Energy, is to collect data daily from the sites, analyze the data, and disseminate information to interested users.

Buildings in the National Solar Data Network are comprised of residential, commercial and institutional structures which are geographically dispersed throughout the continental United States. The variety of solar systems installed employ "active" mechanical equipment systems or "passive" design features, or both, to supply solar energy to typical building thermal loads such as space heating, space cooling, and domestic hot water. Solar systems on some sites are used to supply commercial process heat.

The buildings in the NSDN program are instrumented to monitor thermal energy flows to the space conditioning, hot water, or process loads, from both the solar system and the auxiliary or backup system. Data collection from each site, and transmission to a central computer for processing and analysis is highly automated.



LOYOLA UNIVERSITY

## LOYOLA UNIVERSITY

The Loyola University site is a student dormitory in New Orleans, Louisiana. The active solar energy system is designed to supply the following:

### Annual Design Factors\* (Million BTU)

	<u>Total Load</u>	<u>Solar Contribution</u>	<u>% Solar</u>
Hot Water	1,641.3	852.5	52

It is equipped with:

Collector	4,590 square feet, flat-plate, General Energy Devices, Model No. 24-00C.
Storage	5,000-gallon water tank located on the west side of the building at ground level, Pressure Vessels, Inc., Model No. GH-5000 A-T.
Auxiliary	High temperature and pressure water supplied from a central heating plant with a gas-fired boiler
Control Mode Selector	Hawthorne Industries, Inc., Model BT-100 Differential Controller, ON @ +16°F, OFF @ +3°F

\* DIM Report, AIA Research Corporation.

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SECTION 1

SOLAR SYSTEM PERFORMANCE

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

Solar Fraction <sup>1</sup>	28%
Solar Savings Ratio <sup>2</sup>	27%
Conventional Fuel Savings <sup>3</sup>	351,027 cubic feet of gas
System Performance Factor <sup>4</sup>	0.80
Solar System COP <sup>5</sup>	30.81

Seasonal Energy Requirements  
February 1981 through June 1981  
(Million BTU)

	<u>Total Load</u>	<u>Solar Contribution</u>	<u>% Solar</u>
Hot Water	771.57	215.04	28

Environmental Data

	<u>Measured Average</u>	<u>Long-Term Average</u>
Outdoor temperature	69°F	68°F
Heating-degree days	404	516
Cooling-degree days	1,150	1,002
Daily incident solar energy	1,331 BTU/ft <sup>2</sup>	1,601 BTU/ft <sup>2</sup>

- Solar Fraction =  $\frac{\text{Solar Energy Supplied to Load}}{\text{Total Load}}$
- Solar Savings Ratio =  $\frac{\text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}}{\text{Total Load}}$
- Conventional Fuel Savings = Savings in BTUs x  $979.4 \times 10^{-6} \frac{\text{ft}^3}{\text{BTU}}$
- Ratio of system load to the total equivalent fossil energy expended or required to support the system load
- Solar System COP =  $\frac{\text{Solar Energy Used}}{\text{Solar Unique Operating Energy}}$

MONTHLY REPORT: MARCH 1981  
 SITE SUMMARY: LOYOLA UNIVERSITY

CONVENTIONAL UNITS

GENERAL SITE DATA:

INCIDENT SOLAR ENERGY	187.223	MILLION BTU
	43339	BTU/SQ.FT.
COLLECTED SOLAR ENERGY	64.268	MILLION BTU
	14877	BTU/SQ.FT.
PERCENT OF COLLECTED TO LOADS	E95	PERCENT
COLLECTOR ARRAY EFFICIENCY	0.343	
COLLECTOR ARRAY OPERATIONAL EFFICIENCY	0.363	
AVERAGE AMBIENT TEMPERATURE	62	DEGREES F
AVERAGE BUILDING TEMPERATURE	N.A.	DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY	E0.36	
ECSS OPERATING ENERGY	1.550	MILLION BTU
ECSS PERFORMANCE FACTOR	E14,127	BTU/SQ.FT.
TOTAL SYSTEM OPERATING ENERGY	1.857	MILLION BTU
TOTAL ENERGY CONSUMED	228.207	MILLION BTU
SOLAR DELIVERED/BUILDING AREA	N.A.	BTU/SQ.FT.
AUXILIARY USED/BUILDING AREA	N.A.	BTU/SQ.FT.

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	223.11E	N.A.	N.A.	E223.11 MILLION BTU
SOLAR FRACTION	27E	N.A.	N.A.	E27 PERCENT
SOLAR SAVINGS RATIO	0.000	N.A.	N.A.	0.000 PERCENT
SOLAR ENERGY USED	61.03E	N.A.	N.A.	E61.03 MILLION BTU
OPERATING ENERGY	0.307	N.A.	N.A.	1.857 MILLION BTU
AUX. THERMAL ENERGY	162.081	N.A.	N.A.	162.081 MILLION BTU
AUX. ELECTRIC FUEL	N.A.	N.A.	N.A.	N.A. MILLION BTU
AUX. FOSSIL FUEL	N.A.	N.A.	N.A.	N.A. MILLION BTU
ELECTRICAL SAVINGS	N.A.	N.A.	N.A.	-1.550 MILLION BTU
FOSSIL SAVINGS	101.72E	N.A.	N.A.	E101.72 MILLION BTU

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 2.46

\* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED.

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980.  
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MONTHLY REPORT: MARCH 1981  
 SITE SUMMARY: LOYOLA UNIVERSITY

CONVENTIONAL UNITS

GENERAL SITE DATA:			
INCIDENT SOLAR ENERGY		187.223	MILLION BTU
		43339	BTU/SQ.FT.
COLLECTED SOLAR ENERGY		64.268	MILLION BTU
		14877	BTU/SQ.FT.
AVERAGE AMBIENT TEMPERATURE		62	DEGREES F
AVERAGE BUILDING TEMPERATURE		N.A.	DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY		E0.36	
ECSS OPERATING ENERGY		1.550	MILLION BTU
STORAGE EFFICIENCY		E98.90	PERCENT
EFFECTIVE HEAT TRANSFER COEFFICIENT		I	BTU/DEG F- SQ FT-HR
TOTAL SYSTEM OPERATING ENERGY		1.857	MILLION BTU
TOTAL ENERGY CONSUMED		228.207	MILLION BTU

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL	
LOAD	223.11E	N.A.	N.A.	E223.11	MILLION BTU
SOLAR FRACTION	27E	N.A.	N.A.	E27	PERCENT
SOLAR ENERGY USED	61.03E	N.A.	N.A.	E61.03	MILLION BTU
OPERATING ENERGY	0.307	N.A.	N.A.	1.857	MILLION BTU
AUX. THERMAL ENERGY	162.081	N.A.	N.A.	162.081	MILLION BTU
AUX. ELECTRIC FUEL	N.A.	N.A.	N.A.	N.A.	MILLION BTU
AUX. FOSSIL FUEL	N.A.	N.A.	N.A.	N.A.	MILLION BTU
ELECTRICAL SAVINGS	N.A.	N.A.	N.A.	-1.550	MILLION BTU
FOSSIL SAVINGS	101.72E	N.A.	N.A.	E101.72	MILLION BTU

SYSTEM PERFORMANCE FACTOR: 80.74E  
 INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 2.46

\* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED.

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980.  
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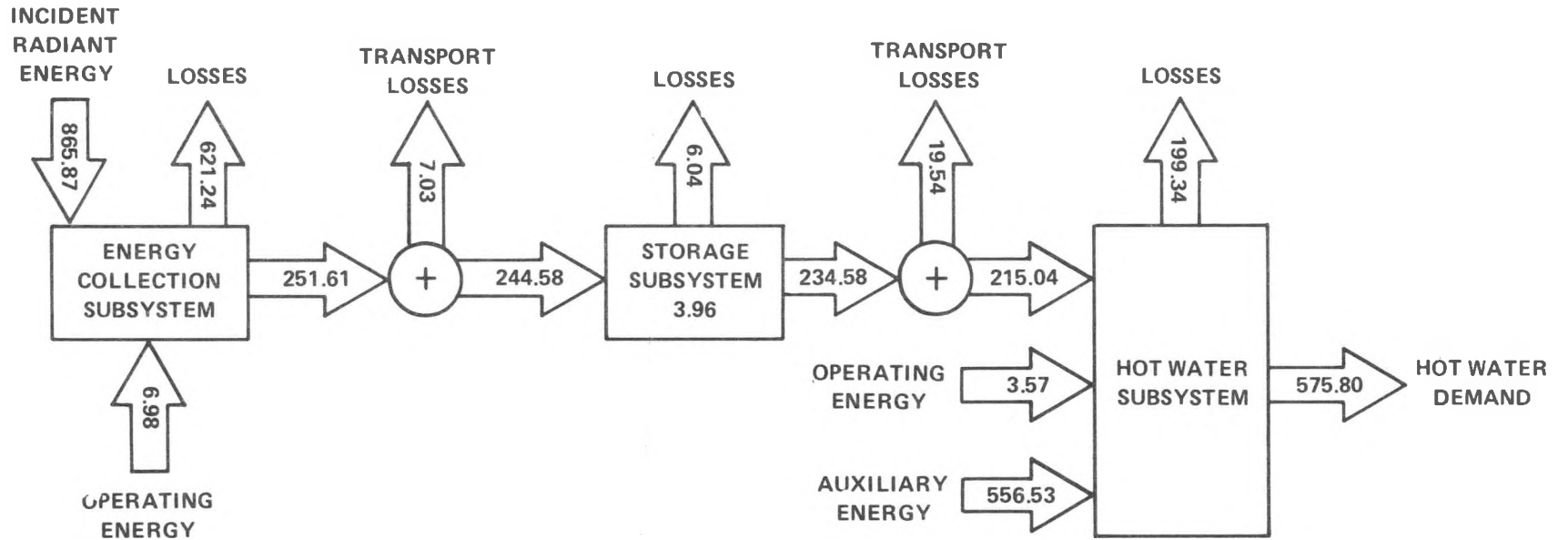


Figure 2. Energy Flow Diagram for Loyola University  
 February 1981 through June 1981  
 (Figures in million BTU)

The solar energy coefficient of performance (COP) is indicated in Table 2. The COP simply provides a numerical value for the relationship of solar energy used or collected and the energy required to collect or deliver it. The greater the COP value, the more efficient the subsystem. The solar energy system at Loyola University functioned at a reporting period weighted average COP value of 30.81 for the period February 1981 through June 1981. The collector subsystem operated at a COP value of 36.05 during the reporting period.

The electrical energy used by the collector pumps is the only solar specific operating energy in the system. The recirculation pump operating energy is not solar specific. The fact that this system requires very little operating energy allows it to operate at high COP values. The COP value for the solar energy system is lower than that for the collector subsystem due to energy losses from the collector subsystem to the load subsystem.

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM
FEB	34.80	39.87
MAR	39.37	41.46
APR	29.86	33.77
MAY	28.53	37.13
JUN	19.43	26.62
WEIGHTED AVERAGE	30.81	36.05

## 1.2 OVERALL SYSTEM PERFORMANCE

### 1.2.1 TYPICAL SYSTEM OPERATION

Curves depicting typical system operation are presented in Figures 3a, 3b, and 3c. The curves were generated from data for March 5, 1981. The solar insolation on this day averaged 1,189 BTU/ft<sup>2</sup>-day which was approximately 22% below the March daily average but well within one standard deviation. The average ambient temperature was 62°F and the average daytime ambient temperature was 68°F. The hot water load of 8.50 million BTU was approximately 18% above the March daily average.

Figure 3a shows that the collector loop began operating at about 8:30 a.m. at an insolation level of approximately 90 BTU/hr-ft<sup>2</sup>. The solar insolation increased steadily and reached a peak of 330 BTU/hr-ft<sup>2</sup> from 1:00 to 1:30 p.m. Operation of the collectors could begin at a low insolation level because storage temperatures were about 60°F on this day. The peak insolation levels would be expected to occur during the early afternoon, rather than at solar noon, since the collectors face 16 degrees west of south. The insolation level slowly decreased through the afternoon but made a sharp drop for a 15 minute period at 3:10 p.m. The drop in insolation was not low enough or of long enough duration to deactivate the collector pump. The collectors continued to operate until 5:39 p.m. when they shut down at the very low insolation level of 25 BTU/hr-ft<sup>2</sup>. From the collector pump power curve it can be seen that the pump came on for a short period after solar insolation had reached zero. A set point problem exists with the controller. This problem can be explained and is illustrated more fully in the discussion of Figure 3b.

The collector inlet and outlet temperatures and the pump power are shown in Figure 3b. Upon pump activation, temperature sensors T101 and T102 indicate a positive energy gain across the collector array. Energy collection continued with the collector temperature differential increasing as the insolation levels rose. At 3:00 p.m., the solar insolation dropped sharply as did the collector outlet temperature. For a short period, the outlet temperature dropped below the collector inlet and storage temperatures. The controller did not detect this negative temperature difference and deactivate the pump. After this, a small positive temperature difference was maintained until 4:51 p.m. when it again went negative. The pump continued to operate until 5:39 p.m., rejecting energy from storage for 48 minutes. The collector controller allows the system to run too long nearly everyday. This may be caused by a misadjusted shutoff set point temperature or a mislocated sensor for the differential controller. Correction of this problem would prevent the rejection of collected solar energy and reduce the operating energy requirement. During the period the collectors were rejecting energy, the average storage tank temperature dropped from 122.7°F to 116.1°F.

Curves depicting the storage temperatures throughout the day are shown in Figure 3c. Note that in the early morning hours the storage tank is stratified with sensor T200 recording higher temperatures than T201. This would be expected since T200 measures the temperature in the top of the tank and T201 measures the temperature at the middle of the tank. At about 4:30 p.m., these two temperatures reverse, with T201 being higher than T200. This continues throughout the day during energy collection and after. At approximately 11:00 p.m. both of the midtank temperature sensors quickly began to decay. It is unknown why T201 remained warmer than T200 for nearly the entire day. Also, note that the two sensors that measure the bottom of the tank temperature decay quickly after the collector pump is deactivated. This decay occurs because there is nearly constant hot water use and the manner in which cold water enters the storage tank allows for good stratification. As hot water is withdrawn from the top of the tank, it is replaced with cold water with little mixing through the use of special stratification manifolds. The midtank temperature sensors began to decay when cold replacement water eventually reached their level in the tank.

MONTHLY REPORT: LOYOLA UNIVERSITY  
HOT WATER SUBSYSTEM I

MARCH 1981

DAY OF MON.	HOT WATER LOAD MILLION BTU	SOLAR FR.OF LOAD PER.	HOT WATER DEMAND MILLION BTU	SOLAR FR.OF DEMAND BTU	SOLAR ENERGY USED MILLION BTU	OPER ENERGY MILLION BTU	AUX THERMAL USED MILLION BTU
(NBS ID)	(N300)	(Q302)	(Q300)	(Q303)	(Q301)		
1						0.011	3.171
2	I	I	I	I	I	0.009	5.393
3						0.012	5.237
4						0.014	6.564
5						0.010	5.784
6						0.007	4.545
7						0.013	5.332
8						0.015	6.202
9						0.010	5.116
10						0.010	5.153
11						0.007	5.357
12						0.013	6.155
13						0.015	6.798
14						0.009	4.526
15						0.007	3.974
16						0.009	4.363
17						0.008	5.592
18						0.007	4.506
19						0.010	4.165
20						0.009	3.990
21						0.013	5.414
22						0.010	4.678
23						0.009	5.494
24						0.007	4.741
25						0.010	6.209
26						0.008	5.216
27						0.007	5.411
28						0.010	5.685
29						0.011	6.095
30						0.008	5.279
31	I	I	I	I	I	0.009	5.937
SUM	223.11E		181.46E		61.03E	0.307	162.081
AVG	7.20E	27E	5.85E	I	1.97E	0.010	5.228
PFRV	0.9677	0.9677	0.9677	0.9677	0.9677	0.9960	0.9960

I-7

\* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

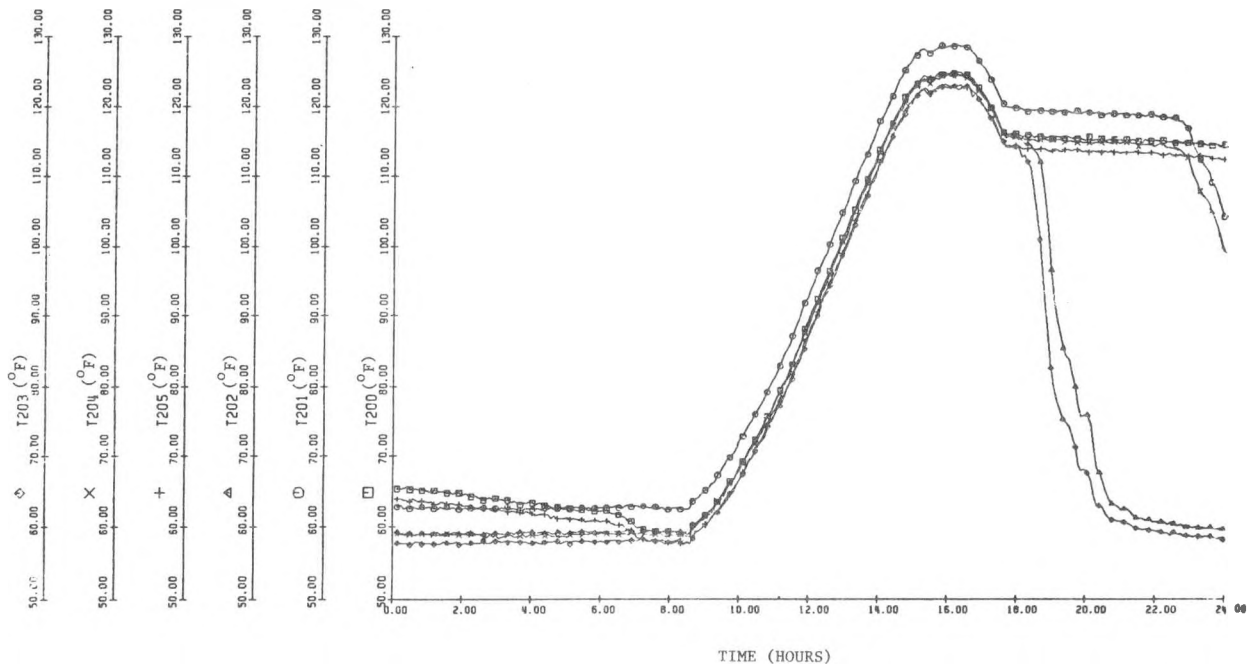


Figure 3c. Typical Storage Fluid Temperature  
Loyola University, March 5, 1981

### 1.2.2 SYSTEM OPERATING SEQUENCE

Figure 4 presents a bar chart showing typical system operating sequences for March 5, 1981. The data correlates with the curves presented in Figure 3a, 3b, and 3c and provides some additional insight into these curves.

From the bar chart, it can be seen that hot water is used continuously with the heaviest consumption in the mid to late morning hours and again from late afternoon to late evening.

The solar storage tank is at its lowest temperature in the morning. It can be seen that large amounts of auxiliary thermal energy are used to meet the large hot water demand during the morning hours. As the day progresses, the collectors are charging storage. This energy added to storage, along with the fact that there is a relatively low hot water demand during the afternoon, permits the storage temperature to rise. After about 4:00 p.m., there is little requirement for auxiliary thermal energy until the next morning, even though there is a large DHW demand during the evening hours.

In the Loyola University system, as long as storage water is warmer than the cold makeup water, solar energy is utilized. On this particular day, the temperature of the water delivered from storage to the DHW system was always warmer than the cold water. This temperature differential ranged from a low of about 4°F in the morning to about 68°F in the late afternoon. There is no provision to temper solar heated water when it is delivered to the DHW system. If its temperature is greater than the set point temperature of the DHW tanks, solar energy will replace some of the standby and recirculation losses.

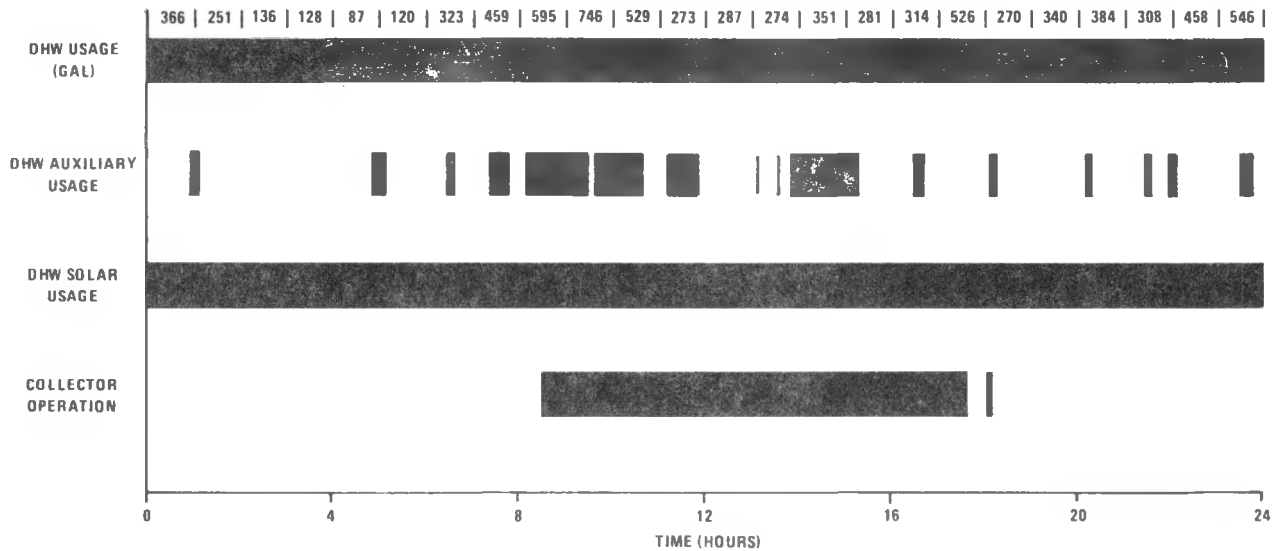


Figure 4. Typical System Operating Sequence  
Loyola University, March 5, 1981

### 1.3 SOLAR ENERGY UTILIZATION

Figure 5 shows the use of solar energy and the percentage of losses.

The losses of solar energy at the different stages through the system, from incident radiation to the load, are also presented in Table 3.

Threshold losses are due to periods of low insolation, at the beginning and end of the day, during which the collector plate temperature is too low to allow the collector pump to operate. The collector pump at Loyola University very often ran too long at the end of the day, causing energy to be rejected through the collectors. This problem may have been caused by a misadjusted controller. If the problem had been repaired, the threshold losses would have increased since the pump would not have run as long.

The collector inefficiency refers to solar energy which was available to be collected but was not, due to reflection, radiation, and convection losses to the environment. If the controller had been repaired, the solar energy collected would have been greater because energy would not have been rejected.

The transport loss is the energy loss from the collectors to storage. The transport and storage loss is the energy lost from the storage vessel itself and the piping from storage to the DHW tank.



\* REFER TO APPENDIX C FOR DEFINITION OF THESE ACRONYMS

Figure 5. Solar Energy Use  
Loyola University  
February 1981 through June 1981

Table 3. SOLAR ENERGY LOSSES

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>
1. SOLAR ENERGY (SE) COLLECTED - SE DIRECTLY TO LOADS (million BTU)	47.84	64.27	54.03	54.59	30.88
2. SE TO STORAGE (million BTU)	45.45	68.21	54.52	48.80	27.60
3. LOSS - COLLECTOR TO STORAGE (%)	5	-6	-1	11	11
4. CHANGE IN STORED ENERGY (million BTU)	0.95	-0.14	0.84	1.85	0.46
5. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million BTU)	41.76	61.03	47.77	41.94	25.01
6. LOSS - STORAGE TO HWSE (%)	5	10	9	7	10

#### 1.4 SOLAR SYSTEM AVAILABILITY

The solar system at Loyola University was operational throughout the entire period of this report, February 1981 through June 1981.

## SECTION 2

### SUBSYSTEM PERFORMANCE

#### 2.1 COLLECTOR

The measured monthly values for the collector subsystem performance are presented in Table 4. The collector subsystem operated well during the reporting period, achieving an average efficiency of 29%. While the collectors were operating, 32% of the available insolation was collected.

Table 4. COLLECTOR SUBSYSTEM PERFORMANCE

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	COLLECTOR ARRAY OPERATIONAL EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
FEB	133.03	47.84	36	123.48	39	1.20	45.45	59
MAR	187.22	64.27	34	177.21	36	1.55	68.21	67
APR	169.42	54.03	32	159.94	34	1.60	54.52	79
MAY	203.52	54.59	27	182.10	30	1.47	48.80	80
JUN	172.68	30.88	18	143.00	22	1.16	27.60	87
TOTAL	865.87	251.61	-	785.73	-	6.98	244.58	-
AVERAGE	173.17	50.32	29	157.15	32	1.40	48.92	74

In this system design, there are no solar heat exchangers at the interface of the subsystems. Cold water is delivered directly to the solar storage tank after being conditioned in a water softening system. Storage water is circulated in the collectors and delivered to the DHW tanks on demand. Because there are no heat exchangers, overall system efficiency is improved. In particular, the collector subsystem efficiency is benefited by the fact that the lowest temperature water possible is delivered to the collectors, reducing the operating point temperature.

The collector array consists of 180 collectors arranged in 15 subarrays of 12 collectors each. They are mounted on a flat roof, six stories above the storage tank and face 16 degrees west of south at an angle of 38 degrees to the horizontal. Due to the low incidence of freezing ambient temperatures in New Orleans, the collector subsystem remains full of water. Recirculation of the collector water is employed for freeze protection. It has been observed that the freeze protection mode is activated at 49°F outdoor ambient temperature. This high set point temperature led to the unnecessary waste of solar energy. The design set point temperature is 38°F.

Although the collector subsystem operated at a high overall efficiency during the reporting period, the performance could have been improved through control set point modification. The data shows that the collectors occasionally were activated too early and continuously operated too long, causing energy to be rejected from storage through the collectors. During the reporting period, this rejected energy totaled 59.05 million BTU including 41.89 million BTU in June alone. This also includes energy rejected for freeze protection during the colder months.

The collectors operated most efficiently during the colder months of February and March. This efficient operation is due to the fact that storage temperatures were relatively low, allowing the collectors to operate at a low inlet water temperature. Also, the average daytime ambient temperatures in February and March were 59°F and 67°F, respectively. This low temperature differential between the collectors and ambient reduced heat loss and increased efficiency. The low storage temperatures can be attributed to the high hot water loads during these months.

## 2.2 STORAGE

Analysis problems were encountered with the storage subsystem during the reporting period. Substantially more energy was calculated as being removed from storage than was delivered to storage, resulting in an energy imbalance. It has been determined that the energy delivered to storage is a valid performance factor, since it compared well with the solar energy collected. This also compared well with predicted values calculated from the manufacturer's collector data. Therefore, the amount of solar energy removed from storage was estimated from the energy delivered to storage, losses, and the change in stored energy. Storage losses were estimated by using the average storage and average ambient temperatures each month and an assumed UA of 50.1 BTU/hr-°F.

Solar energy is stored in a 5,000-gallon water tank located outside the building at ground level. The tank employs STRATA-FLO manifolds at the inlet and outlet to aid in temperature stratification.

Monthly values of the storage subsystem performance are presented in Table 5.

During the reporting period, 244.58 million BTU were delivered to the storage subsystem. Of this, 6.04 million BTU were lost to the ambient environment, 3.96 million BTU remained in storage, and 234.58 million BTU were delivered to the hot water tanks. The pipe connecting storage to the DHW tanks is approximately 35 feet long, three inches in diameter, and well insulated. In transferring energy to the DHW tanks, 19.54 million BTU, or eight percent were lost

Table 5. STORAGE PERFORMANCE

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMPERATURE (°F)	EFFECTIVE HEAT LOSS COEFFICIENT (BTU/hr-°F)	LOSS FROM STORAGE
FEB	45.45	43.96	0.95	99	71	50.22	0.54
MAR	68.21	67.59	-0.14	99	83	48.64	0.76
APR	54.52	52.78	0.84	98	98	50.00	0.90
MAY	48.80	45.24	1.85	96	121	49.96	1.71
JUN	27.60	25.01	0.46	92	141	50.14	2.13
TOTAL	244.58	234.58	3.96	-	-	-	6.04
AVERAGE	48.92	46.92	0.79	98	103	49.79	1.21

from this pipe. This loss is due to the fact that energy is delivered from storage on demand and this configuration allows hot water left in the pipe to lose energy during periods of little or no demand. Physical constraints would not allow the storage tank to be located closer to the DHW tanks.

### 2.3 DOMESTIC HOT WATER (DHW)

The DHW subsystem performance for the Loyola University site for the reporting period is shown in Table 6 and by graphic illustration in Figure 6.

The DHW subsystem required 215.04 million BTU of solar energy and 556.53 million BTU of auxiliary fossil fuel energy to satisfy a hot water load of 771.57 million BTU. The solar fraction of the load was 28% with a total operating energy of 3.57 million BTU. Losses from the DHW subsystem were 199.34 million BTU. A daily average of 6,322 gallons of DHW was consumed at the average temperature of 138°F.

In this system, no operating energy is required to deliver energy from storage to the load. The system operates under city water pressure and, since there are no heat exchangers, solar-heated water is delivered directly from storage to the load on demand.

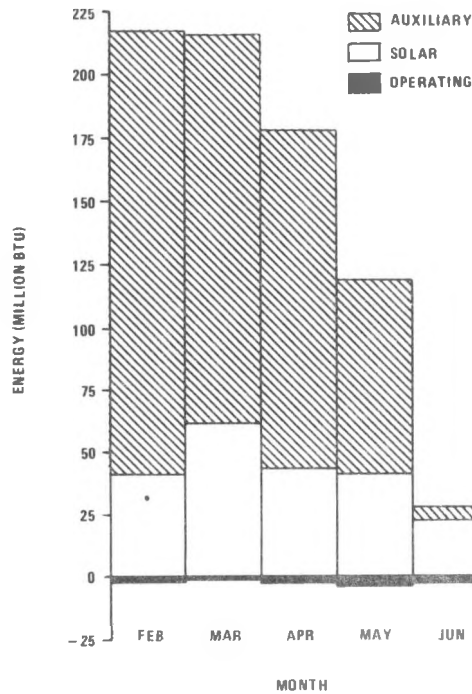
Table 6. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

MONTH	HOT WATER LOAD	SOLAR FRACTION OF LOAD (%)	HOT WATER DEMAND	SOLAR ENERGY USED	AUX THERMAL USED	OPERATING ENERGY USED	AUX FOSSIL FUEL	SUP. WATER TEMP (°F)	HOT WATER TEMP (°F)	HOT WATER CONSUMPTION (GAL)
FEB	223.54	19	186.69	41.76	181.78	0.70	302.97	54	138	267,768
MAR	223.11	27	181.46	61.03	162.08	0.31	270.13	59	138	276,749
APR	178.26	27	117.77	47.77	130.49	0.74	217.48	71	137	214,991
MAY	119.13	35	66.52	41.94	77.19	0.93	128.65	77	137	133,565
JUN	27.53	82	23.36	22.54	4.99	0.89	8.32	85	136	55,182
TOTAL	771.57	-	575.80	215.04	556.53	3.57	927.55	-	-	948,255
AVERAGE	154.31	28	115.16	43.01	111.31	0.71	185.51	64*	138*	189,651

\* Consumption weighted.



OPERATING ENERGY FOR THE SYSTEM IS CONSIDERED A SYSTEM PENALTY AND IS PLOTTED AS A NEGATIVE VALUE BELOW THE ORIGIN.

Figure 6. DHW Subsystem Performance  
Loyola University  
February 1981 through June 1981

Solar heated water is not tempered before delivery to the DHW tanks, therefore water could be delivered to the DHW tanks at a hotter temperature than the thermostat's set point. In some systems, this could be a dangerous situation if the DHW tank is relatively small. At Loyola University, solar heated water is delivered only on demand to two 1,500-gallon DHW tanks. Because of the large volume of these DHW tanks, the relatively low mass flow into them will not change the tank temperature significantly. Since standby and recirculation losses are greater than the excess energy delivered from solar storage when storage temperatures are greater than the DHW tank, solar energy replaces some of these losses.

### SECTION 3

#### OPERATING ENERGY

Measured monthly values of the Loyola University solar energy system and subsystem operating energy for the report period are presented in Table 7. A total 6.98 million BTU of operating energy were consumed by the solar system during the reporting period. This represents the energy required to operate the collector pumps. There is no solar specific operating energy required to operate the DHW subsystem since water is delivered to the DHW tanks from storage via city water pressure.

Total solar system operating energy for Loyola University is the electrical energy required to support the collector, storage, and DHW subsystems without affecting their thermal states.

The solar system at Loyola University operates very efficiently due to the low amount of operating energy consumed. The system delivered 30.81 BTU of solar energy for every one BTU of electrical operating energy required to deliver it.

Table 7. SOLAR OPERATING ENERGY

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

MONTH	TOTAL SOLAR OPERATING ENERGY (Million BTU)
FEB	1.20
MAR	1.55
APR	1.60
MAY	1.47
JUN	1.16
TOTAL	6.98
AVERAGE	1.40

## SECTION 4

## ENERGY SAVINGS

Energy savings for this site for the reporting period, February 1981 through June 1981, are presented in Table 8.

For this five-month period, the total savings were 358.41 million BTU, for a monthly average of 71.68 million BTU. This is approximately 2,584 gallons of oil, or 351,027 cubic feet of natural gas, or 63,026 kwh of electricity. An electrical energy expense of 6.98 million BTU or 2,044 kwh was incurred during the reporting period for the operation of solar energy components.

Table 8. ENERGY SAVINGS

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

(All values in million BTU)

MONTH	SOLAR ENERGY USED	DOMESTIC HOT WATER	ECSS OPERATING ENERGY	NET ENERGY SAVINGS	
		FOSSIL FUEL	SOLAR UNIQUE	ELECTRICAL	FOSSIL FUEL
FEB	41.76	69.60	1.20	-1.20	69.60
MAR	61.03	101.72	1.55	-1.55	101.72
APR	47.77	79.62	1.60	-1.60	79.62
MAY	41.94	69.90	1.47	-1.47	69.60
JUN	22.54	37.57	1.16	-1.16	37.57
TOTAL	215.04	358.41	6.98	-6.98	358.41
AVERAGE	43.01	71.68	1.40	-1.40	71.68

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 transport solar energy from the collector to storage is subtracted from the solar energy contribution to the loads to determine net savings.

The auxiliary source at Loyola University consists of superheated water supplied from a natural-gas central heating plant. This unit is considered to be 60% efficient for computational purposes.

Based on national average costs for natural gas and electricity of \$4.09/mcf and \$5.68/kwh respectively, the solar system provided a net savings of \$1,319.60.

The calculated energy savings for the five-month period are very good. Small improvements in savings could be realized with minor adjustments of the collector controller's ON/OFF set points and freeze protection set point. These modifications would prevent the unnecessary rejection of solar energy from storage and reduce the collector pump operating energy.

During periods when school is in session, there is a 24 hr/day demand on the hot water system. There would appear to be little or no need for hot water recirculation since hot water is delivered to the points of use constantly through demand. Deactivation of the recirculation pumps would provide additional savings by eliminating losses in the return line and the need to operate the recirculation pumps.

## SECTION 5

## WEATHER CONDITIONS

Loyola University is located in New Orleans, Louisiana at 30 degrees N latitude and 90 degrees W longitude.

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the site during the reporting period are presented in Table 9. Also presented in the table are the corresponding long-term average monthly values of the measured weather parameters. These long-term average weather data were obtained from nearby representative National Weather Service and SOLMET meteorological stations. The long-term average insolation values are total global horizontal radiation converted to collector angle and azimuth orientation.

Table 9. WEATHER CONDITIONS

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT <sup>2</sup> -DAY)		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
FEB	1,100	1,408	55	56	284	299	4	35
MAR	1,398	1,564	62	61	120	188	31	55
APR	1,307	1,710	73	69	0	29	271	137
MAY	1,520	1,688	75	75	0	0	305	313
JUN	1,332	1,634	82	80	0	0	539	462
TOTAL	-	-	-	-	404	516	1,150	1,002
AVERAGE	1,331	1,601	69	68	-	-	-	-

During the period from February 1981 through June 1981, the average daily total incident solar radiation on the collector array was 1,331 BTU per square foot per day. This radiation was below the estimated average daily solar radiation for this geographical area during the reporting period of 1,601 BTU per square foot per day for a plane facing 16 degrees west of south with a tilt of 38 degrees to the horizontal. During the period, the highest monthly

average insolation was 1,520 BTU per square foot per day during May. The average ambient temperature during the reporting period was 69°F as compared with the long-term average of 68°F. The highest monthly average ambient temperature was 82°F during June and the lowest monthly average ambient temperature was 55°F during February. The number of heating degree-days for the period (based on a 65°F reference) was 404 as compared with the long-term average of 516. The range of heating degree-days was from a high of 284 during February to a low of 0 during April, May, and June.

Extraterrestrial radiation values are computed (see Footnote 1) and given in the table below for each month. The ratio of total insolation on a tilted surface to extraterrestrial radiation on a parallel surface is called the clearness index.

This parameter quantifies the effects of cloudiness and atmospheric transmission on the insolation received at the earth's surface. The clearness index ranged from a high of 53% during May to a low of 34% during February.

	<u>MONTHS</u>				
	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>
Extraterrestrial Insolation (BTU/day)	3,273	3,279	3,116	2,865	2,715
<u>TTL INS</u> <u>EXT INS</u>	34	43	42	53	49

For a more complete set of meteorological data see Appendix E, which contains daily average values for the months of the reporting period.

1. Computation method given in "TRNSYS, a Transient Simulation Program," Engineering Experiment Station Report #38, Solar Energy Laboratory, University of Wisconsin, Madison.

## SECTION 6

### REFERENCES

- \*1. National Solar Data Network, Department of Energy, prepared under Contract Number DE-AC01-79CS30027, Vitro Laboratories, Silver Spring, Maryland, January 1980.
2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.
3. E. Streed, et al, Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.
- \*4. Mears, J. C., Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.
5. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.
- \*6A. User's Guide to Monthly Performance Reports, June 1980, SOLAR/0004-80/18, Vitro Laboratories, Silver Spring, Maryland.
- \*6B. Instrumentation Installation Guidelines March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.
7. Monthly Performance Report, Loyola University, February 1981, SOLAR/1055-81/02, Vitro Laboratories, Silver Spring, Maryland.
8. Monthly Performance Report, Loyola University, March 1981, SOLAR/1055-81/03, Vitro Laboratories, Silver Spring, Maryland.
9. Monthly Performance Report, Loyola University, April 1981, SOLAR/1055-81/04, Vitro Laboratories, Silver Spring, Maryland.
10. Monthly Performance Report, Loyola University, May 1981, SOLAR/1055-81/05, Vitro Laboratories, Silver Spring, Maryland.
11. Monthly Performance Report, Loyola University, June 1981, SOLAR/1055-81/06, Vitro Laboratories, Silver Spring, Maryland.

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

APPENDIX A  
SYSTEM DESCRIPTION

The Loyola University solar energy system, located in New Orleans, Louisiana, supplies energy necessary to preheat approximately 9,000 gallons of domestic hot water (DHW) each day to Biever Hall Dormitory. Biever Hall is a six-story dormitory that houses 420 students. The system is designed to supply 140°F water to bathrooms, showers, and eight washing machines.

The solar energy system was added to the existing water heating system and has 15 arrays of flat-plate collectors with a gross area of 4,590 square feet, and a net area of 4,320 square feet. The collectors face 16 degrees west of south at an angle of 38 degrees to the horizontal. The system is an open loop system which uses potable water as both the collector fluid and storage medium. City water is preheated by flat-plate collectors on the roof and stored in a 5,000-gallon tank located on the west side of the building at ground level. Upon demand, the preheated water is transported to two existing 1,500-gallon hot water tanks. When solar energy is insufficient to satisfy the hot water load, auxiliary energy is supplied by a central heating plant via a high temperature/high pressure line. The system, shown schematically in Figure A-1, has five modes of operation.

Mode 1 - Collector-to-Storage - This mode activates when the temperature difference between the collector outlet and the water in the bottom of the storage tank exceeds 16°F. Pump EP100, or back-up pump EP101, turns on to circulate the solar heated water from storage to collector and back to storage. This mode terminates when the temperature difference between the collector outlet and the water in the bottom of the storage tank is less than three degrees Fahrenheit.

Mode 2 - Storage-to-Load - This mode activates when there is a hot water demand. In this mode, makeup water from the cold water supply flows through a water softener system and then to the 5,000-gallon storage tank. Solar heated water is then forced out of the top of the tank and transferred to the two 1,500-gallon DHW tanks; where, if not hot enough, auxiliary heat is used to maintain 140°F water temperature.

Mode 3 - Recirculation of DHW - Pump EP300 and, alternately, pump EP301 are used to continuously recirculate the DHW throughout the six-story dormitory. This provides hot water always available at the taps.

Mode 4 - Freeze Protection - When the outdoor ambient temperature is less than or equal to 38°F, mode 1 is then activated. This warm water is pumped through the collector arrays, thus preventing freezing.

Mode 5 - Heat Rejection - When the temperature exiting the collectors equals or exceeds 180°F, a valve is activated, the water is drained and not allowed to enter the storage tank.

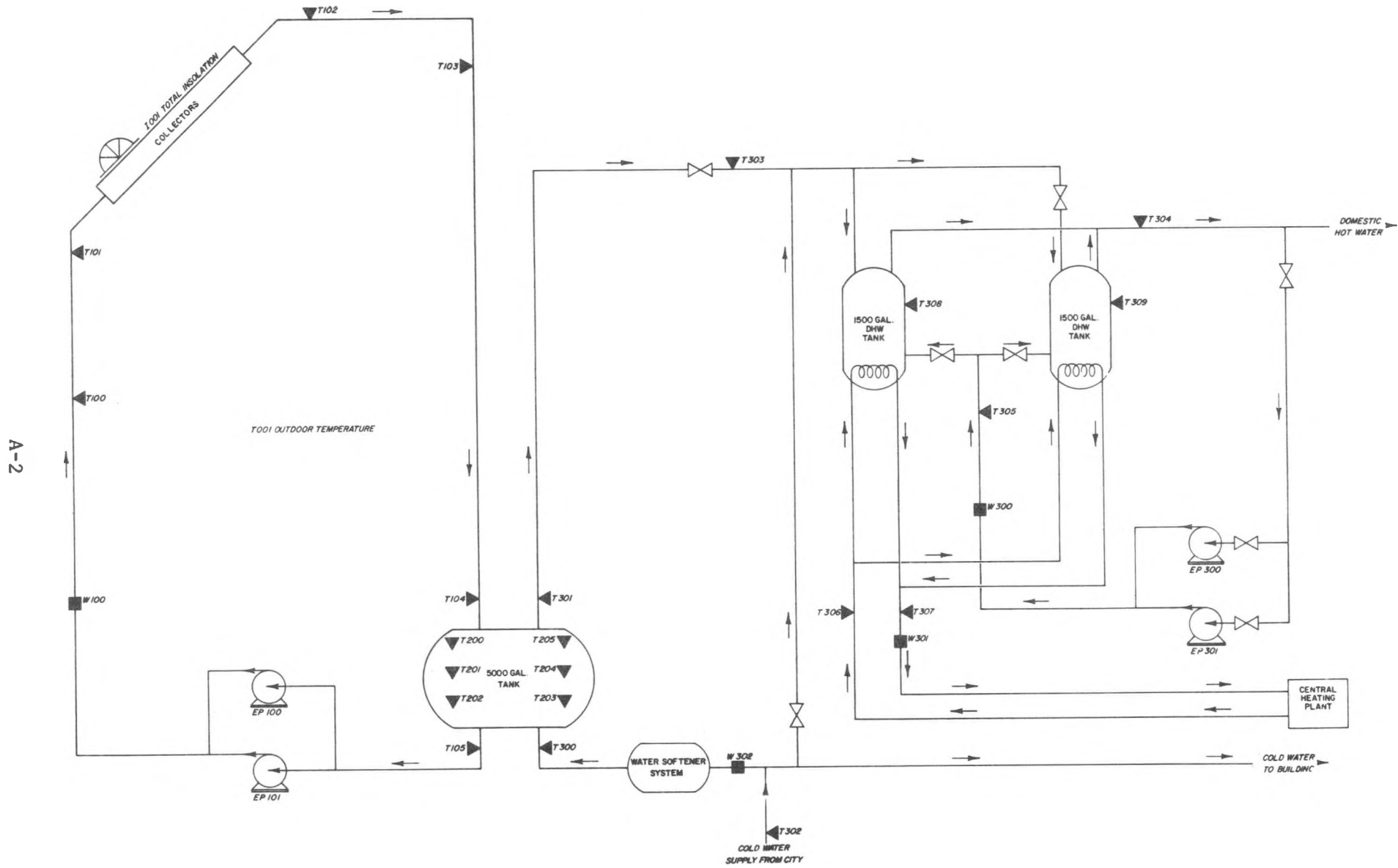


Figure A-1. Loyola University Solar Energy System Schematic

## APPENDIX B

### PERFORMANCE EVALUATION TECHNIQUES

The performance of the Loyola University solar energy system is evaluated by calculating a set of primary performance factors which are based on those in the intergovernmental agency report "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program" (NBSIR-76/1137).

An overview of the NSDN data collection and dissemination process is shown in Figure B-1.

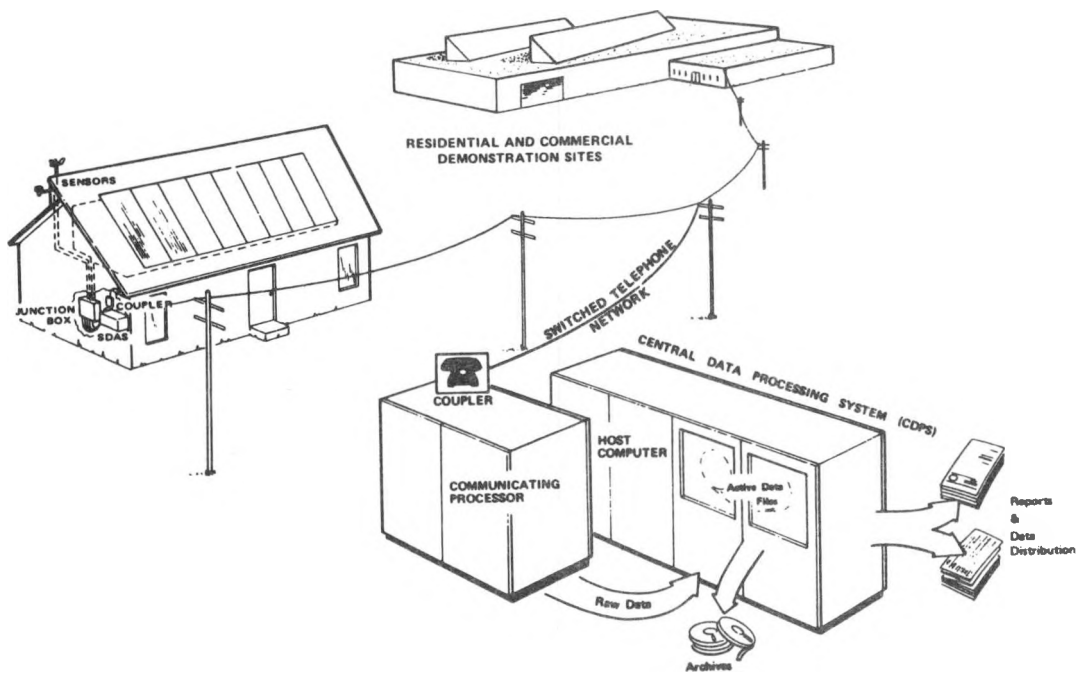


Figure B-1. The National Solar Data Network

## DATA COLLECTION AND PROCESSING

Each site contains standard industrial instrumentation modified for the particular site. Sensors measure temperatures, flows, insolation, electric power, fossil fuel usage, and other parameters. These sensors are all wired into a junction box (J-box), which is in turn connected to a microprocessor data logger called the Site Data Acquisition Subsystem (SDAS). The SDAS can read up to 96 different channels, one channel for each sensor. The SDAS takes the analog voltage input to each channel and converts it to a 10-bit word. At intervals of every 320 seconds, the SDAS samples each channel and records the values on a cassette tape. Some of the channels can be sampled 10 times in each 320 second interval, and the average value is recorded in the tape.

Each SDAS is connected through a modem to voice-grade telephone lines which are used to transmit the data to a central computer facility. This facility is the Central Data Processing System (CDPS), located at Vitro Laboratories in Silver Spring, Maryland. The CDPS hardware consists of an IBM System 7, an IBM 370/145, and an IBM 3033. The System 7 periodically calls up each SDAS in the system and has the SDAS transmit the data on the cassette tape back to the System 7. Typically, the System 7 collects data from each SDAS six times a week, although the tape can hold three to five days of data, depending on the number of channels.

The data received by the System 7 are in the form of digital counts in the range of 0-1,023. These counts are then processed by software in the CDPS, where they are converted from counts to engineering units (EU) by applying appropriate calibration constants. The engineering unit data called "detailed measurements" in the software are then tabulated on a daily basis for the site analyst. The CDPS is also capable of transforming this data into plots, graphs, and processed reports.

## DATA ANALYSIS

The analyst develops a unique set of "site equations" (given in Appendix D) for each site in the NSDN, following the guidelines presented herein.

The equations calculate the flow of energy through the system, including solar energy, auxiliary energy, and losses. These equations are programmed in PL/1 and become part of the Central Data Processing System. The PL/1 program for each site is termed the site software. The site software processes the detailed data, using as input a "measurement record" containing the data for each scan interval. The site software produces as output a set of performance factors, on an hourly, daily, and monthly basis.

These performance factors (Appendix C) quantify the thermal performance of the system by computing energy flows throughout the various subsystems. The system performance may then be evaluated based on the efficiency of the system in transferring these energies.

Performance factors which are considered to be of primary importance are those which are essential for system evaluation. Without these primary performance factors (which are denoted by an asterisk in Appendix C), comparative evaluation of the wide variety of solar energy systems would be impossible. An

example of a primary performance factor is SECA - Solar Energy Collected by the Array. This is quite obviously a key parameter in system analysis.

Secondary performance factors are data deemed important and useful in comparison and evaluation of solar systems, particularly with respect to component interactions and simulation. In most cases these secondary performance factors are computed as functions of primary performance factors.

There are irregularly occurring cases of missing data as is normal for any realtime data collection from mechanical equipment. When data for individual scans or whole hours are missing, values of performance factors are assigned which are interpolated from measured data. If no valid measured data are available for interpolation, a zero value is assigned. If data are missing for a whole day, each hour is interpolated separately. Data are interpolated in order to provide solar system performance factors on a whole hour, whole day and whole month basis for use by architects and designers.

### REPORTING

The performance of the Loyola University solar energy system was analyzed for the period of February 1981 through June 1981 in this report. Monthly performance reports were published through December 1980 for the months when sufficient valid data were available. See the following page for a list of these reports.

OTHER DATA REPORTS ON THIS SITE\*

Monthly Performance Reports:

September 1980, SOLAR/1055-80/09

October 1980, SOLAR/1055-80/10

November 1980, SOLAR/1055-80/11

December 1980, SOLAR/1055-80/12

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\* These reports can be obtained (free) by contacting: U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830.

## APPENDIX C

### PERFORMANCE FACTORS AND SOLAR TERMS

The performance factors identified in the site equations (Appendix D) by the use of acronyms or symbols are defined in this Appendix in Section 1. Section 1 includes the acronym, the actual name of the performance factor, and a short definition.

Section 2 contains a glossary of solar terminology, in alphabetical order. These terms are included for quick reference by the reader.

Section 3 describes general acronyms used in this report.

- Section 1. Performance Factor Definitions and Acronyms
- Section 2. Solar Terminology
- Section 3. General Acronyms

SECTION 1. PERFORMANCE FACTOR DEFINITIONS AND ACRONYMS

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
AXE	Auxiliary Electric Fuel Energy to Load Subsystem	Amount of electrical energy required as a fuel source for all load subsystems.
AXF	Auxiliary Fossil Fuel Energy to Load Subsystem	Amount of fossil energy required as a fuel source for all load subsystems.
* AXT	Auxiliary Thermal Energy to Load Subsystems	Thermal energy delivered to all load subsystems to support a portion of the subsystem loads, from all auxiliary sources.
CAE	SCS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SCS to be converted and applied to the SCS load.
CAF	SCS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SCS to be converted and applied to the SCS load.
CAREF	Collector Array Efficiency	Ratio of the collected solar energy to the incident solar energy.
CAT	SCS Auxiliary Thermal Energy	Amount of energy provided to the SCS by a BTU heat transfer fluid from an auxiliary source.
* CL	Space Cooling Subsystem Load	Energy required to satisfy the temperature control demands of the space cooling subsystem.
CLAREA	Collector Array Area	The gross area of one collector panel multiplied by the number of panels in the array.
COPE	SCS Operating Energy	Amount of energy required to support the SCS operation which is not intended to be applied directly to the SCS load.
CSAUX	Auxiliary Energy to ECSS	Amount of auxiliary energy supplied to the ECSS.
* CSCEF	ECSS Solar Conversion Efficiency	Ratio of the solar energy supplied from the ECSS to the load subsystems to the incident solar energy on the collector array.

\* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.
CSEO	Energy Delivered from ECSS to Load Subsystems	Amount of energy supplied from the ECSS to the load subsystems (including any auxiliary energy supplied to the ECSS).
* CSFR	SCS Solar Fraction	Portion of the SCS load which is supported by solar energy.
CSOPE	ECSS Operating Energy	Amount of energy used to support the ECSS operation (which is not intended to be supplied to the ECSS thermal state).
CSRJE	ECSS Rejected Energy	Amount of energy intentionally rejected or dumped from the ECSS subsystem.
* CSVE	SCS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional SCS and the actual electrical energy required to support the demonstration SCS, for identical SCS loads.
* CSVF	SCS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional SCS and the actual fossil energy required to support the demonstration SCS, for identical loads.
HAE	SHS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SHS to be converted and applied to the SHS load.
HAF	SHS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SHS to be converted and applied to the SHS load.
HAT	SHS Auxiliary Thermal Energy	Amount of energy provided to the SHS by a heat transfer fluid from an auxiliary source.
* HL	Space Heating Subsystem Load	Energy required to satisfy the temperature control demands of the space heating subsystem.

\* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
HOPE	SHS Operating Energy	Amount of energy required to support the SHS operation (which is not intended to be applied directly to the SHS load).
HOURCT	Record Time	Count of hours elapsed from the start of 1977.
* HSMR	SHS Solar Fraction	Portion of the SHS load which is supported by solar energy.
HSE	Solar Energy to SHS	Amount of solar energy delivered to the SHS.
* HSVE	SHS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional SHS and the actual electrical energy required to support the demonstration SHS, for identical SHS loads.
* HSMV	SHS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional SHS and the actual fossil energy required to support the demonstration SHS, for identical SHS loads.
HWAE	HWS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the HWS to be converted and applied to the HWS load.
HWAF	HWS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the HWS to be converted and applied to the HWS load.
HWAT	HWS Auxiliary Thermal Energy	Amount of energy provided to the HWS by a heat transfer fluid from an auxiliary source.
HWCSM	Service Hot Water Consumption	Amount of heated water delivered to the load from the hot water subsystem.
* HWL	Hot Water Subsystem Load	Energy required to satisfy the temperature control demands of the building service hot water system.

\* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
HWOPE	HWS Operating Energy	Amount of energy required to support the HWS operation which is not intended to be applied directly to the HWS load.
HWSE	Solar Energy to HWS	Amount of solar energy delivered to the HWS.
* HWSFR	HWS Solar Fraction	Portion of the HWS load which is supported by solar energy.
* HWSVE	HWS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional HWS and the actual electrical energy required to support the demonstration HWS, for identical HWS loads.
* HWSVF	HWS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional HWS and the actual fossil energy required to support the demonstration HWS, for identical loads.
RELH	Relative Humidity	Average outdoor relative humidity at the site.
* SE	Incident Solar Energy	Amount of solar energy incident upon one square foot of the collector plane.
SEA	Incident Solar Energy on Array	Amount of solar energy incident upon the collector array.
* SEC	Collector Solar Energy	Amount of thermal energy added to the heat transfer fluid for each square foot of the collector area.
SECA	Collected Solar Energy by Array	Amount of thermal energy added to the heat transfer fluid by the collector array.
SEDF	Diffuse Insolation	Amount of diffuse solar energy incident upon one square foot of a collector plane.
SEOP	Operational Incident Solar Energy	Amount of incident solar energy upon the collector array whenever the collector loop is active.

\* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
* SEL	Solar Energy to Load Subsystems	Amount of solar energy supplied by the ECSS to all load subsystems.
* SFR	Solar Fraction of System Load	Portion of the system load which was supported by solar energy.
STECH	Change in ECSS Stored Energy	Change in ECSS stored energy during reference time period.
STEFF	ECSS Storage Efficiency	Ratio of the sum of energy supplied by ECSS storage and the change in ECSS stored energy to the energy delivered to the ECSS storage.
STEI	Energy Delivered to ECSS Storage	Amount of energy delivered to ECSS storage by the collector array and from auxiliary sources.
STEO	Energy Supplied by ECSS Storage	Amount of energy supplied by ECSS storage to the load subsystems.
* SYSL	System Load	Energy required to satisfy all desired temperature control demands at the output of all subsystems.
* SYSOPE	System Operating Energy	Amount of energy required to support the system operation, including all subsystems, which is not intended to be applied directly to the system load.
* SYSPF	System Performance Factor	Ratio of the system load to the total equivalent fossil energy expended or required to support the system load.
* TA	Ambient Temperature	Average temperature of the ambient air.
* TB	Building Temperature	Average temperature of the controlled space of the building.
TCECOP	TCE Coefficient of Performance	Coefficient of performance of the thermodynamic conversion equipment.
TCEI	TCE Thermal Input Energy	Equivalent thermal energy which is supplied as a fuel source to thermodynamic conversion equipment.

\* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
TCEL	Thermodynamic Conversion Equipment Load	Controlled energy output of thermodynamic conversion equipment.
TCEOPE	TCE Operating Energy	Amount of energy required to support the operation of thermodynamic conversion equipment which is not intended to appear directly in the load.
TCERJE	TCE Reject Energy	Amount of energy intentionally rejected or dumped from thermodynamic conversion equipment as a by-product or consequence of its principal operation.
TDA	Daytime Average Ambient Temperature	Average temperature of the ambient air during the daytime (during normal collector operation period).
* TECSM	Total Energy Consumed by System	Amount of energy demand of the system from external sources; sum of all fuels, operating energies, and collected solar energy.
THW	Service Hot Water Temperature	Average temperature of the service hot water supplied by the system.
TST	ECSS Storage Temperature	Average temperature of the ECSS storage medium.
* TSVE	Total Electrical Energy Savings	Difference in the estimated electrical energy required to support an assumed similar conventional system and the actual electrical energy required to support the system, for identical loads; sum of electrical energy savings for all subsystems.
* TSVF	Total Fossil Energy Savings	Difference in the estimated fossil energy required to support an assumed similar conventional system and the actual fossil energy required to support the system, for identical loads; sum of fossil energy savings of all subsystems.
TSW	Supply Water Temperature	Average temperature of the supply water to the hot water subsystem.

\* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
WDIR	Wind Direction	Average wind direction at the site.
WIND	Wind Velocity	Average wind velocity at the site.

\* Primary Performance Factors

## SECTION 2. SOLAR TERMINOLOGY

Absorptivity	The ratio of absorbed radiation by a surface to the total incident radiated energy on that surface.
Active Solar System	A system in which a transfer fluid (liquid or air) is circulated through a solar collector where the collected energy is converted, or transferred, to energy in the medium.
Air Conditioning	Popularly defined as space cooling, more precisely, the process of treating indoor air by controlling the temperature, humidity and distribution to maintain specified comfort conditions.
Ambient Temperature	The surrounding air temperature.
Auxiliary Energy	In solar energy technology, the energy supplied to the heat or cooling load from other than the solar source, usually from a conventional heating or cooling system. Excluded are operating energy, and energy which may be supplemented in nature but does not have the auxiliary system as an origin, i.e., energy supplied to the space heating load from the external ambient environment by a heat pump. The electric energy input to a heat pump is defined as operating energy.
Auxiliary Energy Subsystem	In solar energy technology the Auxiliary Energy System is the conventional heating and/or cooling equipment used as supplemental or backup to the solar system.
Array	An assembly of a number of collector elements, or panels, into the solar collector for a solar energy system.
Backflow	Reverse flow.
Backflow Preventer	A valve or damper installed to prevent reverse flow.
Beam Radiation	Radiated energy received directly, not from scattering or reflecting sources.
Collected Solar Energy	The thermal energy added to the heat transfer fluid by the solar collector.

Collector Array Efficiency	Same as Collector Conversion Efficiency. Ratio of the collected solar energy to the incident solar energy. (See also Operational Collector Efficiency.)
Collector Subsystem	The assembly of components that absorbs incident solar energy and transfers the absorbed thermal energy to a heat transfer fluid.
Concentrating Solar Collector	A solar collector that concentrates the energy from a larger area onto an absorbing element of smaller area.
Conversion Efficiency	Ratio of thermal energy output to solar energy incident on the collector array.
Conditioned Space	The space in a building in which the air is heated or cooled to maintain a desired temperature range.
Control System or Subsystem	The assembly of electric, pneumatic, or hydraulic, sensing, and actuating devices used to control the operating equipment in a system.
Cooling Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is <u>above</u> 65°F.
Cooling Tower	A heat exchanger that transfers waste heat to outside ambient air.
Diffuse Radiation	Solar Radiation which is scattered by air molecules, dust, or water droplets and incapable of being focused.
Drain Down	An arrangement of sensors, valves and actuators to automatically drain the solar collectors and collector piping to prevent freezing in the event of cold weather.
Duct Heating Coil	A liquid-to-air heat exchanger in the duct distribution system.
Effective Heat Transfer Coefficient	The heat transfer coefficient, per unit plate area of a collector, which is a measure of the total heat losses per unit area from all sides, top, back, and edges.
Energy Gain	The thermal energy gained by the collector transfer fluid. The thermal energy output of the collector.

Energy Savings	The estimated difference between the fossil and/or electrical energy requirements of an assumed conventional system (carrying the full measured load) and the actual electrical and/or fossil energy requirements of the installed solar-assisted system.
Expansion Tank	A tank with a confined volume of air (or gas) whose inlet port is open to the system heat transfer fluid. The pressure and volume of the confined air varies as to the system heat transfer fluid expands and contracts to prevent excessive pressure from developing and causing damage.
F-Curve	The collector instantaneous efficiency curve. Used in the "F-curve" procedure for collector analysis (see Instantaneous Efficiency).
Fixed Collector	A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.
Flat Plate Collector	A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).
Focusing Collector	A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.
Fossil Fuel	Petroleum, coal, and natural gas derived fuels.
Glazing	In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel.

Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is <u>below</u> 65°F.
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{T_i - T_a}{I}$ , under steady state conditions (see Operating Point).
Instantaneous Efficiency Curve	A plot of solar collector efficiency against operating point, $\frac{T_i - T_a}{I}$ (see Operating Point).
Incidence Angle	The angle between the line to a radiating source (the sun) and a line normal to the plane of the surface being irradiated.
Incident Solar Energy	The amount of solar energy irradiating a surface taking into account the angle of incidence. The effective area receiving energy is the product of the area of the surface times the cosine of the angle of incidence.
Insolation	Incoming solar radiation.
Load	That to which energy is supplied, such as space heating load or cooling load. The system load is the total solar and auxiliary energy required to satisfy the required heating or cooling.
Manifold	The piping that distributes the transport fluid to and from the individual panels of a collector array.
Microclimate	Highly localized weather features which may differ from long term regional values due to the interaction of the local surface with the atmosphere.

Nocturnal Radiation	The loss of thermal energy by the solar collector to the night sky.
Operating Energy	The amount of energy (usually electrical energy) required to operate the solar and auxiliary equipments and to transport the thermal energy to the point of use, and which is not intended to directly affect the thermal state of the system.
Operating Point	A solar energy system has a dynamic operating range due to changes in level of insolation (I), fluid input temperature (T), and outside ambient temperature (Ta). The operating point is defined as:
	$\frac{T_i - T_a}{I} \quad \frac{^{\circ}\text{F} \times \text{hr.} \times \text{sq. ft.}}{\text{BTU}}$
Operational Collector Efficiency	Ratio of collected solar energy to incident solar energy <u>only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.</u>
Outgassing	The emission of gas by materials and components, usually during exposure to elevated temperature, or reduced pressure.
Passive Solar System	A system which uses architectural components of the building to collect, distribute, and store solar energy.
Pebble Bed (Rock Bed)	A space filled with uniform-sized pebbles to store solar-source energy by raising the temperature of the pebbles.
Reflected Radiation	Insolation reflected from a surface, such as the ground or a reflecting element onto the solar collector.
Rejected Energy	Energy intentionally rejected, dissipated, or dumped from the solar system.
Retrofit	The addition of a solar energy system to an existing structure.
Selective Surface	A surface that has the ability to readily absorb solar radiation, but re-radiates little of it as thermal radiation.

Sensor	A device used to monitor a physical parameter in a system, such as temperature or flow rate, for the purpose of measurement or control.
Solar Conditioned Space	The area in a building that depends on solar energy to provide a fraction of the heating and cooling needs.
Solar Fraction	The fraction of the total load supplied by solar energy. The ratio of solar energy supplied to loads divided by total load. Often expressed as a percentage.
Solar Savings Ratio	The ratio of the solar energy supplied to the load minus the solar system operating energy, divided by the system load.
Storage Efficiency, $N_s$	Measure of effectiveness of transfer of energy through the storage subsystem taking into account system losses.
Storage Subsystem	The assembly of components used to store solar-source energy for use during periods of low insolation.
Stratification	A phenomenon that causes a distinct thermal gradient in a heat transfer fluid, in contrast to a thermally homogeneous fluid. Results in the layering of the heat transfer fluid, with each layer at a different temperature. In solar energy systems, stratification can occur in liquid storage tanks or rock beds, and may even occur in pipes and ducts. The temperature gradient or layering may occur in a horizontal, vertical or radial direction.
System Performance Factor	Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
Ton of Refrigeration	The heat equivalent to the melting of one ton (2,000 pounds) of ice at 32°F in 24 hours. A ton of refrigeration will absorb 12,000 BTU/hr, or 288,000 BTU/day.
Tracking Collector	A solar collector that moves to point in the direction of the sun.
Zone	A portion of a conditioned space that is controlled to meet heating or cooling requirements separately from the other space or other zones.

### SECTION 3. GENERAL ACRONYMS

ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineering.
BTU	British Thermal Unit, a measure of heat energy. The quantity of heat required to raise the temperature of one pound of pure water one Fahrenheit degree. One BTU is equivalent to $2.932 \times 10^{-4}$ kwh of electrical energy.
COP	Coefficient of Performance. The ratio of total load to solar-source energy.
DHW	Domestic Hot Water.
ECSS	Energy Collection and Storage System.
HWS	Domestic or Service Hot Water Subsystem.
KWH	Kilowatt Hours, a measure of electrical energy. The product of kilowatts of electrical power applied to a load times the hours it is applied. One kwh is equivalent to 3,413 BTU of heat energy.
NSDN	National Solar Data Network.
SCS	Space Cooling Subsystem.
SHS	Space Heating Subsystem.
SOLMET	Solar Radiation/Meteorology Data.

APPENDIX D  
PERFORMANCE EQUATIONS  
LOYOLA UNIVERSITY

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance computations 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  $\text{lb}_m/\text{min}$  and  $\Delta H$  is the enthalpy change, in  $\text{BTU}/\text{lb}_m$ , of the fluid as it passes through the heat exchanging component.

For a liquid system  $\Delta H$  is generally given by

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

where  $C_p$  is the average specific heat, in  $\text{BTU}/\text{lb}_m\text{-}^\circ\text{F}$ , of the heat transfer fluid and  $\Delta T$ , in  $^\circ\text{F}$ , is the temperature differential across the heat exchanging component.

\* See Appendix B.

For an air system  $\Delta H$  is generally given by

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

where  $H_a(T)$  is the enthalpy, in BTU/lb<sub>m</sub>, 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

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

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.

### Letter Designations

C or CP	=	Specific Heat
D	=	Direction or Position
EE	=	Electric Energy
EP	=	Electric Power
F	=	Fuel Flow Rate
HWD	=	Functional procedure to calculate the specific heat of water at the average of the inlet and outlet temperatures
H	=	Enthalpy
HR	=	Humidity Ratio
I	=	Incident Solar Flux (Insolation)
M	=	Mass Flow Rate
N	=	Performance Parameter
P	=	Pressure
PD	=	Differential Pressure
Q	=	Thermal Energy
RHO	=	Density
T	=	Temperature
TD	=	Differential Temperature
V	=	Velocity
W	=	Heat Transport Medium Volume Flow Rate
TI	=	Time
<u>P</u>	=	Appended to a function designator to signify the value of the function during the previous iteration

Subsystem Designations  
Number Sequence

Subsystem/Data Group

001 to 099	Climatological
100 to 199	Collector and Heat Transport
200 to 299	Thermal Storage
300 to 399	Hot Water
400 to 499	Space Heating
500 to 599	Space Cooling
600 to 699	Building/Load

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

COLLECTOR AND STORAGE SUBSYSTEM OPERATING ENERGY

$$\text{CSOPE} = (\text{EP100} + \text{EP101}) \times 56.8833$$

AVERAGE AMBIENT TEMPERATURE (°F)

$$\text{TA} = (1/60) \times \sum \text{T001} \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$\text{TDA} = (1/360) \times \sum \text{T001} \times \Delta\tau$$

for  $\pm$  three hours from solar noon

AVERAGE COLD WATER TEMPERATURE (°F)

$$\text{TSW} = \sum (\text{T302} \times \text{M302}/\text{M302})$$

AVERAGE HOT WATER TEMPERATURE (°F)

$$\text{THW} = \sum (\text{T304} \times \text{M302}/\text{M302})$$

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT<sup>2</sup>)

$$\text{SE} = (1/60) \times \sum \text{I001} \times \Delta\tau$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$\text{SEOP} = \text{SE} \times \text{COLLECTOR AREA} \times (1/60) \times \Delta\tau$$

when the collector loop is active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$\text{SECA} = \sum [\text{M100} \times \text{CP} \times (\text{T102} - \text{T101})] \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \sum [M100 \times CP (T104 - T105) \times \Delta\tau]$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \sum [M302 \times CP \times (T301 - T300) \times \Delta\tau]$$

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TST = (1/60) \times \sum [(T200 + T201 + T202 + T203 + T204 + T205)/6]$$

HOT WATER CONSUMED (GALLONS)

$$HWCSM = \sum (WD302)$$

$$\text{where } WD302 = W302 \text{ (current scan)} - W302 \text{ (previous scan)}$$

HOT WATER SOLAR ENERGY USED (BTU)

$$HWSE = \sum M302 \times CP \times (T303 - T300) \times \Delta\tau$$

HOT WATER FOSSIL SAVINGS (BTU)

$$HWSVF = HWSE/0.6$$

HOT WATER OPERATING ENERGY

$$HWOPE = (EP300 + EP301) \times 56.8833$$

HOT WATER AUXILIARY THERMAL ENERGY (BTU)

$$HWAT = M301 \times CP \times (T306 - T307)$$

HOT WATER AUXILIARY FOSSIL ENERGY (BTU)

$$HWAFF = HWAT/0.6$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

$$\text{where } CLAREA = \text{collector area (ft}^2\text{)}$$

COLLECTED SOLAR ENERGY PER SQUARE FOOT OF COLLECTOR (BTU/ft<sup>2</sup>)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY (PERCENT)

$$CLEF = SECA/SEA$$

OPERATIONAL COLLECTOR EFFICIENCY (PERCENT)

$$\text{CLEFOP} = \text{SECA}/\text{SEOP}$$

CHANGE IN STORED ENERGY (BTU)

$$\text{STECH} = \text{STECH}_1 - \text{STECH}_{1p}$$

where  $\text{STECH}_1$  is energy contained in storage and subscript  $p$  refers to a prior reference value.

STORAGE EFFICIENCY

$$\text{STEFF} = (\text{STECH} + \text{STEO})/\text{STEI}$$

ENERGY DELIVERED FROM ECSS TO HOT WATER SUBSYSTEM

$$\text{CSEO} = \text{HWSE}$$

SOLAR ENERGY TO LOAD SUBSYSTEMS

$$\text{SEL} = \text{CSEO}$$

ECSS SOLAR CONVERSION EFFICIENCY

$$\text{CSCEF} = \text{SEL}/\text{SEA}$$

HOT WATER LOAD

$$\text{HWL} = \text{HWSE} \times \text{HWAT}$$

HOT WATER DEMAND

$$\text{HWDM} = \text{M302} \times \text{CP} \times (\text{T304} - \text{T302})$$

HOT WATER SOLAR FRACTION

$$\text{HWSFR} = \text{HWSE}/\text{HWL}$$

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

$$\text{AXT} = \text{HWAT}$$

SYSTEM LOAD (BTU)

$$\text{SYSL} = \text{HWL}$$

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

$$\text{SFR} = \text{HWSFR}$$

SYSTEM OPERATING ENERGY

$$\text{SYSOPE} = \text{CSOPE} + \text{HWOPE}$$

AUXILIARY FOSSIL ENERGY TO LOAD (BTU)

$$\text{AXF} = \text{HWAFF}$$

TOTAL ENERGY CONSUMED (BTU)

$$\text{TECSM} = \text{SECA} + \text{AXT} + \text{SYSOPE}$$

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

$$\text{TSVE} = -\text{CSOPE}$$

TOTAL FOSSIL ENERGY SAVINGS (BTU)

$$\text{TSVF} = \text{HWSVF}$$

SYSTEM PERFORMANCE FACTOR

$$\text{SYSPF} = \text{SYSL} / [\text{AXF} + ((\text{AXE} + \text{SYSOPE}) \times 3.33)]$$

**APPENDIX E**  
**METEOROLOGICAL CONDITIONS**

LOYOLA UNIVERSITY LONG-TERM WEATHER DATA

COLLECTOR TILT: 38.0 DEGREES  
 LATITUDE: 29.95 DEGREES

LOCATION: NEW ORLEANS, LOUISIANA  
 COLLECTOR AZIMUTH: -16.00 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
FEB	2,267	1,113	0.49121	1.264	1,407	299	35	56
MAR	2,755	1,416	0.51384	1.104	1,563	188	55	61
APR	3,211	1,781	0.55465	0.960	1,710	29	137	69
MAY	3,489	1,969	0.56435	0.857	1,688	0	313	75
JUN	3,586	2,006	0.55934	0.815	1,634	0	462	80

LEGEND:

HOBAR - Monthly average daily extraterrestrial radiation (ideal) in BTU/day-ft<sup>2</sup>.

HBAR - Monthly average daily radiation (actual) in BTU/day-ft<sup>2</sup>.

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 x HBAR) in BTU/day-ft<sup>2</sup>.

HDD - Number of heating degrees-days per month.

CDD - Number of cooling degrees-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

MONTHLY REPORT: LOYOLA UNIVERSITY  
 FEBRUARY 1981  
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	319	59	66
2	2015	44	44
3	1846	48	50
4	566	48	55
5	133	42	43
6	132	47	50
7	233	52	55
8	2000	54	55
9	1183	54	57
10	0	62	61
11	2242	27	35
12	2106	35	38
13	491	42	44
14	264	47	50
15	125	52	51
16	401	60	65
17	362	61	65
18	882	60	63
19	1538	63	69
20	1751	67	72
21	709	63	68
22	1043	60	62
23	2155	59	67
24	2065	63	74
25	920	64	71
26	1793	66	75
27	1983	66	76
28	1535	65	72
SUM	30795	-	-
AVG	1100	55	59

MONTHLY REPORT: LOYOLA UNIVERSITY  
 MARCH 1981  
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	352	67	71
2	1700	61	62
3	598	61	64
4	184	67	71
5	2141	62	68
6	1943	58	61
7	362	58	60
8	388	56	57
9	2174	59	64
10	1378	58	63
11	1634	61	67
12	710	59	63
13	615	57	59
14	1982	61	72
15	1393	63	71
16	1967	63	67
17	1913	60	68
18	1907	65	75
19	2274	52	54
20	2079	57	63
21	408	61	65
22	1900	61	68
23	2296	56	58
24	2219	58	64
25	1440	60	69
26	1966	63	72
27	1485	64	71
28	1053	68	72
29	259	70	71
30	2201	73	79
31	418	72	77
SUM	43339	-	-
AVG	1398	62	67

MONTHLY REPORT: LOYOLA UNIVERSITY  
 APRIL 1981  
 ENVIRONMENTAL SUMMARY

MONTHLY REPORT: LOYOLA UNIVERSITY  
 MAY 1981  
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	481	72	74
2	916	72	78
3	990	73	79
4	1289	76	79
5	2273	68	70
6	1806	66	72
7	1617	66	72
8	1145	70	75
9	1199	73	80
10	1640	71	79
11	846	72	77
12	1365	74	80
13	945	74	81
14	1293	74	80
15	1870	75	84
16	1043	73	80
17	1337	74	79
18	1591	75	81
19	1561	76	81
20	1389	76	81
21	1462	76	82
22	1116	76	80
23	914	73	79
24	1124	71	74
25	596	72	77
26	1918	72	80
27	1824	74	82
28	1591	76	83
29	1174	77	83
30	904	75	82
SUM	39218	-	-
AVG	1307	73	79

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1790	75	80
2	1856	73	77
3	1557	72	78
4	464	74	76
5	1189	74	82
6	436	70	72
7	1336	69	69
8	1550	72	77
9	1502	74	81
10	1865	69	75
11	2035	68	73
12	1962	71	80
13	2076	73	81
14	1620	74	80
15	2020	71	75
16	918	73	76
17	1760	78	82
18	1200	79	82
19	1159	77	79
20	1036	65	69
21	2102	70	77
22	1752	73	81
23	1590	75	82
24	1611	78	84
25	709	77	80
26	1498	78	83
27	1826	81	84
28	1781	83	90
29	1916	82	90
30	1830	82	86
31	1163	80	87
SUM	47110	-	-
AVG	1520	75	80

MONTHLY REPORT: LOYOLA UNIVERSITY  
 JUNE 1981  
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	955	76	82
2	1566	81	87
3	1343	81	86
4	881	81	85
5	683	81	84
6	1737	83	89
7	954	80	80
8	1328	82	83
9	1716	84	89
10	1114	81	90
11	1175	81	87
12	1680	84	89
13	1807	84	89
14	1781	84	96
15	1712	85	91
16	1614	85	91
17	1814	86	92
18	1104	86	91
19	1867	86	93
20	1333#	82#	87#
21	1333#	82#	87#
22	1135#	80#	87#
23	1035	80	81
24	865	79	81
25	791	80	84
26	1033	82	86
27	1728	84	90
28	1609	85	90
29	559	79	77
30	1720	82	89
SUM	39972	-	-
AVG	1332	82	87

# <40% VALID DATA.

## APPENDIX F

### SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

The Loyola University solar site has been instrumented and operational since December 1979. There have been no problems with the solar system through June 1981. Data system problems prevented the collection of data for most of the operational period. These problems were primarily involved with temperature sensors in the collector/storage subsystem and with flow meter W301 which measures auxiliary energy usage. In February 1981, the faulty temperature sensors were repaired and the flow meter was modified. After this, useful information on the system's operation could be obtained and monthly reports were written.

APPENDIX G

CONVERSION FACTORS

Energy Conversion Factors

<u>Fuel Type</u>	<u>Energy Content</u>	<u>Fuel Source Conversion Factor</u>
Distillate fuel oil <sup>1</sup>	138,690 BTU/gallon	$7.21 \times 10^{-6}$ gallon/BTU
Residual fuel oil <sup>2</sup>	149,690 BTU/gallon	$6.68 \times 10^{-6}$ gallon/BTU
Kerosene	135,000 BTU/gallon	$7.41 \times 10^{-6}$ gallon/BTU
Propane	91,500 BTU/gallon	$10.93 \times 10^{-6}$ gallon/BTU
Natural gas	1,021 BTU/cubic feet	$979.4 \times 10^{-6}$ cubic feet/ BTU
Electricity	3,413 BTU/kilowatt-hour	$292.8 \times 10^{-6}$ kwh/BTU

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<sup>1</sup>No. 1 and No. 2 heating oils, diesel fuel, No. 4 fuel oils

<sup>2</sup>No. 5 and No. 6 fuel oils

## APPENDIX H

### SENSOR TECHNOLOGY

#### Temperature Sensors

Temperatures are measured by a Minco Products S53P platinum Resistance Temperature Detector (RTD). Because the resistance of platinum wire varies as a function of temperature, measurement of the resistance of a calibrated length of platinum wire can be used to accurately determine the temperature of the wire. This is the principle of the platinum RTD which utilizes a tiny coil of platinum wire encased in a copper-tipped probe to measure temperature.

Ambient temperature sensors are housed in a WeatherMeasure Radiation Shield in order to protect the probe from solar radiation. Care is taken to locate the sensor away from extraneous heat sources which could produce erroneous temperature readings. Temperature probes mounted in pipes are installed in stainless steel thermowells for physical protection of the sensor and to allow easy removal and replacement of the sensors. A thermally-conductive grease is used between the probe and the thermowell to assure faster temperature response.

All temperature sensors are individually calibrated at the factory. In addition, the bridge circuit is calibrated in the field using a five-point check.

Nominal Resistance @ 25°C:	100 ohms
No. of Leads:	3
Electrical Connection:	Wheatstone Bridge
Time Constant	1.5 seconds max. in water at 3 fps
Self Heating:	27 mw/°F

#### WIND SENSOR

Wind speed and direction are measured by a WeatherMeasure W102-P-DC/540 or W101-P-DC/540 wind sensor. Wind speed is measured by means of a four-bladed propeller coupled to a DC generator.

Wind direction is sensed by means of a dual-wiper 1,000-ohm long-life conductive plastic potentiometer. It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

Size:	29-3/4"L X 30"H
Starting Speed:	1 mph
Complete Tracking:	3 mph
Maximum Speed:	200 mph
Distance Constant (30 mph):	6.2'
Accuracy:	± 1% below 25 mph ± 3% above 25 mph
Time Constant:	0.145 second

## HUMIDITY SENSORS

The WeatherMeasure HMP-14U Solid State Relative Humidity Probe is used for the measurement of relative humidity. The operation of the sensor is based upon the capacitance of the polymer thin film capacitor. A one-micron-thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance change proportional to relative humidity.

Range:	0-100% R.H.
Response Time:	1 second to 90% humidity change at 20°C
Temperature Coefficient:	0.05% R.H./°C
Accuracy:	± 3% from 0-80% R.H. ± 5-6% 80-100% R.H.
Sensitivity:	0.2% R.H.

## INSOLATION SENSORS

The Eppley Model PSP pyranometer is used for the measurement of insolation. The pyranometer consists of a circular multijunction thermopile of the plated, (copper-constantan) wirewound type which is temperature compensated to render the response essentially independent of ambient temperature. The receiver is coated with Parsons' black lacquer (non-wavelength-selective absorption). The instrument is supplied with a pair of precision-ground polished concentric hemispheres of Schott optical glass transparent to light between 285 and 2800 nm of wavelength. The instrument is provided with a dessicator which may be readily inspected. Pyranometers designated as shadowband pyranometers are equipped with a shadowband which may be adjusted to block out any direct solar radiation. These instruments are used for the measurement of diffuse insolation.

Sensitivity:	9 $\mu$ V/W/m <sup>2</sup>
Temperature Dependence:	± 1% over ambient temperature range -20°C to 40°C
Linearity:	0.5% from 0 to 2,800 W/M <sup>2</sup>
Response Time:	1 second
Cosine Error:	± 1% 0-70° zenith angle ± 3% 70-80° zenith angle

## LIQUID FLOW SENSORS (NON-TOTALIZING)

The Ramapo Mark V strain gauge flow meters are used for the measurement of liquid flow. The flow meters sense the flow of the liquids by measuring the force exerted by the flow on a target suspended in the flow stream. This force is transmitted to a four active arm strain gauge bridge to provide a signal proportional to flow rate squared. The flow meters are available in a screwed end configuration, a flanged configuration, and a wafer configuration. Each flow meter is calibrated for the particular fluid being used in the application.

Materials:	Target - 17-PH stainless steel
	Body - Brass or stainless steel
	Seals - Buna-N
Fluid Temperature:	-40°F to 250°F
Calibration Accuracy:	± 1% ( $\frac{1}{2}$ " to $3\frac{1}{2}$ " line size)
	± 2% (4" and greater line size)
Repeatability and Hysteresis:	0.25% of reading

#### LIQUID FLOW SENSORS (TOTALIZING)

Hersey Series 400 flow meters are used to measure totalized liquid flow. The meter is a nutating disk, positive displacement type meter. An R-15 register with an SPDT reed switch is used to provide an output to the data acquisition subsystem.

The output of the reed switch is input to a Martin DR-1 Digital Ramp which counts the number of pulses and produces a zero to five volt analog signal corresponding to the pulse count.

Materials:	Meter body	- bronze
	Measuring chamber	- plastic
Accuracy:	± 1.5%	

#### AIR FLOW SENSORS

The Kurz 430 Series of thermal anemometers is used for the measurement of air flow. The basic sensing element is a probe which consists of a velocity sensor and a temperature sensor. The velocity sensor is heated and operated as a constant temperature thermal anemometer which responds to a "standard" velocity (referenced to 25°C and 760 mm Hg) or mass flow by sensing the cooling effect of the air as it passes over the heated sensor. The temperature sensor compensates for variations in ambient temperature.

Since the probe measures air velocity at only one point in the cross section of the duct, it is necessary to perform a careful duct mapping to relate the probe reading to the amount of air flowing through the entire duct. This is done by dividing the duct into small areas and taking a reading at the center of each area using a portable probe. The readings are then averaged to determine the overall duct velocity. The reading at the permanently installed probe is then ratioed to this reading. This duct mapping is done for each mode.

Accuracy:	± 2% of full scale over temperature range -20°C to 60°C
	± 5% of full scale over temperature range -60°C to 250°C
Response Time:	0.025 second
Repeatability:	0.25% full scale

### FUEL OIL FLOW SENSOR

The Kent Mini-Major is used as a flow oil flow meter. The meter utilizes an oscillating piston as a positive displacement element. The oscillating piston is connected to a pulser which sends pulses to the Site Data Acquisition Subsystem for totalization.

Operating Temperature:	100°C (max)
Flow Range:	0.6 to 48 gph
Accuracy:	± 1% of full scale

### FUEL GAS FLOW SENSOR

The American AC-175 gas meter is used for the measurement of totalized fuel gas flow. The drop in pressure between the inlet and outlet of the meter is responsible for the action of the meter. The principle of measurement is positive displacement. Four chambers in the meter fill and empty in sequence. The exact volume of compartments is known, so by counting the number of displacements the volume is measured. Sliding control valves control the entrance and exit of the gas to the compartments. The meter is temperature compensated to reference all volumetric readings to 60°F.

Rated Capacity:	175 cubic ft/hr
Max Working Pressure:	5 psi

### ELECTRIC POWER SENSORS

Ohio Semitronics Series PC5 wattmeters are used as electric power sensors. They utilize Hall effect devices as multipliers taking the product of the instantaneous voltage and current readings to determine the electrical power. This technique automatically takes power factor into consideration and produces a true power reading.

Power Factor Range:	1 to 0 (lead or lag)
Response Time:	250 ms
Temperature Effect:	1% of reading
Accuracy:	0.5% of full scale

### HEAT FLUX SENSORS

The Hy-Cal Engineering Model BI-7X heat flow sensor is used for the measurement of heat flux. The sensor consists basically of an insulating wafer, with a series of thermocouples arranged such that consecutive thermoelectric junctions fall on opposite sides of the wafer. This assembly is bonded to a heat sink to assure heat flow through the sensor. Heat is received on the exposed surface of the wafer and conducted through the heat sink. A temperature drop across the wafer is thus developed and is measured directly by each junction combination embodied along the wafer. Since the differential thermocouples are connected electrically in series, the voltages produced by each set of junctions is additive, thereby amplifying the signal directly proportional to

the number of junctions. The temperature drop across the wafer, and thus the output signal, is directly proportional to the heating rate.

Operation Temperature:	-50° to 200°F
Response Time:	6 seconds
Linearity:	2%
Repeatability:	0.5%
Sensitivity:	2 mv/BTU/ft <sup>2</sup> -hr
Size:	2" X 2"

APPENDIX I  
TYPICAL MONTHLY DATA

MONTHLY REPORT: MARCH 1981  
 SITE SUMMARY: LOYOLA UNIVERSITY

SI UNITS

GENERAL SITE DATA:

INCIDENT SOLAR ENERGY	197.520	GIGA JOULES
	492153	KJ/SQ.M.
COLLECTED SOLAR ENERGY	67.803	GIGA JOULES
	168942	KJ/SQ.M.
AVERAGE AMBIENT TEMPERATURE	16	DEGREES C
AVERAGE BUILDING TEMPERATURE	N.A.	DEGREES C
ECSS SOLAR CONVERSION EFFICIENCY	E0.36	
ECSS OPERATING ENERGY	1.636	GIGA JOULES
STORAGE EFFICIENCY	E98.90	PERCENT
EFFECTIVE HEAT TRANSFER COEFFICIENT	I	W/SQ M-DEG K
TOTAL SYSTEM OPERATING ENERGY	1.959	GIGA JOULES
TOTAL ENERGY CONSUMED	240.758	GIGA JOULES

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	235.38E	N.A.	N.A.	E235.38 GIGA JOULES
SOLAR FRACTION	27E	N.A.	N.A.	E27 PERCENT
SOLAR ENERGY USED	64.39E	N.A.	N.A.	E64.39 GIGA JOULES
OPERATING ENERGY	0.324	N.A.	N.A.	1.959 GIGA JOULES
AUX. THERMAL ENG	170.996	N.A.	N.A.	170.996 GIGA JOULES
AUX. ELECTRIC FUEL	N.A.	N.A.	N.A.	N.A. GIGA JOULES
AUX. FOSSIL FUEL	N.A.	N.A.	N.A.	N.A. GIGA JOULES
ELECTRICAL SAVINGS	N.A.	N.A.	N.A.	-1.636 GIGA JOULES
FOSSIL SAVINGS	107.31E	N.A.	N.A.	E107.31 GIGA JOULES

SYSTEM PERFORMANCE FACTOR: 80.74E

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 2.46

\* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED.

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980.  
 SOLAR/0004-80/18

## 1.1 SUMMARY AND CONCLUSIONS

During the reporting period the solar system performed well, supplying 28% of the hot water load. The design solar fraction of 52%, however, was not met. The design hot water load was based on a constant demand which required 4.50 million BTU per day. In practice, the hot water load varied substantially according to the time of the school year and whether or not classes were in session. The hot water load was greater than predicted during the winter months. A reduction could be seen in April during a week-long spring break as well as in May when the spring semester ended. Hot water consumption in June was only 20% of that in March. In addition, the cold water supply temperature rose significantly during the reporting period, further reducing the hot water load.

Standby DHW tank losses and recirculation losses are generally replaced by auxiliary energy in this system design. Hot water is supplied at an average temperature of 138°F. There is no provision to temper solar heated water if its temperature exceeds the DHW tank set point temperature. Under these conditions, solar energy replaced standby and recirculation losses. Of the total amount of thermal energy added to the DHW subsystem, 25% was lost in standby and recirculation losses.

The monthly thermal performance of the solar and conventional systems is presented in Figure 1 and Table 1. Figure 2, the Energy Flow Diagram, illustrates the system energy flows during the reporting period. The collector subsystem operated at an average efficiency of 29%, collecting 251.61 million BTU. Of this, 215.04 million BTU, or 85%, were delivered to the load resulting in natural gas savings of 351,027 cubic feet. The auxiliary system utilized 556.53 million BTU of thermal energy which is equivalent to 927.55 million BTU of fossil energy.

The misadjustment of control set points allowed the collectors to operate too long at the end of the day. During these times, the system incurred an electrical expense to operate the collector pumps when little or no solar energy was collected. Very often, stored solar energy was rejected.

Freeze protection is provided by storage water recirculation which is set to activate at 49°F outdoor ambient temperature. This set point should be reduced to the design value of 38°F to avoid the unnecessary rejection of solar energy.

During the five-month reporting period, the available solar insolation was 17% below the long-term average. The average ambient temperature was 1°F higher than the long-term average.

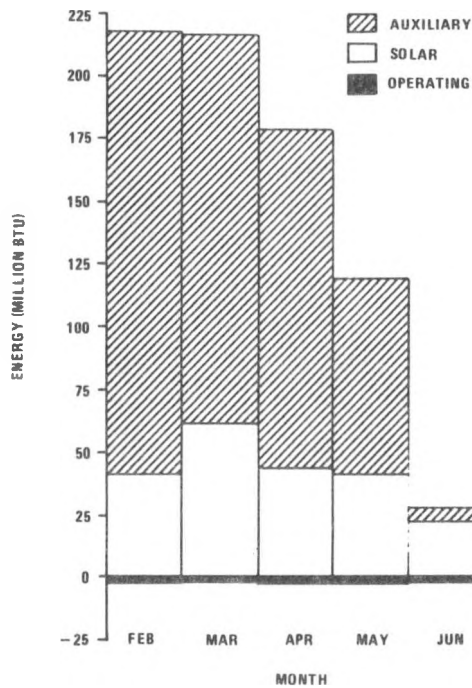
An energy imbalance, involving the storage subsystem, occurred throughout the reporting period. The cause of the imbalance is unknown. As a result, several performance factors were estimated. These include energy removed from storage, solar energy used and hot water consumption.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

LOYOLA UNIVERSITY  
FEBRUARY 1981 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED	AUXILIARY ENERGY	OPERATING ENERGY	ENERGY SAVINGS		SOLAR FRACTION (%)
				FOSSIL		FOSSIL	ELECTRICAL	
FEB	47.84	223.54	41.76	302.97	1.90	69.60	-1.20	19
MAR	64.27	223.11	61.03	270.13	1.86	101.72	-1.55	27
APR	54.03	178.26	47.77	217.48	2.34	79.62	-1.60	27
MAY	54.59	119.13	41.94	128.65	2.39	69.90	-1.47	35
JUN	30.88	27.53	22.54	8.32	2.05	37.57	-1.16	82
TOTAL	251.61	771.57	215.04	927.55	10.54	358.41	-6.98	-
AVERAGE	50.32	154.31	43.01	185.51	2.11	71.68	-1.40	28



OPERATING ENERGY FOR THE SYSTEM IS CONSIDERED A SYSTEM PENALTY AND IS PLOTTED AS A NEGATIVE VALUE BELOW THE ORIGIN.

Figure 1. System Thermal Performance  
Loyola University  
February 1981 through June 1981

MONTHLY REPORT: LOYOLA UNIVERSITY  
ENERGY COLLECTION AND STORAGE SUBSYSTEM (ECSS)

MARCH 1981

DAY OF MONTH	INCIDENT SOLAR ENERGY MILLION BTU	AMBIENT TEMP DEG-F	ENERGY TO LOADS MILLION BTU	AUX THERMAL TO ECSS MILLION BTU	ECSS OPERATING ENERGY MILLION BTU	ECSS ENERGY REJECTED MILLION BTU	ECSS SOLAR CONVERSION EFFICIENCY
(NBS ID)	(Q001)	(N113)			(Q102)		(N111)
1	1.521	67	I	N	0.039	N	I
2	7.345	61		O	0.047	O	
3	2.583	61		T	0.036	T	
4	0.797	67			0.032		
5	9.250	62		A	0.056	A	
6	8.393	58		P	0.052	P	
7	1.562	58		P	0.027	P	
8	1.678	56		L	0.032	L	
9	9.393	59		I	0.052	I	
10	5.953	58		C	0.052	C	
11	7.058	61		A	0.054	A	
12	3.066	59		B	0.046	B	
13	2.657	57		L	0.037	L	
14	8.560	61		E	0.056	E	
15	6.017	63			0.053		
16	8.499	63			0.055		
17	8.263	60			0.054		
18	8.240	65			0.055		
19	9.823	52			0.052		
20	8.979	57			0.053		
21	1.762	61			0.026		
22	8.206	61			0.054		
23	9.918	56			0.062		
24	9.588	58			0.057		
25	6.221	60			0.076		
26	8.492	63			0.056		
27	6.415	64			0.062		
28	4.551	68			0.057		
29	1.118	70			0.031		
30	9.508	73			0.073		
31	1.807	72	I		0.057		I
SUM	187.223	-	67.59E	N.A.	1.550	N.A.	-
AVG	6.039	62	2.18E	N.A.	0.050	N.A.	I
PFRV	0.9960	0.9960	0.9677	N.A.	0.9960	N.A.	0.9677

4-I

\* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: LOYOLA UNIVERSITY  
COLLECTOR SUBSYSTEM PERFORMANCE

MARCH 1981

DAY OF MONTH (NBSID)	INCIDENT SOLAR ENERGY MILLION BTU (Q001)	OPERATIONAL INCIDENT ENERGY MILLION BTU	COLLECTED SOLAR ENERGY MILLION BTU (Q100)	DAYTIME AMBIENT TEMP DEG F	COLLECTOR SUBSYSTEM EFFICIENCY (N100)	OPERATIONAL COLLECTOR SUBSYSTEM EFFICIENCY
1	1.521	1.406	0.737	71	0.485	0.524#
2	7.345	7.090	3.076	62	0.419	0.434
3	2.583	1.979	0.787	64	0.305	0.398
4	0.797	0.733	0.409	71	0.513	0.558#
5	9.250	9.004	3.442	68	0.372	0.382
6	8.393	7.980	3.099	61	0.369	0.388
7	1.562	1.171	0.441	60	0.282	0.376#
8	1.678	1.089	0.421	57	0.251	0.387#
9	9.393	8.876	3.367	64	0.358	0.379
10	5.953	5.639	2.070	63	0.348	0.367
11	7.058	6.792	2.682	67	0.380	0.395
12	3.066	2.739	1.017	63	0.332	0.371
13	2.657	2.332	0.892	59	0.336	0.383#
14	8.560	8.177	3.477	72	0.406	0.425
15	6.017	5.577	2.276	71	0.378	0.408
16	8.499	8.209	2.933	67	0.345	0.357
17	8.263	7.794	2.897	68	0.351	0.372
18	8.240	8.089	3.130	75	0.380	0.387
19	9.823	9.203	3.197	54	0.325	0.347
20	8.979	8.510	3.211	63	0.358	0.377
21	1.762	1.264	0.475	65	0.269	0.375#
22	8.206	7.757	3.127	68	0.381	0.403
23	9.918	9.624	2.563	58	0.258	0.266
24	9.588	9.307	3.045	64	0.318	0.327
25	6.221	5.991	1.403	69	0.226	0.234
26	8.492	8.256	2.852	72	0.336	0.345
27	6.415	6.245	1.923	71	0.300	0.308
28	4.551	4.312	1.393	72	0.306	0.323
29	1.118	0.857	0.272	71	0.243	0.318#
30	9.508	9.437	2.963	79	0.312	0.314
31	1.807	1.766	0.692	77	0.383	0.392
SUM	187.223	177.206	64.268	-	-	-
AVG	6.039	5.716	2.073	67	0.343	0.363
PFRV	0.9960	0.9960	0.9960	0.9960	0.9960	0.7726

I-5

\* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

STORAGE PERFORMANCE

DAY OF MONTH (NBS ID)	ENERGY TO STORAGE MILLION BTU (Q200)	ENERGY FROM STORAGE MILLION BTU (Q201)	CHANGE IN STORED ENERGY MILLION BTU (Q202)	STORAGE AVERAGE TEMP DEG F	EFFECTIVE HEAT TRANSFER COEFFICIENT BTU/DEG F/ SQ FT/HR
1	0.762	I	-0.517	71	I
2	3.220		0.697	79	
3	0.896		-0.533	72	
4	0.486		-0.234	65	
5	3.574		1.315	86	
6	3.234		0.120	90	
7	0.501		-1.027	71	
8	0.508		0.045	63	
9	3.513		1.463	88	
10	2.195		-0.363	84	
11	2.765		0.148	85	
12	1.141		-0.665	74	
13	0.987		0.100	67	
14	3.650		0.852	84	
15	2.432		-0.154	87	
16	3.063		0.396	91	
17	3.012		-0.025	91	
18	3.247		0.171	95	
19	3.353		0.180	92	
20	3.300		0.628	92	
21	0.557		-1.513	77	
22	3.269		1.062	82	
23	2.812		0.267	92	
24	3.179		0.137	94	
25	1.616		-0.408	85	
26	3.005		0.482	91	
27	2.091		-0.527	88	
28	1.521		-0.136	79	
29	0.349		-0.215	70	
30	3.120		1.096	93	
31	0.848	I	-0.646	81	I
SUM	68.205	67.59E	-0.136	-	-
AVG	2.200	2.18E	-0.004	83	I
PFRV	0.9960	0.9677	N.A.	0.9960	0.9960

9-I

\* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

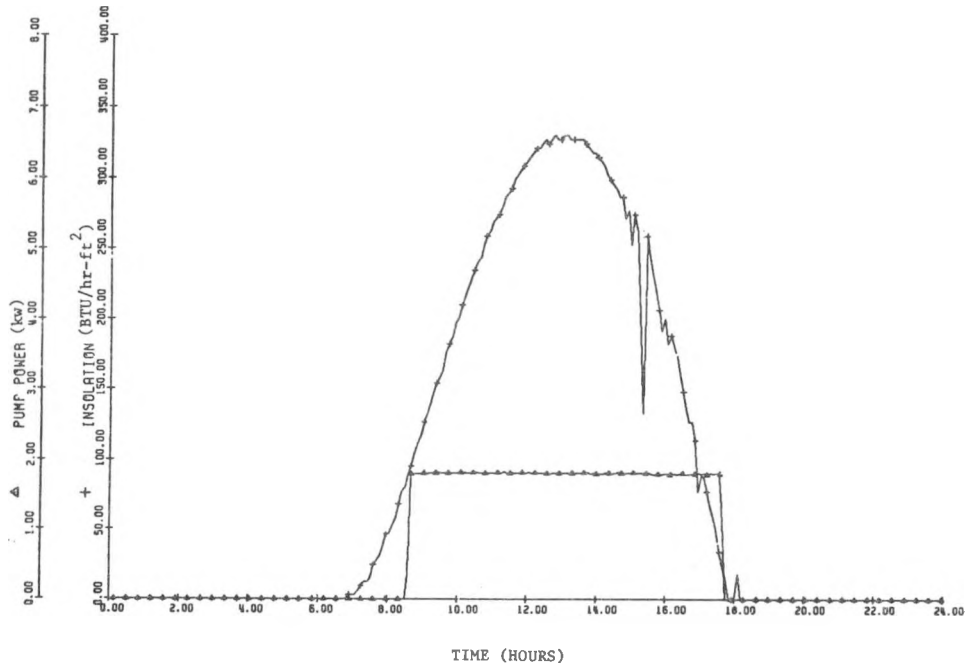


Figure 3a. Typical Insolation Data  
Loyola University, March 5, 1981

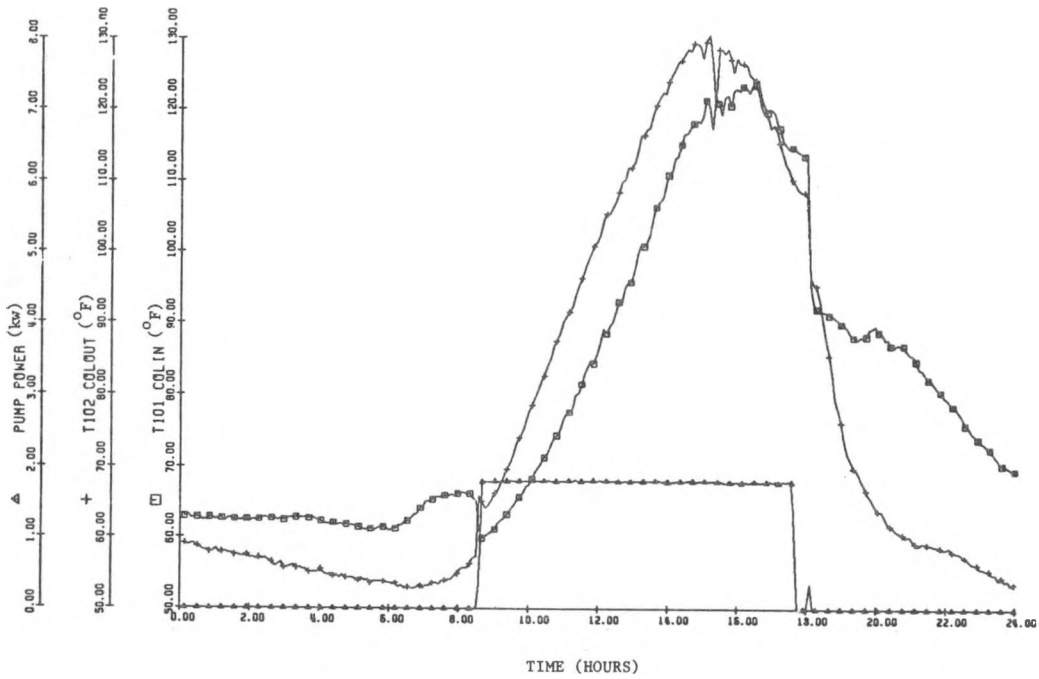


Figure 3b. Typical Collector Array Temperatures, Inlet/Outlet  
Loyola University, March 5, 1981

MONTHLY REPORT: LOYOLA UNIVERSITY  
HOT WATER SUBSYSTEM II

MARCH 1981

DAY OF MON.	AUX ELECT FUEL MILLION BTU (Q305)	AUX FOSSIL FUEL MILLION BTU (Q306)	ELECT ENERGY SAVINGS MILLION BTU (Q311)	FOSSIL ENERGY SAVINGS MILLION BTU (Q313)	SUPPLY WATER TEMP DEG F (Q305)	HOT WATER TEMP DEG F (N307)	HOT WATER USED GAL (N308)	SOLAR SPECIFIC OPER ENERGY MILLION BTU
1	N	N	N	I	57	137	I	0.000
2	O	O	O	I	57	138	I	0.000
3	T	T	T	I	58	139	I	0.000
4				I	58	138	I	0.000
5	A	A	A	I	58	138	I	0.000
6	P	P	P	I	59	138	I	0.000
7	P	P	P	I	59	138	I	0.000
8	L	L	L	I	58	138	I	0.000
9	I	I	I	I	58	138	I	0.000
10	C	C	C	I	58	138	I	0.000
11	A	A	A	I	58	139	I	0.000
12	B	B	B	I	58	138	I	0.000
13	L	L	L	I	58	138	I	0.000
14	E	E	E	I	58	138	I	0.000
15				I	58	138	I	0.000
16				I	58	138	I	0.000
17				I	59	138	I	0.000
18				I	59	138	I	0.000
19				I	59	138	I	0.000
20				I	59	138	I	0.000
21				I	60	138	I	0.000
22				I	61	139	I	0.000
23				I	61	138	I	0.000
24				I	61	138	I	0.000
25				I	61	137	I	0.000
26				I	61	138	I	0.000
27				I	61	138	I	0.000
28				I	62	138	I	0.000
29				I	63	138	I	0.000
30				I	63	138	I	0.000
31				I	64	138	I	0.000
SUM	N.A.	N.A.	N.A.	101.72E	-	-	276.749	0.000
AVG	N.A.	N.A.	N.A.	3.28E	59	138	8927	0.000
PFRV	N.A.	N.A.	N.A.	0.9677	0.9677	0.9677	0.9677	0.9973

8-I

\* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: LOYOLA UNIVERSITY

MARCH 1981

ENVIRONMENTAL SUMMARY

DAY OF MONTH	TOTAL INSOLATION BTU/SQ.FT (Q001)	DIFFUSE INSOLATION BTU/SQ.FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	352	N	67	71	N	N	N
2	1700	O	61	62	O	O	O
3	598	T	61	64	T	T	T
4	184		67	71			
5	2141	A	62	68	A	A	A
6	1943	P	58	61	P	P	P
7	362	P	58	60	P	P	P
8	388	L	56	57	L	L	L
9	2174	I	59	64	I	I	I
10	1378	C	58	63	C	C	C
11	1634	A	61	67	A	A	A
12	710	B	59	63	B	B	B
13	615	L	57	59	L	L	L
14	1982	E	61	72	E	E	E
15	1393		63	71			
16	1967		63	67			
17	1913		60	68			
18	1907		65	75			
19	2274		52	54			
20	2079		57	63			
21	408		61	65			
22	1900		61	68			
23	2296		56	58			
24	2219		58	64			
25	1440		60	69			
26	1966		63	72			
27	1485		64	71			
28	1053		68	72			
29	259		70	71			
30	2201		73	79			
31	418		72	77			
SUM	43339	N.A.	-	-	-	-	-
AVG	1398	N.A.	62	67	N.A.	N.A.	N.A.
PFRV	0.9960	N.A.	0.9960	0.9960	N.A.	N.A.	N.A.

\* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; † <40% VALID DATA; PFRV RELIABILITY VALUE.