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CATHEDRAL SQUARE

BURLINGTON, VERMONT

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

JANUARY 1982 THROUGH APRIL 1982

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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.

CATHEDRAL SQUARE

CATHEDRAL SQUARE

The Cathedral Square solar site is a 10-story multi-unit apartment building in Burlington, Vermont. The active solar energy system is designed to supply the following:

Annual Design Factors
(Million BTU)

	Total Load	Solar Contribution	% Solar
Hot Water	740.71	377.91	51

It is equipped with:

Collector: 1,798-square-foot, flat-plate, Daystar 21-B.

Storage: 2,699-gallon water tank, Adamson, MI68, located in an enclosed mechanical room on the roof.

Auxiliary: Two natural-gas boilers (Bryan, CL210W-AG, 1,680,000 BTU/hour) supply hot water to immersed heat exchanger in auxiliary storage tank.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1

SOLAR SYSTEM PERFORMANCE

CATHEDRAL SQUARE
JANUARY 1982 THROUGH APRIL 1982

Solar Fraction[1]	26%
Solar Savings Ratio[2]	0.25
Conventional Fuel Savings[3]	105,912 cubic feet of natural gas at the expense of 966 kwh of electrical energy
System Performance Factor[4]	0.67
Solar System COP[5]	19.66

Seasonal Energy Requirements
January 1982 through April 1982
(Million BTU)

	Total Load	Solar Contribution	% Solar
Hot Water	249.53	64.88	26

Environmental Data

	Measured Average	Long-Term Average
Outdoor temperature	27°F	27°F
Heating degree-days (Total)	4,550	4,566
Daily incident solar energy	1,085 BTU/ft^2	958 BTU/ft^2

1. $$\text{Solar Fraction} = \frac{\text{Solar Energy Supplied to Load}}{\text{Total Load}} \times 100$$

2. $$\text{Solar Savings Ratio} = \frac{\text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}}{\text{Total Load}}$$

3. $$\text{Conventional Fuel Savings} = \frac{\text{Savings in BTU} \times 979.4 \times 10^{-6} \text{ cubic feet/BTU}}{\text{Electrical Expense in BTU} \times 292.8 \times 10^{-6} \text{ kwh/BTU}}$$

4. Ratio of system load to the total equivalent fossil energy expended or required to support the system load.

5. $$\text{Solar System COP} = \frac{\text{Solar Energy Used}}{\text{Solar-Unique Operating Energy}}$$

1.1 SUMMARY AND CONCLUSIONS

The Cathedral Square site is a 10-story, 101-unit apartment building in Burlington, Vermont. The solar system consists of an array of 80 Daystar 21-B collectors with a gross area of 1,798 square feet. The array faces 42 degrees west of south at a tilt of 45 degrees. Solar energy storage is provided by a 2,699-gallon water tank located in an enclosed mechanical room on the roof. Auxiliary thermal energy is supplied by two Bryan natural-gas-fired boilers with a heat exchanger in the hot water tank.

During the four-month period of January 1982 through April 1982, the solar system supplied 64.88 million BTU or 26% of the system load. While this is very good performance, it is considerably less than the design solar fraction of 51%. The projections of system performance were based on hot water consumption of 2,600 gallons per day, while the actual consumption averaged 1,572 gallons per day. The annual design solar contribution was estimated to be 377.91 million BTU. From the long-term weather data (see Appendix E), the total yearly expected solar insolation in the plane of the collectors is calculated as 710.70 million BTU. For the system to meet the design solar contribution, 53% of the long-term expected insolation would have to be collected, stored, and delivered to the load. This level of expected system performance is unrealistic. The solar system at Cathedral Square actually supplied energy equal to 28% of the total measured insolation in the plane of the collectors. This amount is considered to be very good performance which compares well to the best Domestic Hot Water (DHW) solar systems.

The solar system thermal performance is indicated in Table 1. Figure 1, a bar chart, and Figure 2, an energy flow diagram, also present the overall thermal performance of the solar system during the reporting period.

The total system load of 249.53 million BTU was met with 64.88 million BTU of solar energy and 184.65 million BTU of auxiliary thermal energy. This performance resulted in a solar fraction of 26% and fossil energy savings of 108.14 million BTU. The solar system incurred an electrical operating energy expense of 3.30 million BTU.

The solar system performed efficiently in the delivery of collected energy to the load. Of the 78.62 million BTU collected, 83% was eventually delivered to the load.

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 Cathedral Square functioned at a weighted average COP value of 19.66, indicating very good performance. The collector and DHW load subsystems also operated exceptionally well at weighted COP values of 36.91 and 55.45, respectively.

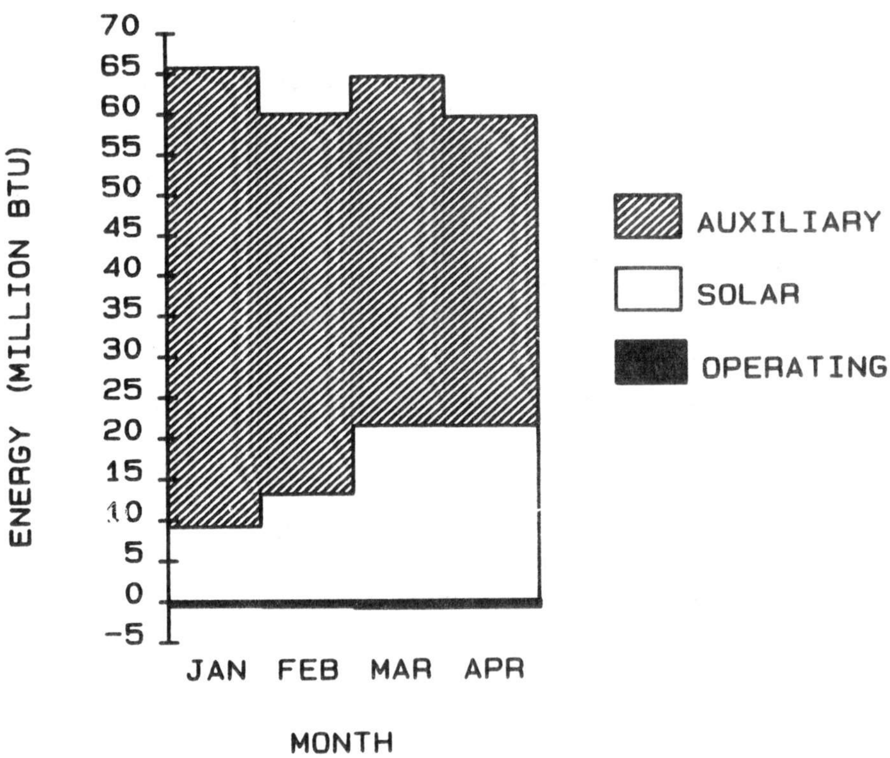
The measured monthly values for the collector subsystem performance are presented in Table 3. The collector subsystem operated very well during the reporting period. The system collected 78.62 million BTU, achieving an average total efficiency of 34%. While the collectors were operating, 43% of the available insolation was collected. The collector pump required 2.13

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

CATHEDRAL SQUARE
JANUARY 1982 THROUGH APRIL 1982

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED	AUXILIARY ENERGY FOSSIL	SOLAR OPERATING ENERGY	ENERGY SAVINGS FOSSIL	ENERGY SAVINGS ELECTRICAL	SOLAR FRACTION (%)
JAN	11.53	65.67	9.10	94.29	0.66	15.16	-0.66	14
FEB	16.71	59.89	13.06	78.05	0.76	21.77	-0.76	22
MAR	26.23	64.48	21.39	71.81	0.95	35.66	-0.95	33
APR	24.15	59.49	21.33	63.60	0.93	35.55	-0.93	36
TOTAL	78.62	249.53	64.88	307.75	3.30	108.14	-3.30	-
AVERAGE	19.66	62.38	16.22	76.94	0.83	27.04	-0.83	26



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
Cathedral Square
January 1982 through April 1982

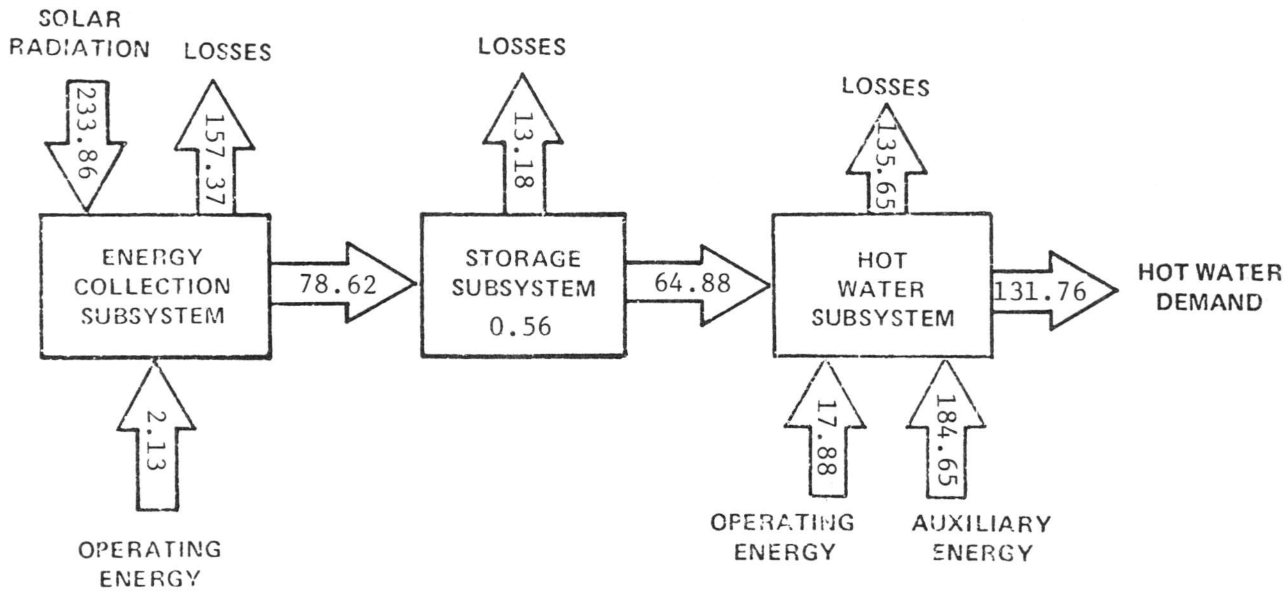


Figure 2. Energy Flow Diagram for Cathedral Square
January 1982 through April 1982
(Figures in million BTU)

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

CATHEDRAL SQUARE
JANUARY 1982 THROUGH APRIL 1982

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	DOMESTIC HOT WATER SOLAR
JAN	13.79	32.03	30.33
FEB	17.18	34.10	48.37
MAR	22.52	40.35	71.30
APR	22.94	38.33	71.10
WEIGHTED AVERAGE	19.66	36.91	55.45

Table 3. COLLECTOR SUBSYSTEM PERFORMANCE

CATHEDRAL SQUARE
JANUARY 1982 THROUGH APRIL 1982

(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	DAYTIME AMBIENT TEMPERATURE (°F)
JAN	37.76	11.53	31	28.35	41	0.36	15
FEB	52.15	16.71	32	39.77	42	0.49	27
MAR	73.33	26.23	36	60.30	44	0.65	37
APR	70.62	24.15	34	55.76	43	0.63	42
TOTAL	233.86	78.62	-	184.18	-	2.13	-
AVERAGE	58.47	19.66	34	46.05	43	0.53	30

million BTU of operating energy. This resulted in a very good collector subsystem coefficient of performance (COP) of 36.91.

The orientation of the collector array at 42 degrees west of south does not appear to impose a disadvantage on the system's ability to help meet the early morning peak hot water load. The maximum rate of solar energy collection occurs in the midafternoon hours which coincides well with the increased hot water load in the late afternoon and early evening. Because of low hot water consumption through the night, excess collected solar energy is available the next morning to help meet the high hot water load.

The performance of the solar storage tank is not given due to an energy imbalance which occurred throughout the reporting period. The tank increased in temperature from an average of 73°F in January to an average of 98°F in April. This is an increase in stored energy of approximately 0.56 million BTU.

The solar energy system supplied 64.88 million BTU to the hot water load. Therefore, losses from the collector heat exchanger, the load heat exchanger, the storage tank, and the connecting piping amounted to 13.18 million BTU. The solar system operated at an overall delivery and storage efficiency, from collection to load, of 83%.

The Domestic Hot Water (DHW) subsystem performance is given in Table 4.

Table 4. DOMESTIC HOT WATER SUBSYSTEM

CATHEDRAL SQUARE
JANUARY 1982 THROUGH APRIL 1982

(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	AUX FOSSIL FUEL	SUP WATER TEMP (°F)	HOT WATER TEMP (°F)	HOT WATER CONSUMPTION (GAL)
JAN	65.67	14	28.33	9.10	56.57	94.29	38	123	40,158
FEB	59.89	22	31.58	13.06	46.83	78.05	37	122	44,519
MAR	64.48	33	37.10	21.39	43.09	71.81	37	121	53,085
APR	59.49	36	34.75	21.33	38.16	63.60	38	120	50,910
TOTAL	249.53	-	131.76	64.88	184.65	307.75	-	-	188,672
AVERAGE	62.38	26	32.94	16.22	46.16	76.94	38	122	47,168

The hot water load of 249.53 million BTU was met with 64.88 million BTU of solar energy and 184.65 million BTU of auxiliary energy. The solar fraction of the load averaged 26%. A total of 188,672 gallons of hot water were consumed. Raising the temperature of this water from an average of 38°F to 122°F resulted in a hot water demand of 131.76 million BTU. (The hot water demand plus system thermal losses equals the hot water load.)

The DHW subsystem had thermal losses of 117.77 million BTU. The majority of these losses occurred during the recirculation of hot water. The recirculation piping is uninsulated and is primarily located in unheated areas of the building.

Solar energy is delivered to the DHW storage tank by constantly circulating solar storage water through two series-piped heat exchangers. Cold supply water is heated as it passes through these heat exchangers before it is delivered to the DHW tank. If the temperature of the solar storage tank exceeds the DHW storage tank temperature, pump P8 is energized. This pump circulates water from the DHW tank, through the heat exchangers, and back to the tank.

The DHW subsystem employs constant circulation of hot water to insure the availability of hot water on demand. Auxiliary energy is supplied to the DHW storage tank by circulating hot water from two gas-fired boilers through an immersed heat exchanger. Thermal losses from the recirculation piping and the DHW storage tank are generally replaced by auxiliary energy. Only when the solar storage temperature is greater than the DHW tank temperature, and pump P8 is activated, does solar energy replace these losses. There is little or no hot water consumption between 11:00 p.m. and 6:00 a.m. Consideration should be given to putting the recirculation pumps and the solar distribution pumps on a timer to prevent operation during this time period. A timer would reduce both the operating energy requirement and recirculation losses, thus increasing savings.

Hot water is recirculated to the faucets by pumps P6 and P6A, which operate alternately. Throughout the reporting period, pump P6 has been malfunctioning. When it is activated, electrical power is used but there is no flow observed in the recirculation line. This occurrence has allowed an analysis of the change in DHW system performance when the recirculation system is not operating.

A detailed discussion of the effect of no recirculation during a number of days in February is given in Appendix H. The following general conclusions are made, however, which apply only to load characteristics and system operation at Cathedral Square. The total amount of thermal energy consumed by the DHW subsystem was essentially the same during periods of recirculation and periods of no recirculation. However, solar energy use increased slightly while auxiliary energy use decreased by an equal amount when there was no recirculation. The amount of hot water consumed increased significantly while there was no recirculation, because of the unavailability of hot water at the taps. Energy losses from the supply piping caused users to run the water longer to attain the desired temperature. Because of this increased consumption, more cold supply water passed through the solar heat exchangers thus increasing solar utilization. Auxiliary energy normally replaces recirculation losses. Since there were no recirculation losses during this time, auxiliary energy usage was decreased. Thermal losses from the DHW subsystem as a percent of the load were the same whether the recirculating system was operating or not. Therefore, with no recirculation, energy savings can be realized through increased use of solar energy and decreased use of auxiliary and pump operating energy. These savings are at the expense of increased water consumption.

Solar system operating energies are presented in Table 5. During the reporting period, operation of the collector subsystem required 2.13 million BTU. This value includes energy consumed by pumps P1, P1A and P2. The delivery of solar energy from storage to the load required 1.17 million BTU of operating energy.

Table 5. SOLAR OPERATING ENERGY

CATHEDRAL SQUARE
JANUARY 1982 THROUGH APRIL 1982

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY	DHW OPERATING ENERGY	TOTAL SOLAR OPERATING ENERGY
JAN	0.36	0.30	0.66
FEB	0.49	0.27	0.76
MAR	0.65	0.30	0.95
APR	0.63	0.30	0.93
TOTAL	2.13	1.17	3.30
AVERAGE	0.53	0.29	0.83

Energy savings provided by the solar system at Cathedral Square are presented in Table 6.

During the four-month reporting period, the solar system saved 108.14 million BTU of fossil fuel. These savings are equivalent to 780 gallons of No. 2 fuel oil or 105,912 cubic feet of natural gas. The system incurred an electrical energy expense of 3.30 million BTU, or about 966 kwh, for solar system operating energy.

Solar energy system savings are realized whenever energy provided by the solar system is used to meet system demands which would otherwise be met by auxiliary energy services. The operating energy required to transport solar energy from the collectors to storage and from storage to the load is subtracted from the fossil fuel savings to determine net savings. Auxiliary energy is supplied by gas-fired boilers which are assumed to be 60% efficient for computational purposes. Solar energy used by the system is converted to fossil savings using this efficiency.

Table 6. ENERGY SAVINGS

CATHEDRAL SQUARE
JANUARY 1982 THROUGH APRIL 1982

(All values in million BTU)

MONTH	SOLAR ENERGY USED	DOMESTIC HOT WATER		ECSS OPERATING ENERGY SOLAR-UNIQUE	NET ENERGY SAVINGS	
		ELECTRICAL	FOSSIL FUEL		ELECTRICAL	FOSSIL FUEL
JAN	9.10	-0.30	15.16	-0.36	-0.66	15.16
FEB	13.06	-0.27	21.77	-0.49	-0.76	21.77
MAR	21.39	-0.30	35.66	-0.65	-0.95	35.66
APR	21.33	-0.30	35.55	-0.63	-0.93	35.55
TOTAL	64.88	-1.17	108.14	-2.13	-3.30	108.14
AVERAGE	16.22	-0.30	27.04	-0.53	-0.83	27.04

Based on national average costs for natural gas and electricity of \$4.67/1,000 cubic feet and 6.63 cents/kwh, respectively, the system provided net dollar savings of \$430.56 for the four-month period. These savings, normalized by collector area, amount to 23.95 cents per square foot of collector for this four-month period.

The Cathedral Square site is located in Burlington, Vermont at 44 degrees north latitude and 73 degrees west longitude.

Monthly average values of the total daily incident solar energy per square foot of collector and the average outdoor ambient temperature measured at the site are presented in Table 7. 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 measurements converted to collector angle and azimuth orientation.

During the period from January 1982 through April 1982, the average daily total incident solar radiation on the collector array was 1,085 BTU per square foot per day. This radiation was significantly greater than the long-term estimated value of 958 BTU per square foot per day for a plane facing 42 degrees west of south with a tilt of 45 degrees to the horizontal. The measured average daily values ranged widely from 677 BTU per square foot per day in January to 1,316 BTU per square foot per day in March.

The average ambient temperature was 27°F which is the same as the long-term average. The number of heating degree-days for the period (based on a 65°F reference) was 4,550 as compared to the long-term average of 4,566.

Table 7. WEATHER CONDITIONS

CATHEDRAL SQUARE
JANUARY 1982 THROUGH APRIL 1982

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
JAN	677	590	13	17	1,624	1,494
FEB	1,036	815	23	19	1,179	1,299
MAR	1,316	1,100	33	29	1,004	1,113
APR	1,309	1,327	39	43	743	660
TOTAL	-	-	-	-	4,550	4,566
AVERAGE	1,085	958	27	27	1,138	1,142

1.2 SYSTEM OPERATION

1.2.1 TYPICAL SYSTEM OPERATION

The operation of the solar system at Cathedral Square is represented in Figures 3a, 3b, 3c, and 3d. The measurements made by selected sensors on January 27, 1982 have been plotted in these figures to illustrate the typical operation of the solar system and the variation of system temperatures throughout the day.

On Figure 3a, the measurements of the collector inlet and outlet temperature sensors, T100 and T150 respectively, and the total solar insolation pyranometer, I001, are plotted. The period that the collector pump was operating is also indicated.

The collector inlet temperature sensor, T100, measured it's minimum temperature of 32°F through the night. It can be assumed that the actual temperature was lower than this. The collector outlet temperature sensor, T150, measured about 68°F at 2400 hours. Its measured temperature fell throughout the night, reaching its lowest temperature of 44°F at 1013 hours when the collector pump was activated. The large temperature difference between the inlet and outlet temperature sensors and their constant drop through the night indicate that residual energy in the collector loop was being rejected through a thermosiphoning effect. This is not a significant problem since this energy cannot be utilized and would probably be lost through the piping insulation regardless. From other data, it is not apparent that energy was being withdrawn from the solar storage tank and rejected to the environment.

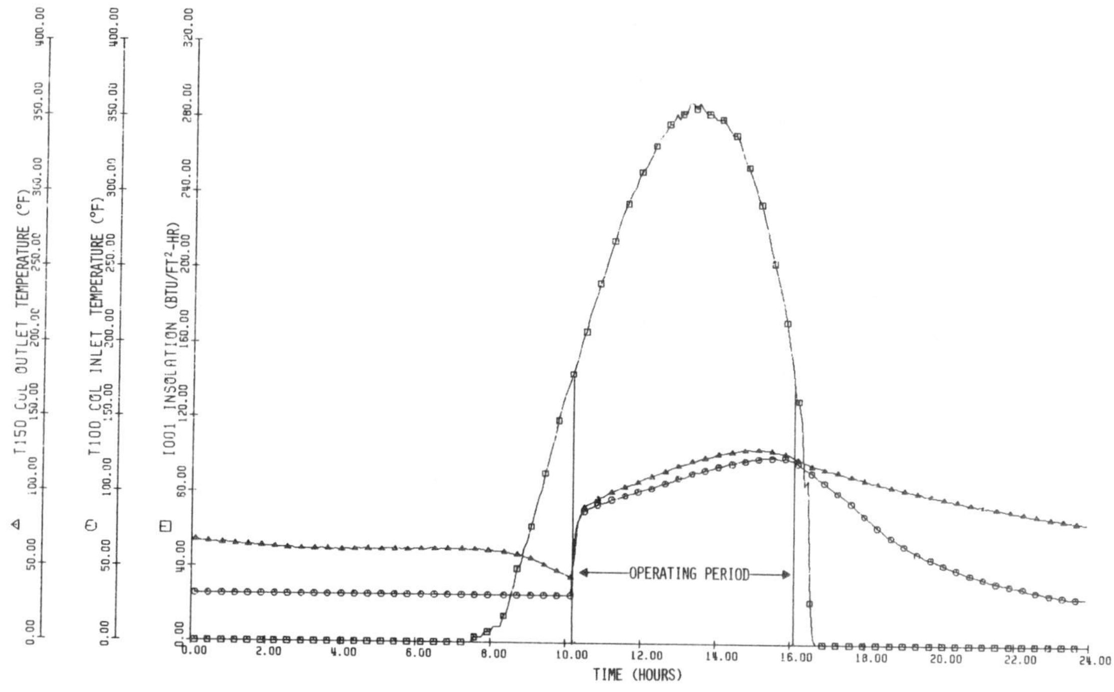


Figure 3a. Typical Insolation Data and Collector Inlet/Outlet Temperatures
Cathedral Square
January 27, 1982

At 1013 hours, with the pyranometer measuring 149.9 BTU/hr-ft^2, the collector pump was activated. A negative temperature differential was measured across the collector array for about 10 minutes. After this, the outlet temperature rose above the inlet temperature. The temperature differential increased to a maximum value of 9.3°F at 1309 hours, at the same time as the maximum insolation value for the day of 288.5 BTU/hr-ft^2. The maximum collector outlet temperature of 130°F was attained at 1450 hours, approximately one hour and 40 minutes after the maximum inlet/outlet differential was recorded. The collector pump deactivated at 1605 hours with a measured 2.1°F temperature differential across the array. The pyranometer measured 132.9 BTU/hr-ft^2 when the collector pump was activated.

Figure 3b is a plot of measurements by sensors T200, T201, and T202, the storage tank temperatures. These sensors show that the storage tank started the day in the range of 94°F to 96°F. Sensor T201, which measures the temperature at the middle of the storage tank, read about 1.5°F higher than T200, which measured the temperature in the top of the tank. The tank temperature dropped about 1°F until there was hot water usage.

When hot water consumption commenced at 0600 hours, the T202 reading began to drop rapidly, reaching a minimum temperature of 82°F by the time the collector pump was activated. The measurement by sensor T201 also began to show a drop in temperature shortly after hot water consumption began, but its decline lagged behind sensor T202.

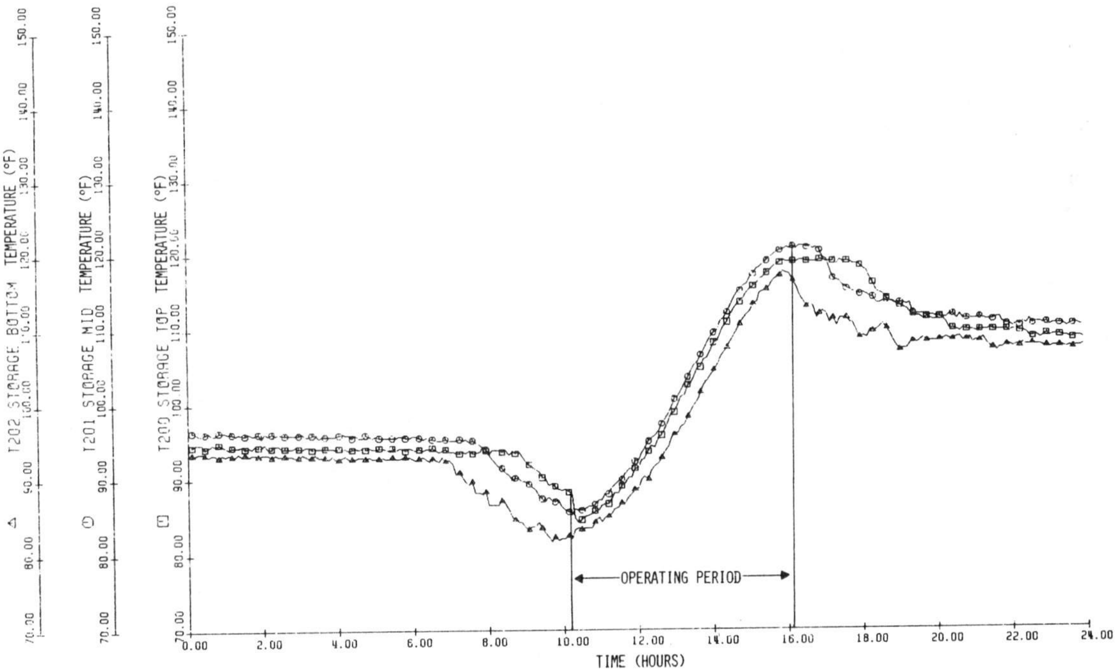


Figure 3b. Typical Storage Fluid Temperatures
Cathedral Square
January 27, 1982

After the collector pump began operating at 1013 hours, sensor measurements of T200 and T201 continued to decline in temperature for about 10 minutes. This was probably due to cold fluid in the collector return line which takes a period of time to completely pass through the heat exchanger. After this, the storage tank temperature rose through the day from an average of 85°F at startup, to an average of 119°F after the collector pump shut down at 1605 hours. All three temperature sensors tracked each other closely as the tank temperature rose through the day.

Figure 3c is a plot of flow meter W301 and temperature sensors T350 and T300. Flow meter W301 measures the total cold make-up water from 0 to 1,000 gallons for the DHW storage tank. Sensors T350 and T300 measure the inlet and outlet temperatures, respectively, on the storage side of the solar heat exchangers. The plot is presented to illustrate the delivery of solar energy from storage.

The pump which delivers energy from storage, P3 or P3A, operates 24 hours/day to insure that solar energy is always available at the heat exchangers. From 2400 hours to 0600 hours, there was a temperature differential of less than 1°F across the heat exchangers. This shows that a small amount of solar energy was lost to the environment during constant circulation. When hot water consumption began, it can be observed that the temperature differential increased across the heat exchangers, varying with the rate of consumption. As the consumption rate increased, the temperature differential increased.

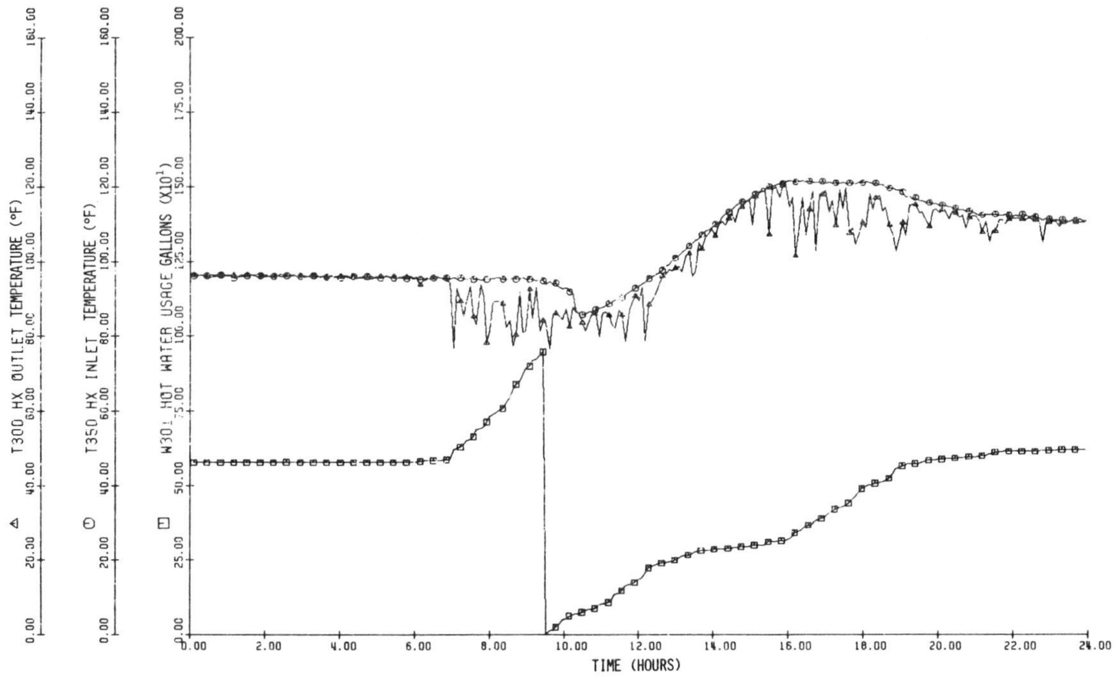


Figure 3c. Typical Domestic Hot Water Consumption and Solar Heat Exchangers Inlet/Outlet Temperatures
Cathedral Square
January 27, 1982

Three system water temperatures are presented in Figure 3d to illustrate the areas where energy is added to the system. Temperature sensor T352 measures the hot water temperature, sensor T351 measures the temperature of the solar-heated water leaving the heat exchangers, and sensor T301 measures the temperature of the cold entering water.

The lack of hot water consumption in the early morning hours is indicated by several temperature sensors. Sensor T352 measured a temperature that declined from 130°F at 2400 hours to 125°F at 0600 hours. The measurements by sensor T351 indicated a temperature drop because of thermal losses to the environment. Sensor T301 showed a slow temperature increase due to thermal energy gains from the room air.

Normal hot water consumption begins at 0600 hours. The hot water temperature sensor, T352, showed a slow decrease in temperature for about three hours. This occurred because hot water consumption was relatively high. Cold water is introduced to the DHW tank and the auxiliary system cannot maintain the outlet temperature. At about 1100 hours, the tank temperature was about 130°F and was maintained near this level for the rest of the day.

At 0600 hours, the temperature of the solar heated water leaving the heat exchangers began to increase. This temperature is quite variable depending on the amount of hot water consumption. Sensor T351's measurement slowly decreased in temperature after its initial rise, as energy was being withdrawn

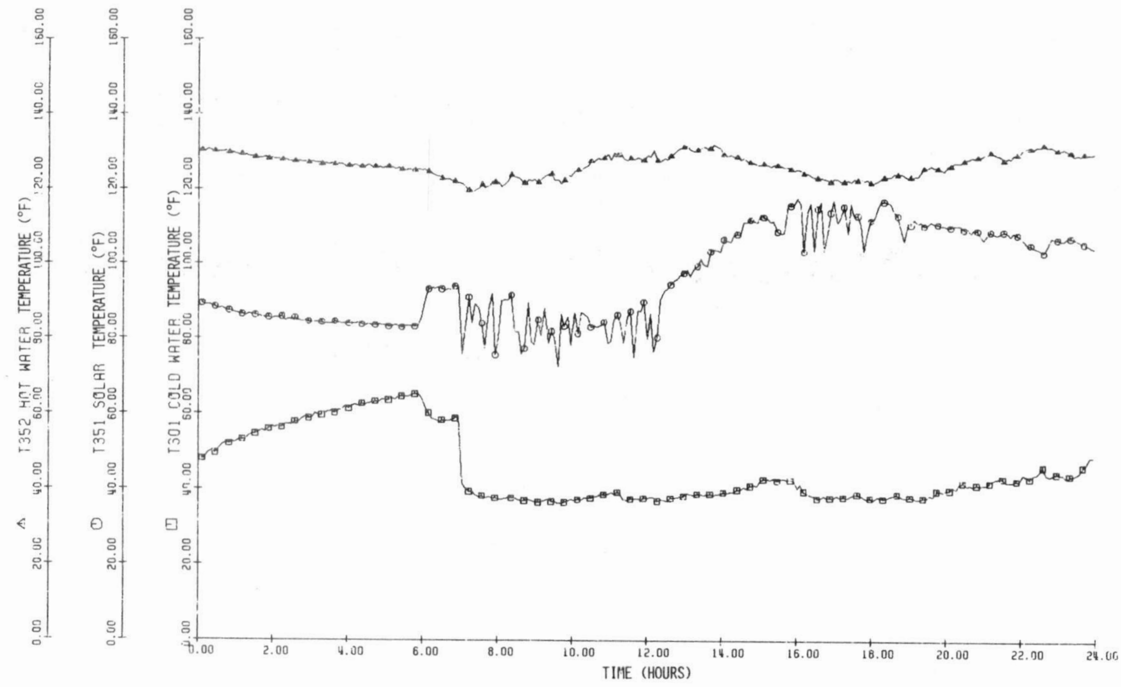


Figure 3d. Typical Domestic Hot Water Subsystem Temperatures
Cathedral Square
January 27, 1982

from the storage tank. After the collector pump was activated and solar energy was being collected, the temperature measured by T351 began to rise in temperature along with storage. This temperature rise was not constant, but varied considerably with changes in consumption. By the time the collector pump was deactivated, storage had reached its maximum temperature of about 119°F. The temperature of the water leaving the heat exchangers nearly equaled this temperature. A small amount of hot water consumption continued for the remainder of the day. The plot shows that the solar system continued to supply most of the energy required to heat the water, thus, reducing auxiliary energy consumption.

Sensor T301's reading quickly dropped in temperature after hot water consumption began. It remained essentially unchanged throughout the day. This would be expected since the cold water temperature does not change quickly but changes seasonally. Small rises in temperature are due to ambient gains because of low consumption.

1.2.2 SYSTEM OPERATING SEQUENCE

Figure 4 presents a bar chart showing typical system operating sequences on January 27, 1982. This data correlates with the curves present in Figures 3a, 3b, 3c, and 3d and provides additional insight into those curves.

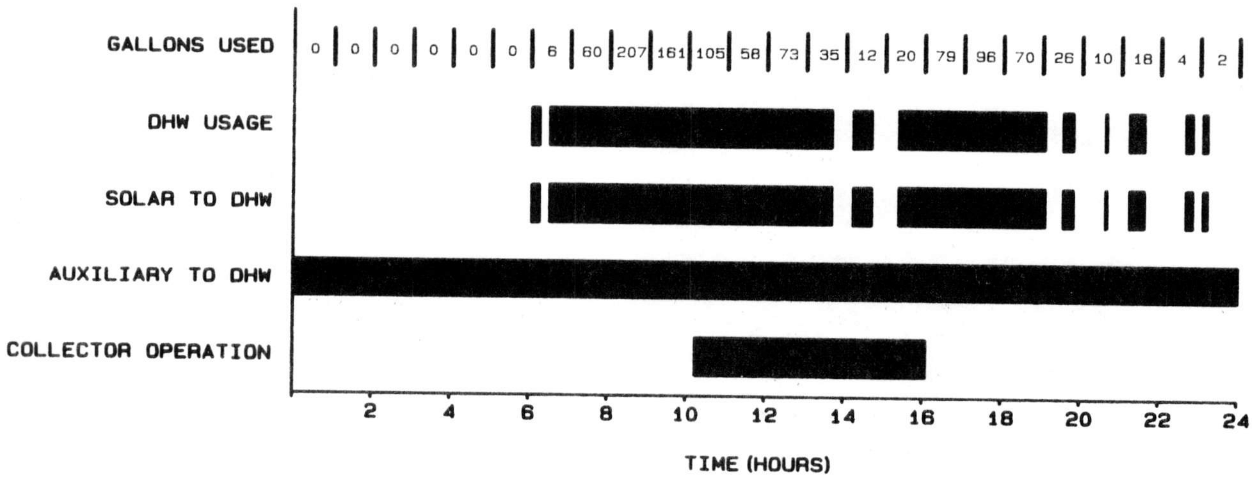


Figure 4. Typical System Operating Sequence
Cathedral Square
January 27, 1982

From this bar chart, it can be seen that domestic hot water consumption occurs primarily from 0600 hours to 2300 hours. This consumption pattern is consistent throughout the year. Hot water usage peaks from 0700 hours to 1100 hours and then drops to moderate use around noon. In the midafternoon and late evening hours, the hot water demand is low. An increase in consumption occurs during the late afternoon and early evening hours.

When the temperature of the solar storage tank is less than the DHW storage tank, solar energy can be delivered to the subsystem only on hot water demand by passing cold supply water through the solar heat exchangers. Therefore, Figure 4 shows that solar energy is used only when hot water consumption is indicated.

Auxiliary energy is delivered continuously to the DHW storage tank. This delivery occurs at a greater rate during periods of hot water consumption. Substantial amounts of auxiliary energy are also utilized during periods of no hot water demand to replace recirculation system losses.

The solar collector subsystem operated on this day from 1013 hours to 1605 hours. This operating time approximately bisects the period of hot water consumption. Thus, collected solar energy is utilized quickly due to the presence of a hot water load during and after the collection period. Hot water consumption was 1,042 gallons on this day with 490 gallons, or 47%, being used before the collector pump was activated. The total hot water use at this building is evenly distributed with about 50% occurring before noon and 50% after noon. The collectors face 42 degrees west of south at the site, thus the system cannot take advantage of early morning insolation to help meet the early hot water load. Low or no hot water consumption in the late evening and early morning hours, however, allows the storage tank to remain at a relatively high temperature through the night. Therefore, solar energy is available in the morning hours to help meet the heavy load, offsetting the disadvantage imposed by collector orientation.

1.3 SOLAR ENERGY UTILIZATION

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

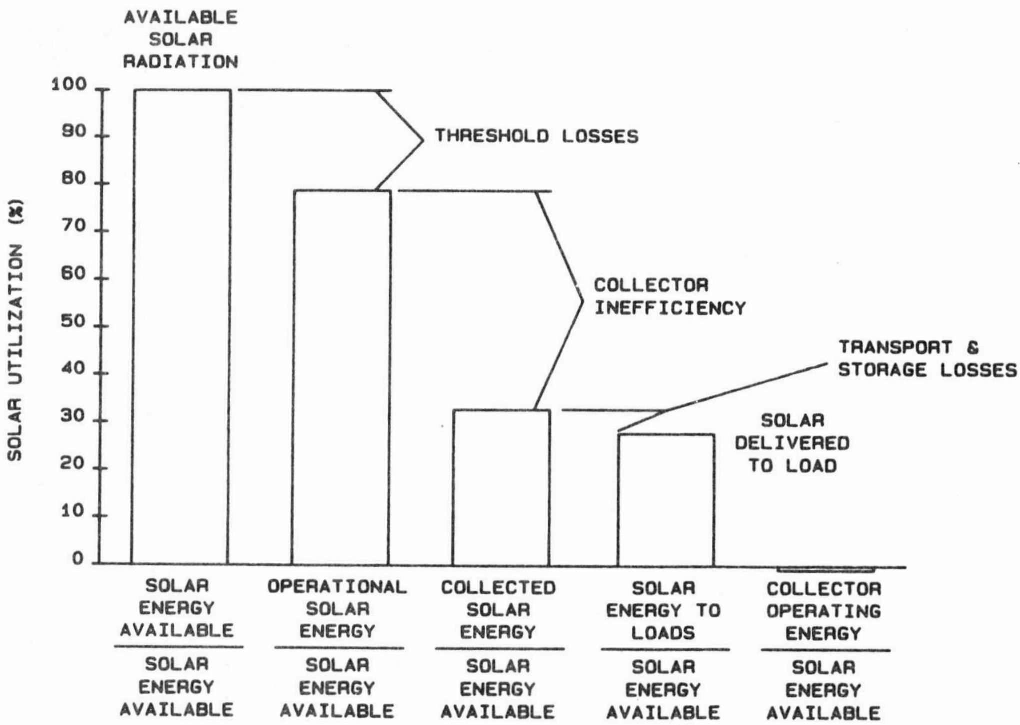


Figure 5. Solar Energy Use
Cathedral Square
January 1982 through April 1982

The collector subsystem at Cathedral Square operated to collect energy while 79% of the total insolation was available. The threshold losses of 21% 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. If the collectors operated during these times, energy would be rejected rather than collected.

The operational collector inefficiency refers to solar energy which was available to be collected while the pump was operating but was not because of reflection, reradiation, and convection losses to the environment. These losses are due to collector inefficiency and amount to 45% of the total available insolation.

Transport and storage losses amounted to six percent of the available insolation. These losses occur from the storage tank, the collector and load heat exchangers, and interconnecting piping. The energy required to operate the collector pumps is shown below the axis to indicate that it is considered a system penalty. This energy amounted to less than one percent of the available insolation.

Overall, the solar system at Cathedral Square performed very efficiently. The system utilized 64.88 million BTU of solar energy, or 28% of the total solar insolation available. Of the 78.62 million BTU collected, 83% was eventually utilized by the system. This excellent performance can be attributed to several factors. Low supply water temperatures, especially in the cold months, allow solar energy to be utilized at low storage temperatures. These low storage temperatures allow the collectors to operate cooler and more efficiently. Because overall system temperatures are low, this reduces thermal losses to the environment from pipes, heat exchangers, and storage vessels. During the four-month period of this report, the system supplied 26% of the hot water load. Since the system operated very efficiently, this indicates that the system is somewhat undersized for the load. This attribute is advantageous to solar utilization however, since solar energy is used shortly after collection, thus reducing the potential for thermal losses.

SECTION 2

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 Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.

4. 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, NY, 1977.

*5A. User's Guide to Monthly Performance Reports, November 1981, SOLAR/0004-80/18, Vitro Laboratories, Silver Spring, Maryland.

*5B. Instrumentation Installation Guidelines, March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.

6. Monthly Performance Report, Cathedral Square, January 1982, Vitro Laboratories, Silver Spring, Maryland.

7. Monthly Performance Report, Cathedral Square, February 1982, Vitro Laboratories, Silver Spring, Maryland.

8. Monthly Performance Report, Cathedral Square, March 1982, Vitro Laboratories, Silver Spring, Maryland.

9. Monthly Performance Report, Cathedral Square, April 1982, Vitro Laboratories, Silver Spring, Maryland.

*10. Solar Energy System Performance Evaluation, Cathedral Square, January 1980 through December 1980, SOLAR/1060-81/14, Vitro Laboratories, Silver Spring, Maryland.

*11. Solar Energy System Performance Evaluation, Cathedral Square, July 1981 through December 1981, SOLAR/1060-82/14, 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 Cathedral Square site is a 10-story building located in Burlington, Vermont. The building has 101 apartments, each containing approximately 500 square feet of living space. Solar energy is used to preheat the domestic hot water (DHW). The solar energy system has an array of flat-plate collectors, Daystar 21-B, with an effective area of 1,798 square feet, requiring a gross area of 2,342 square feet. The array faces 42 degrees west of due south at a tilt of 45 degrees to the horizontal. A 67% propylene glycol/water solution is the transfer medium that delivers solar energy from the collector array to a water storage heat exchanger. The transfer medium that delivers solar energy from storage to the hot water heat exchanger is water. Solar energy is stored in a 2,699-gallon solar storage tank. Energy is exchanged from the solar storage tank to the 865-gallon conventional DHW storage tank when there is a sufficient temperature difference between the two tanks. When there is a hot water demand, cold supply water flows past the solar storage heat exchanger into the DHW storage tank. Two gas-fired boilers supply any auxiliary thermal energy required to satisfy the hot water load. The solar system, shown schematically in Figure A-1, has two modes of operation.

Mode 1 - Collector-to-Storage - This mode activates when the collector temperature exceeds the solar thermal storage temperature by approximately 10°F. Pumps in the collector heat exchanger/storage loop are activated. The propylene glycol/water solution flows through the collector array and the collector heat exchanger, and water flows through the heat exchanger and solar thermal storage tank. When the collector temperature is within approximately 3°F of the solar energy storage temperature, the pumps are deenergized and the mode is terminated.

Mode 2 - Storage-to-Preheat - This mode activates when the temperature of the solar thermal storage exceeds the temperature on the discharge side of the DHW preheat heat exchanger by approximately 10°F. Pumps in the solar thermal storage to DHW preheat exchanger loop are activated. The water flows from solar thermal storage through the DHW heat exchanger and back to storage. The city water is preheated, on demand, as it passes through the DHW preheat heat exchanger. This mode terminates when the temperature of the hot water on the discharge side of the DHW preheat heat exchanger is within approximately 3°F of the temperature of solar thermal storage.

SUBSYSTEMS

Collector - The collector array consists of 80 Daystar 21-B collectors with a gross area of 1,798 square feet. The collectors face 42 degrees west of south and are tilted to an altitude angle of 45 degrees to the horizontal. Freeze protection is provided by a 67% propylene glycol/water solution. The collectors have a 3/16-inch low iron content, tempered glass cover plate with a net aperture of 21 square feet. The absorber plate is copper with copper tubing and repainted black. The absorber has an absorbitivity of 0.98. Special features include a folded polymer heat trap with transmissivity of 0.94 and an integrated temperature delimiter which maintains internal collector temperatures below 270°F. The optical efficiency is 0.83. This model is no longer manufactured by Daystar.

Storage - Solar energy storage is provided by a 2,699-gallon Adamson model OLD DOMINION MI68 steel tank with stone lining. The tank is installed horizontally and insulated to R-14.

Solar energy is withdrawn from storage and passed by a shell and tube heat exchanger where energy is transferred to incoming makeup water or water circulated from the hot water tank.

Hot Water - The hot water subsystem consists of an 865-gallon steel hot water tank with concrete lining. The tank is insulated with fiberglass to R-6.8. Water is constantly removed and circulated to the load by pumps P6 and P6A. If the water in the 865-gallon hot water tank is at least 10°F lower than the water in the solar storage tank, pump P8 activates, withdrawing water from the hot water tank and passing it by the solar heat exchanger.

Auxiliary - Auxiliary thermal energy is provided by two Bryan natural-gas-fired boilers, model CL210W-AG, with inputs of 2.10 million BTU/hour and outputs of 1.68 million BTU/hour. Heat exchange occurs at a tube and shell heat exchanger in the hot water tank.

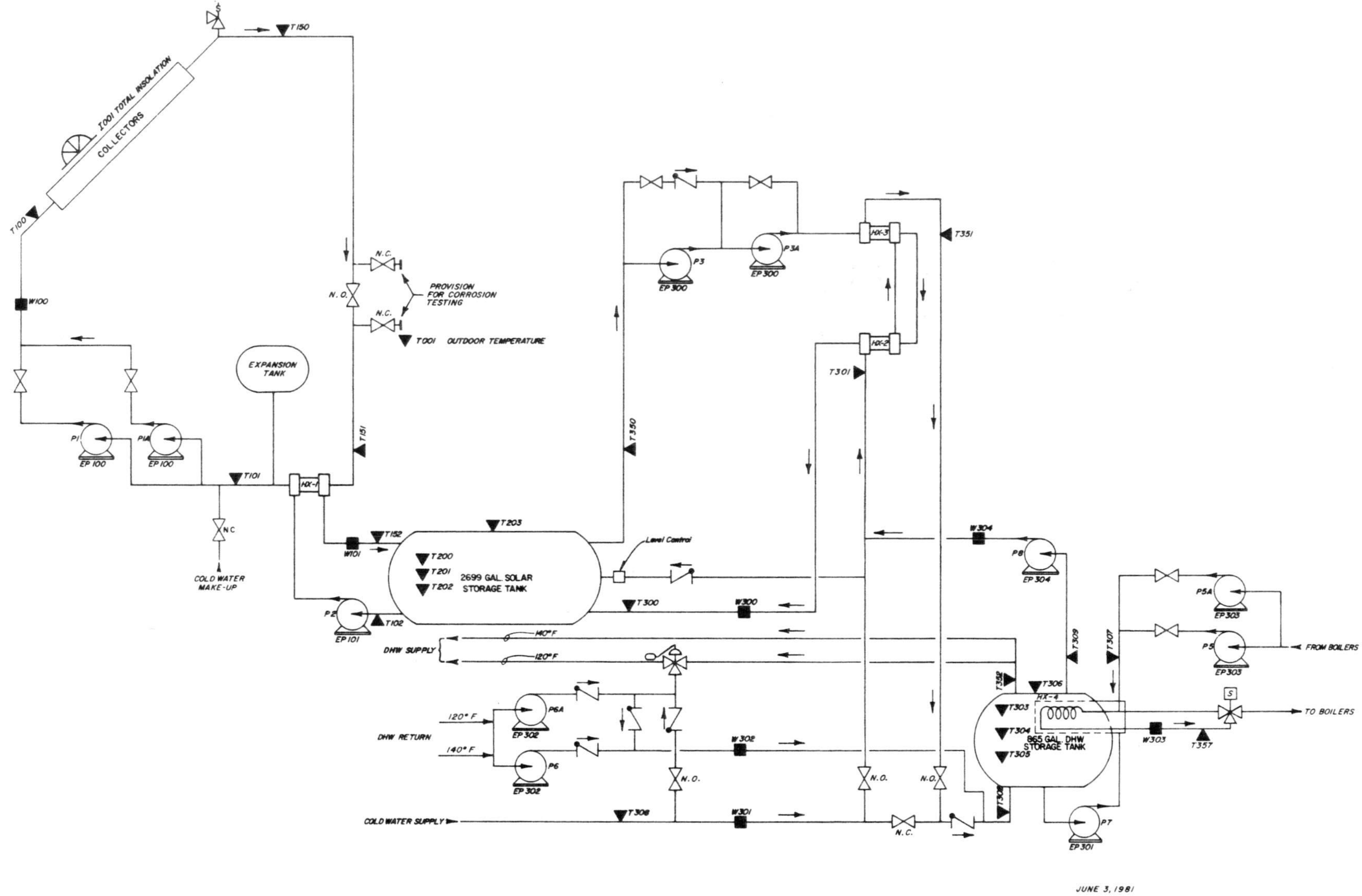


Figure A-1. Cathedral Square Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Cathedral Square 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.

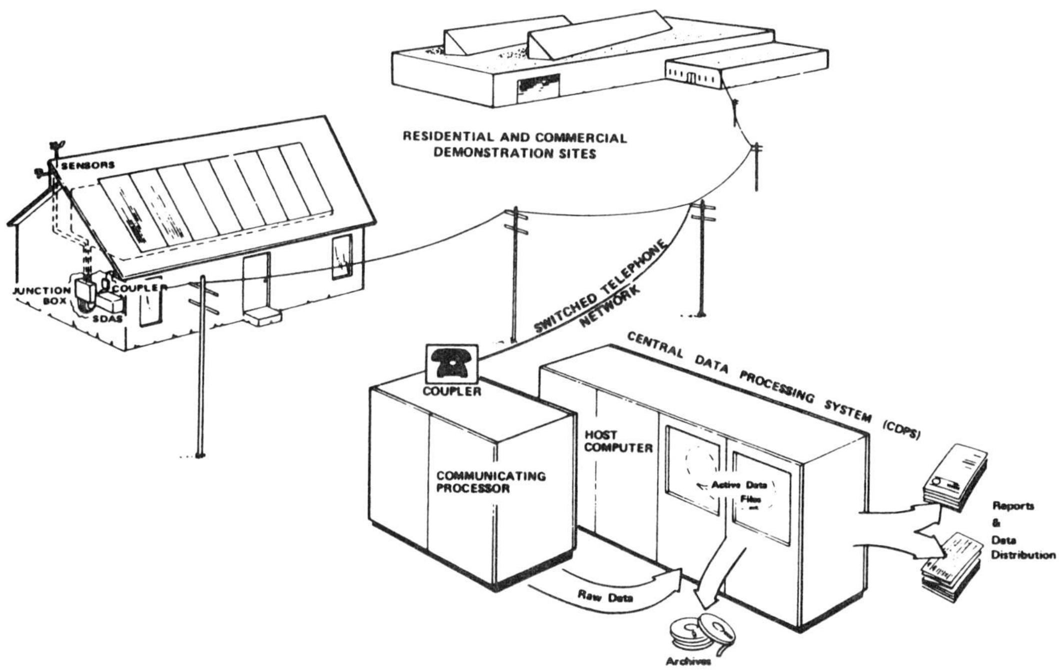


Figure B-1. The National Solar Data Network

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 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 0-1023. 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.

Solar system performance reports present system parameters as monthly values. If some of the data during the month is not collected due to solar system instrumentation system, or data acquisition problems, or if some of the collected data is invalid, then the collected valid data is extrapolated to provide the monthly performance estimates. Researchers and other users who require unextrapolated, "raw" data may obtain data by contacting Vitro Laboratories.

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 real time 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 solar energy system at the Cathedral Square site was analyzed during the January 1982 through April 1982 period, and Monthly Performance Reports were prepared. See the following page for a list of these reports.

In addition, data are included in this report which are not in Monthly Performance Reports.

OTHER DATA REPORTS ON THIS SITE

Monthly Performance Reports:

*June 1979, SOLAR/1060-79/06
*July 1979, SOLAR/1060-79/07
*August 1979, SOLAR/1060-79/08
*September 1979, SOLAR/1060-79/09
*October 1979, SOLAR/1060-79/10
*January 1980, SOLAR/1060-80/01
*February 1980, SOLAR/1060-80/02
*March 1980, SOLAR/1060-80/03
*April 1980, SOLAR/1060-80/04
*May 1980, SOLAR/1060-80/05
*June 1980, SOLAR/1060-80/06
*July 1980, SOLAR/1060-80/07
*August 1980, SOLAR/1060-80/08
*September 1980, SOLAR/1060-80/09
*October 1980, SOLAR/1060-80/10
*November 1980, SOLAR/1060-80/11
*December 1980, SOLAR/1060-80/12
March 1981
July 1981
August 1981
September 1981
October 1981
November 1981
December 1981
January 1982
February 1982
March 1982
April 1982

Solar Energy System Performance Evaluations:

*SOLAR/1060-81/14
*SOLAR/1060-82/14

* These reports can be obtained 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

ACRONYM	NAME	DEFINITION
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.
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.
CLEF	Collector Array Efficiency	Ratio of the collected solar energy to the incident solar energy.
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

ACRONYM	NAME	DEFINITION
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

ACRONYM	NAME	DEFINITION
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.
* HSFR	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.
* HSVF	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	Amount of energy supplied to the HWS.
* HWDM	Hot Water Demand	Energy required to satisfy the temperature control demands of the building service hot water system.

* Primary Performance Factors

ACRONYM	NAME	DEFINITION
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

ACRONYM	NAME	DEFINITION
* 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.
STOCAP	Storage Tank Capacity	Volume of storage tank in gallons.
* 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

ACRONYM	NAME	DEFINITION
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

ACRONYM	NAME	DEFINITION
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.
Controlled Delivered Energy	The heating load derived from the summation of measured solar and auxiliary components.
Cooling Degree-Days	The sum over a specified period of time of the number of degrees the average daily temperature is above 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 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, $\frac{Ti-Ta}{I}$, under steady state conditions (see Operating Point).

Instantaneous Efficiency Curve — A plot of solar collector efficiency against operating point, $\frac{Ti-Ta}{I}$ (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:

$$\frac{Ti-Ta}{I} \left(\frac{°F \times hr. \times sq.\ ft.}{BTU}\right)$$

Operational Collector Efficiency — Ratio of collected solar energy to incident solar energy only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.

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 Contribution of Load | The portion of total load actually met by solar energy.

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.

Solar-Unique Operating Energy | Operating energy which is expended on the solar system.

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 x 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

CATHEDRAL SQUARE

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

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

where I001 is the solar radiation measurement provided by the pyranometer in BTU per square foot per hour, CLAREA 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 convert the solar radiation "rate" to the proper units of time.

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

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

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

For a liquid system ΔH is generally given by

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

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

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* See Appendix B.

For an air system ΔH is generally given by

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

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

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

For electrical power, a general example is

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

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

Letter Designations

C or CP	=	Specific Heat
D	=	Direction or Position
DS	=	Discrete Switch Position
EE	=	Electric Energy
EP	=	Electric Power
ET	=	Elapsed Time of Operation
F	=	Fuel Flow Rate
H	=	Enthalpy
HR	=	Humidity Ratio
HWD	=	Functional procedure to calculate the enthalpy change of water at the average of the inlet and outlet temperatures
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
WT	=	Total Volume Flow
TI	=	Time
_P	=	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

AVERAGE AMBIENT TEMPERATURE (°F)

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

DAYTIME AVERAGE BUILDING TEMPERATURE (°F)

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

for ± three hours from solar noon

SUPPLY WATER TEMPERATURE (°F)

$$TSW = T308 \text{ when } M301 > 0$$

HOT WATER TEMPERATURE (°F)

$$THW = T352 \text{ when } M301 + M302 > 0$$

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT^2)

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

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

when the collector loop is active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma\ [M100 \times CP \times (T150 - T100)] \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma\ [M101 \times CP \times (T152 - T102)] \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma\ [M300 \times CP \times (T350 - T300)] \times \Delta\tau$$

AVERAGE TEMPERATURE OF STORAGE (°F)

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

ENERGY DELIVERED FROM ECSS TO HOT WATER SUBSYSTEM (BTU)

$$CSEO = \Sigma\ [M300 \times CP \times (T350 - T300)] \times \Delta\tau$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = 56.8833 \times \Sigma\ (EP100 + EP101) \times \Delta\tau$$

when system is in the collector-to-storage mode

HOT WATER SUBSYSTEM OPERATING ENERGY (BTU)

$$HWOPE = 56.8833 \times \Sigma\ (EP300 + EP301 + EP302 + EP303 + EP304) \times \Delta\tau$$
$$HWOPE1 = 56.8833 \times \Sigma\ (EP300 + EP304) \times \Delta\tau$$

HOT WATER CONSUMED (GALLONS)

$$HWCSM = \Sigma\ WD301$$

where WD301 = W301 (current) - W301 (previous)

SOLAR ENERGY TO HOT WATER SUBSYSTEM (BTU)

$$HWSE = \Sigma\ [(M301 + M304) \times CP \times (T351 - T301)] \times \Delta\tau$$

HOT WATER SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HWAT = \Sigma\ [M303 \times CP \times (T307 - T357)] \times \Delta\tau$$

HOT WATER SUBSYSTEM AUXILIARY FOSSIL FUEL ENERGY (BTU)

$$HWAF = HWAT/0.6$$

HOT WATER DEMAND (BTU)

$$HWDM = M301 \times CP \times (T352 - T308) \times \Delta\tau$$

HOT WATER SUBSYSTEM LOAD (BTU)

HWL = HWSE + HWAT

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

SEA = CLAREA x SE

COLLECTED SOLAR ENERGY (BTU)

SEC = SECA/CLAREA

COLLECTOR ARRAY EFFICIENCY (%)

CLEF = SECA/SEA

OPERATIONAL COLLECTOR ARRAY EFFICIENCY (%)

CLEFOP = SECA/SEOP

CHANGE IN STORED ENERGY (BTU)

$STECH = STECH1 - STECH1_p$

where the subscript $_p$ refers to a prior reference value

STORAGE EFFICIENCY

STEFF = (STECH + STEO)/STEI

STORAGE PERFORMANCE

STPER = (STEI - STEO - STECH)/(TST - TENV)

where TENV is average value of T203

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = HWSE

ECSS SOLAR CONVERSION EFFICIENCY

CSCEF = SEL/SEA

HOT WATER SUBSYSTEM SOLAR FRACTION (PERCENT)

HWSFR = 100 x HWSE/(HWSE + HWAT)

HOT WATER SUBSYSTEM FOSSIL FUEL SAVINGS (BTU)

HWSVF = HWSE/0.6

HOT WATER SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

HWSVE = -HWOPE1

SYSTEM LOAD (BTU)

SYSL = HWL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = HWSFR

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HWAT

AUXILIARY FOSSIL FUEL ENERGY TO LOADS (BTU)

AXF = HWAF

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HWOPE + CSOPE

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXF + SECA

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

TSVE = HWSVE - CSOPE

SYSTEM PERFORMANCE FACTOR

SYSPF = SYSL/(AXF + SYSOPE x 3.33)

APPENDIX E

CATHEDRAL SQUARE LONG-TERM WEATHER DATA

COLLECTOR TILT: 45 DEGREES
LATITUDE: 44 DEGREES

LOCATION: BURLINGTON, VERMONT
COLLECTOR AZIMUTH: 42 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1100.	387.	0.35200	1.523	590.	1494	0	17.
FEB	1577.	608.	0.38568	1.339	815.	1299	0	19.
MAR	2218.	940.	0.42390	1.170	1100.	1113	0	29.
APR	2913.	1298.	0.44554	1.022	1327.	660	0	43.
MAY	3425.	1574.	0.45963	0.926	1458.	331	15	55.
JUN	3642.	1729.	0.47479	0.885	1531.	63	69	65.
JUL	3530.	1722.	0.48773	0.904	1557.	20	169	70.
AUG	3109.	1475.	0.47444	0.983	1450.	49	123	67.
SEP	2466.	1121.	0.45445	1.115	1250.	191	20	59.
OCT	1763.	741.	0.42030	1.296	960.	502	0	49.
NOV	1210.	376.	0.31072	1.387	522.	840	0	37.
DEC	973.	284.	0.29176	1.476	419.	1314	0	23.

LEGEND:

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

APPENDIX F

FLUID SAMPLE ANALYSIS

The purpose of the chemical analysis of antifreeze solutions is to identify three characteristics of the liquid: (1) the thermal properties, (2) the freezing point, and (3) the occurrence or likelihood of corrosion. The percent and type of antifreeze affect the first two characteristics. In general, the glycol concentration should be somewhere in the range of 50% to give a freezing point of -37°F for ethylene glycol and -25°F for propylene glycol. This percentage of glycol also insures proper corrosion protection, because corrosion inhibitor concentrations are designed for this concentration.

The corrosivity of a liquid is hard to evaluate quantitatively. In general:

1. pH should be between 7.5 and 9.0.

2. Reserve alkalinity varies with antifreeze manufacturer. The alkalinity might range from eight to 25 for fresh antifreezes. With time, the alkalinity tends to decrease and, if it reaches zero, then the liquid can rapidly turn acidic (i.e., pH less than seven). This is very undesirable.

3. Chloride concentration should be less than 50 ppm.

Presence of other components is indicative of type of antifreeze, type of water, and products of corrosion. Presence of silicon is generally indicative of automotive antifreeze, and a requirement to change the liquid at two-year intervals. Presence of ash, calcium, and magnesium indicate minerals in water and possibility of scaling. Copper, iron, or aluminum indicate that these metals in the system might be corroding.

The analysis of the fluid sample taken at Cathedral Square is presented below. The sample, taken on September 10, 1981, was clear amber in color.

Water Content by K.F.* (%)	33.2
pH	9.9
Reserve Alkalinity	12.2
Sodium (mg./liter)	29
Silicon (mg./liter)	2
Calcium (mg./liter)	4.45
Magnesium (mg./liter)	1.3
Boron (mg./liter)	13.8
Clorides (mg./liter)	3.7
O-Phosphorous (as P) (mg./liter)	2,967
Propylene Glycol (%)	66.8
Potassium (mg./liter)	6,750
Ash (%)	0
Copper (mg./liter)	0
Iron (mg./liter)	0
Aluminum (mg./liter)	0
Zinc (mg./liter)	0

* Karl Fischer method.

The fluid sample's reserve alkalinity and chloride concentration are well within the normal limits. The pH is slightly above the recommended range. A small amount of silicon is present. This may be residue from the ethylene glycol which the system used previous to the propylene glycol solution. A small amount of calcium and magnesium is present indicating a possible scaling problem which should be monitored. There are no metallic elements present which indicates no corrosion.

APPENDIX G

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

Prior to December 1979, the solar energy system at Cathedral Square operated in a preheat-only configuration so that solar energy was only delivered to the hot water tank when there was a hot water draw. This configuration was inefficient because of low hot water usage. This problem was remedied by the addition of the line with pump P8 in December 1979. This pump was controlled so that, if the temperature of solar storage exceeded the temperature of the hot water tank by more than 10°F, pump P8 activated, passing water from the hot water tank through the solar heat exchanger. This "fix" improved performance considerably. The data in this report includes only data for performance of the system after this change was implemented.

Other minor problems and changes include the following:

DATE	EVENT
1/80	Leak in collector loop.
3/80	Set temperature of hot water tank was reduced to 115°F.
5/80	Controls for pumps P3 and P3A failed.
6/80	Collector pump ran continuously due to control problem.
10/80	Transient effects near temperature sensor which controls pump P8 caused intermittent cycling. Pipe was rewrapped with insulation relieving problem somewhat, but controls were scheduled for change in 1981.
11/80	Faulty motor switches for pumps P3 and P3A prevented flow from storage.
2/81-5/81	System deactivated to perform following: 1. System piping was reconfigured so cold supply water always passes through both load heat exchangers HX-2 and HX-3. Previously, only one heat exchanger was utilized when DHW consumption was less than 30 gpm. 2. Iron pipes and fittings in system were replaced with copper or brass to prevent the possibility of corrosion due to oxygenated water. 3. Collector and storage subsystems were drained and flushed. 4. Non-diaphragm type expansion tank was replaced with diaphragm type.
7/81	67% propylene glycol solution was added to collector array.

APPENDIX H

RECIRCULATION SYSTEM OPERATION

Pumps P6 and P6A provide recirculation of hot water to the load. In December, pump P6 was malfunctioning. It was observed that the pump was drawing power but there was no flow in the pipe. This pump was deactivated and pump P6A was turned on to provide recirculation. The grantee was notified about the defective pump. It was observed in the data that pump P6 was turned on for two periods during February, of about six days each.

The operation of the recirculation system affects hot water consumption and energy flows. The following presents average daily values of several factors for 12 days when the recirculation system was operating and for 12 days when it was inoperable due to the use of pump P6. Energy values are given in millions of BTU and water consumption in gallons.

Factor	Recirculation Operable	Recirculation Inoperable
Hot Water Used (Total)	15,581 gallons	22,529 gallons
Hot Water Used/Day	1,298 gallons/day	1,877 gallons/day
Hot Water Load (Total)	25.32	25.92
Hot Water Load/Day	2.11/day	2.16/day
Demand Load (Total)	11.00	16.08
Demand Load/Day	0.92/day	1.34/day
Solar Used (Total)	5.24	6.11
Solar Used/Day	0.44/day	0.51/day
Auxiliary Used (Total)	20.06	19.80
Auxiliary Used/Day	1.67/day	1.65/day

During the period when the recirculation system was inoperable, the amount of hot water used increased an average of 579 gallons/day. This also caused the demand load to increase from an average of 0.92 million BTU per day to 1.34 million BTU per day. The hot water load, however, remained essentially unchanged even though hot water consumption increased. The hot water demand increased during the period of no recirculation because of the unavailability of hot water at the faucets. The lack of recirculation allowed water in the supply piping to cool during periods of low or no consumption. Therefore, not all the energy calculated in the demand load was delivered at the faucets; some energy was lost in the supply piping.

Thermal losses from the DHW subsystem are calculated as the difference between the hot water load and the hot water demand. During the period that the recirculation system was operating, the system lost 14.32 million BTU, or 57% of the hot water load. When the recirculation system was inoperable, these losses amounted to 9.84 million BTU, or 38% of the hot water load. These losses, however, do not include the previously mentioned losses from the supply piping. These losses can be estimated by calculating the energy required to heat the extra demand required when the recirculation system was inoperable. This extra demand of 579 gallons per day, at an average 85°F temperature rise, consumed approximately 4.92 million BTU. Since this extra demand load is considered to be a loss from the system, adding it to the 9.84 million BTU loss calculated previously gives a total loss of about 14.76 million BTU while the recirculation system was not operating. This amounts to 57% of the hot water load, which is exactly the same loss percent as when the recirculation system was operating. Apparently, the thermal losses as a percent of the hot water load are the same whether the recirculation system is operating or not. A reduction in operating energy can be realized by not using the recirculation pump, but this may be offset by the cost of increased hot water consumption.

While the recirculation system was inoperable, it appears that the utilization of solar energy increased from 0.44 million BTU per day to 0.51 million BTU per day. This was caused by the increased flow of cold city water through the solar heat exchangers because of the increased hot water demand. Auxiliary energy use during this period was down slightly. In this system design, auxiliary energy replaces recirculation losses and, because the recirculation system was not operating, auxiliary energy use was lowered.

APPENDIX I

CONVERSION FACTORS

Energy Conversion Factors

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

[1]No. 1 and No. 2 heating oils, diesel fuel, No. 4 fuel oils

[2]No. 5 and No. 6 fuel oils

APPENDIX J

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 μ V/W/m^2
Temperature Dependence:	± 1% over ambient temperature range -20°C to 40°C
Linearity:	0.5% from 0 to 2,800 W/M^2
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% (½" to 3½" 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^2-hr
Size:	2" X 2"

APPENDIX K

MONTHLY REPORT: JANUARY 1982
SITE SUMMARY: CATHEDRAL SQUARE P2631R

	CONVENTIONAL UNITS
GENERAL SITE DATA:	
INCIDENT SOLAR ENERGY	37.762 MILLION BTU
	21002 BTU/SQ.FT.
COLLECTED SOLAR ENERGY	11.534 MILLION BTU
	6415 BTU/SQ.FT.
AVERAGE AMBIENT TEMPERATURE	13 DEGREES F
AVERAGE BUILDING TEMPERATURE	N.A. DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY	0.24
ECSS OPERATING ENERGY	0.360 MILLION BTU
STORAGE EFFICIENCY	94.57 PERCENT
EFFECTIVE HEAT TRANSFER COEFFICIENT	0.382 BTU/DEG F-SQ FT-HR
TOTAL SYSTEM OPERATING ENERGY	5.304 MILLION BTU
TOTAL ENERGY CONSUMED	111.176 MILLION BTU

SUBSYSTEM SUMMARY:	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	65.533	N.A.	N.A.	65.533 MILLION BTU
SOLAR FRACTION	14	N.A.	N.A.	14 PERCENT
SOLAR ENERGY USED	9.096	N.A.	N.A.	9.096 MILLION BTU
OPERATING ENERGY	4.944	N.A.	N.A.	5.304 MILLION BTU
AUX. THERMAL ENERGY	56.574	N.A.	N.A.	56.574 MILLION BTU
AUX. ELECTRIC FUEL	N.A.	N.A.	N.A.	N.A. MILLION BTU
AUX. FOSSIL FUEL	94.290	N.A.	N.A.	94.290 MILLION BTU
ELECTRICAL SAVINGS	-0.304	N.A.	N.A.	-0.664 MILLION BTU
FOSSIL SAVINGS	15.160	N.A.	N.A.	15.160 MILLION BTU

SYSTEM PERFORMANCE FACTOR: 0.59

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 4.04

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

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, NOVEMBER 1981.
SOLAR/0004-81/18
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MONTHLY REPORT: JANUARY 1982
SITE SUMMARY: CATHEDRAL SQUARE P2631R

SI UNITS

GENERAL SITE DATA:

INCIDENT SOLAR ENERGY	39.839	GIGA JOULES
	238502	KJ/SQ.M.
COLLECTED SOLAR ENERGY	12.168	GIGA JOULES
	72846	KJ/SQ.M.
AVERAGE AMBIENT TEMPERATURE	-11	DEGREES C
AVERAGE BUILDING TEMPERATURE	N.A.	DEGREES C
ECSS SOLAR CONVERSION EFFICIENCY	0.24	
ECSS OPERATING ENERGY	0.380	GIGA JOULES
STORAGE EFFICIENCY	94.57	PERCENT
EFFECTIVE HEAT TRANSFER COEFFFICIENT	2.171	W/SQ M-DEG K
TOTAL SYSTEM OPERATING ENERGY	5.595	GIGA JOULES
TOTAL ENERGY CONSUMED	117.291	GIGA JOULES

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL	
LOAD	69.137	N.A.	N.A.	69.137	GIGA JOULES
SOLAR FRACTION	14	N.A.	N.A.	14	PERCENT
SOLAR ENERGY USED	9.596	N.A.	N.A.	9.596	GIGA JOULES
OPERATING ENERGY	5.216	N.A.	N.A.	5.595	GIGA JOULES
AUX. THERMAL ENG	59.686	N.A.	N.A.	59.686	GIGA JOULES
AUX. ELECTRIC FUEL	N.A.	N.A.	N.A.	N.A.	GIGA JOULES
AUX. FOSSIL FUEL	99.476	N.A.	N.A.	99.476	GIGA JOULES
ELECTRICAL SAVINGS	-0.321	N.A.	N.A.	-0.701	GIGA JOULES
FOSSIL SAVINGS	15.994	N.A.	N.A.	15.994	GIGA JOULES

SYSTEM PERFORMANCE FACTOR: 0.59

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 4.04

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

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, NOVEMBER 1981.
SOLAR/0004-81/18

MONTHLY REPORT: CATHEDRAL SQUARE P2631R JANUARY 1982

ENERGY COLLECTION AND STORAGE SUBSYSTEM (ECSS)

DAY OF MONTH (NBS ID)	INCIDENT SOLAR ENERGY MILLION BTU (Q001)	AMBIENT TEMP DEG-F (N113)	ENERGY TO LOADS MILLION BTU	AUX THERMAL TO ECSS MILLION BTU	ECSS OPERATING ENERGY MILLION BTU (Q102)	ECSS ENERGY REJECTED MILLION BTU	ECSS SOLAR CONVERSION EFFICIENCY (N111)
1	0.053	34	0.170	N	0.000	N	3.174
2	2.502	15	0.228	O	0.027	O	0.083
3	0.212	18	0.436	T	0.000	T	1.776
4	0.059	35	0.274		0.000		4.514
5	1.760	28	0.219	A	0.020	A	0.132
6	0.231	26	0.243	P	0.000	P	1.101
7	0.642	28	0.152	P	0.003	P	0.265
8	1.703	11	0.197	L	0.016	L	0.119
9	1.629	7	0.309	I	0.020	I	0.198
10	1.123	7	0.273	C	0.012	C	0.246
11	0.567	4	0.149	A	0.002	A	0.340
12	2.387	0	0.202	B	0.026	B	0.086
13	0.411	4	0.341	L	0.000	L	0.768
14	0.606	8	0.179	E	0.000	E	0.314
15	0.908	15	0.104		0.013		0.141
16	0.783	16	0.107		0.014		0.159
17	0.700	-4	0.080		0.003		0.156
18	1.836	0	0.262		0.022		0.151
19	2.633	7	0.477		0.022		0.166
20	1.301	14	0.463		0.012		0.350
21	1.997	-2	0.514		0.025		0.254
22	2.602	-3	0.567		0.025		0.193
23	0.098	11	0.449		0.000		4.049
24	0.397	21	0.225		0.000		0.601
25	2.379	2	0.273		0.026		0.112
26	2.605	0	0.420		0.025		0.148
27	2.878	4	0.546		0.025		0.161
28	0.257	21	0.551		0.000		1.867
29	1.848	22	0.433		0.019		0.214
30	0.084	24	0.358		0.000		3.945
31	0.570	20	0.195		0.004		0.379
SUM	37.762	-	9.395	N.A.	0.360	N.A.	-
AVG	1.218	13	0.303	N.A.	0.012	N.A.	0.241
PFRV	0.9704	0.9704	0.9704	N.A.	0.9704	N.A.	0.9691

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

MONTHLY REPORT: CATHEDRAL SQUARE P2631R JANUARY 1982

COLLECTOR SUBSYSTEM PERFORMANCE

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	0.053	0.000	0.000	34	0.000	0.000
2	2.502	2.354	0.939	17	0.375	0.399
3	0.212	0.000	0.000	20	0.000	0.000
4	0.059	0.000	0.000	37	0.000	0.000
5	1.760	1.670	0.744	22	0.423	0.445
6	0.231	0.000	0.000	29	0.000	0.000
7	0.642	0.120	0.058	30	0.091	0.486
8	1.703	1.316	0.597	12	0.351	0.454
9	1.629	1.273	0.449	10	0.276	0.353
10	1.123	0.911	0.372	13	0.331	0.408
11	0.567	0.064	0.015	2	0.026	0.230
12	2.387	2.150	0.901	7	0.377	0.419
13	0.411	0.000	0.000	7	0.000	0.000
14	0.606	0.000	0.000	9	0.000	0.000
15	0.908	0.475	0.167	17	0.184	0.351
16	0.783	0.498	0.206	18	0.263	0.413
17	0.700	0.121	0.034	-6	0.049	0.284
18	1.836	1.553	0.639	1	0.348	0.411
19	2.633	2.154	0.902	14	0.342	0.419
20	1.301	0.967	0.417	21	0.321	0.431
21	1.997	1.756	0.669	4	0.335	0.381
22	2.602	2.291	0.897	3	0.345	0.392
23	0.098	0.000	0.000	11	0.000	0.000
24	0.397	0.000	0.000	22	0.000	0.000
25	2.379	2.193	0.968	6	0.407	0.441
26	2.605	2.280	0.876	4	0.336	0.384
27	2.878	2.522	0.995	11	0.346	0.394
28	0.257	0.000	0.000	22	0.000	0.000
29	1.848	1.526	0.645	24	0.349	0.422
30	0.084	0.000	0.000	26	0.000	0.000
31	0.570	0.153	0.044	17	0.077	0.285
SUM	37.762	28.349	11.534	-	-	-
AVG	1.218	0.914	0.372	15	0.305	0.407
PFRV	0.9704	0.9704	0.9704	0.9704	0.9704	0.9704

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

MONTHLY REPORT: CATHEDRAL SQUARE P2631R JANUARY 1982

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	0.000	0.170	-0.175	69	0.09
2	0.810	0.228	0.591	79	0.06
3	0.000	0.436	-0.429	82	0.09
4	0.000	0.274	-0.274	67	0.00
5	0.658	0.219	0.425	70	0.18
6	0.000	0.243	-0.270	73	0.76
7	0.064	0.152	-0.113	65	0.32
8	0.530	0.197	0.341	69	0.10
9	0.380	0.309	0.033	79	0.32
10	0.313	0.273	-0.028	76	0.68
11	0.012	0.149	-0.185	65	0.88
12	0.763	0.202	0.557	72	0.02
13	0.000	0.341	-0.382	76	0.27
14	0.000	0.179	-0.225	63	0.75
15	0.126	0.104	-0.015	57	1.02
16	0.177	0.107	0.045	57	0.76
17	0.026	0.080	-0.110	56	0.77
18	0.540	0.262	0.268	60	0.11
19	0.759	0.477	0.349	74	0.54
20	0.357	0.463	-0.108	78	0.03
21	0.553	0.514	0.033	77	0.03
22	0.740	0.567	0.216	83	0.20
23	0.000	0.449	-0.456	77	0.06
24	0.000	0.225	-0.259	61	1.85
25	0.820	0.273	0.582	68	0.27
26	0.713	0.420	0.310	87	0.08
27	0.793	0.546	0.308	101	0.21
28	0.000	0.551	-0.553	96	0.01
29	0.550	0.433	0.137	85	0.21
30	0.000	0.358	-0.365	82	0.09
31	0.036	0.195	-0.191	69	1.08
SUM	9.722	9.395	-0.201	-	-
AVG	0.314	0.303	-0.006	73	0.38
PFRV	0.9704	0.9704	N.A.	0.9704	0.9704

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

MONTHLY REPORT: CATHEDRAL SQUARE P2631R JANUARY 1982

HOT WATER SUBSYSTEM I

DAY OF MON. (NBS ID)	HOT WATER LOAD MILLION BTU	SOLAR FR.OF LOAD PER. (N300)	HOT WATER DEMAND MILLION BTU (Q302)	SOLAR FR.OF DEMAND BTU	SOLAR ENERGY USED MILLION BTU (Q300)	OPER ENERGY MILLION BTU (Q303)	AUX THERMAL USED MILLION BTU (Q301)
1	1.802	9	0.631	15	0.169	0.171	1.633
2	2.066	10	0.602	9	0.207	0.174	1.859
3	1.841	20	0.877	22	0.376	0.173	1.465
4	2.225	12	1.075	15	0.267	0.173	1.958
5	2.105	11	0.781	10	0.232	0.173	1.873
6	2.040	12	0.793	15	0.255	0.172	1.785
7	2.059	8	0.777	10	0.170	0.173	1.889
8	2.121	10	0.802	9	0.203	0.166	1.918
9	2.294	12	0.917	12	0.322	0.155	2.015
10	2.003#	13#	0.798	14#	0.276	0.158	1.747#
11	2.293	9	0.819	11	0.193	0.157	2.090
12	1.951	11	0.693	8	0.206	0.156	1.731
13	2.224	14	0.888	14	0.316	0.156	1.922
14	2.191	8	0.868	10	0.190	0.157	2.007
15	1.930	5	0.899	6	0.128	0.156	1.827
16	1.996	6	0.800	7	0.124	0.155	1.875
17	2.125	5	0.713	6	0.109	0.158	2.016
18	2.057	13	1.405	11	0.278	0.155	1.782
19	2.176	20	1.227	17	0.437	0.153	1.739
20	2.070	22	1.208	24	0.455	0.152	1.616
21	2.205	22	1.377	21	0.507	0.154	1.722
22	2.058	23	1.199	23	0.501	0.155	1.581
23	2.092	19	1.103	22	0.398	0.154	1.694
24	2.137	11	1.189	13	0.239	0.153	1.898
25	2.400	11	1.003	10	0.267	0.155	2.133
26	2.413	16	0.840	16	0.387	0.157	2.027
27	2.108	22	0.760	22	0.463	0.156	1.646
28	2.110	23	0.833	26	0.479	0.155	1.631
29	2.193	18	0.875	21	0.395	0.155	1.797
30	2.139	16	0.799	17	0.332	0.155	1.807
31	2.110	10	0.773	13	0.216	0.154	1.894
SUM	65.533	-	28.325	-	9.096	4.944	56.574
AVG	2.114	14	0.914	15	0.293	0.159	1.825
PFRV	0.9328	0.9328	0.9691	0.9328	0.9691	0.9704	0.9328

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

MONTHLY REPORT: CATHEDRAL SQUARE P2631R JANUARY 1982

HOT WATER SUBSYSTEM II

DAY OF MON. (NBS)	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)	TEMPERED HOT WATER USED GAL	HOT WATER USED GAL (N308)	SOLAR SPECIFIC OPER ENERGY MILLION BTU
1	N	2.721	-0.010	0.282	42	121	N	956	0.010
2	O	3.098	-0.010	0.345	41	125	O	864	0.010
3	T	2.441	-0.010	0.627	42	118	T	1376	0.010
4		3.263	-0.010	0.445	41	118		1655	0.010
5	A	3.122	-0.010	0.386	40	122	A	1154	0.010
6	P	2.975	-0.010	0.425	40	121	P	1181	0.010
7	P	3.148	-0.010	0.283	40	121	P	1150	0.010
8	L	3.197	-0.010	0.338	40	122	L	1175	0.010
9	I	3.358	-0.010	0.537	40	124	I	1311	0.010
10	C	2.911#	-0.010	0.461	39	124	C	1129	0.010
11	A	3.483	-0.010	0.321	39	123	A	1173	0.010
12	B	2.884	-0.010	0.344	39	125	B	963	0.010
13	L	3.203	-0.010	0.526	39	124	L	1246	0.010
14	E	3.345	-0.010	0.317	38	123	E	1236	0.010
15		3.044	-0.010	0.214	39	121		1313	0.010
16		3.125	-0.010	0.207	39	122		1157	0.010
17		3.360	-0.010	0.182	38	125		990	0.010
18		2.970	-0.010	0.463	37	120		2030	0.010
19		2.898	-0.010	0.728	37	126		1653	0.010
20		2.693	-0.010	0.758	37	123		1683	0.010
21		2.871	-0.010	0.844	37	125		1885	0.010
22		2.634	-0.010	0.836	38	124		1663	0.010
23		2.824	-0.010	0.663	38	126		1497	0.010
24		3.164	-0.010	0.398	37	124		1628	0.010
25		3.555	-0.010	0.445	36	126		1345	0.010
26		3.378	-0.010	0.644	37	126		1124	0.010
27		2.743	-0.010	0.771	37	124		1042	0.010
28		2.718	-0.010	0.799	37	123		1161	0.010
29		2.996	-0.010	0.658	37	121		1244	0.010
30		3.012	-0.010	0.553	37	124		1103	0.010
31		3.157	-0.010	0.360	37	124		1070	0.010
SUM	N.A.	94.290	-0.304	15.160	-	-	N.A.	40158	0.304
AVG	N.A.	3.042	-0.010	0.489	38	123	N.A.	1295	0.010
PFRV	N.A.	0.9328	0.9704	0.9691	0.9691	0.9691	N.A.	0.9691	0.9704

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

MONTHLY REPORT: CATHEDRAL SQUARE P2631R JANUARY 1982

ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	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	30	N	34	34	N	N	N
2	1392	O	15	17	O	O	O
3	118	T	18	20	T	T	T
4	33		35	37			
5	979	A	28	22	A	A	A
6	129	P	26	29	P	P	P
7	357	P	28	30	P	P	P
8	947	L	11	12	L	L	L
9	906	I	7	10	I	I	I
10	624	C	7	13	C	C	C
11	315	A	4	2	A	A	A
12	1328	B	0	7	B	B	B
13	229	L	4	7	L	L	L
14	337	E	8	9	E	E	E
15	505		15	17			
16	435		16	18			
17	390		-4	-6			
18	1021		0	1			
19	1465		7	14			
20	723		14	21			
21	1111		-2	4			
22	1447		-3	3			
23	55		11	11			
24	221		21	22			
25	1323		2	6			
26	1449		0	4			
27	1601		4	11			
28	143		21	22			
29	1028		22	24			
30	47		24	26			
31	317		20	17			
SUM	21002	N.A.	-	-	-	-	-
AVG	677	N.A.	13	15	N.A.	N.A.	N.A.
PFRV	0.9704	N.A.	0.9704	0.9704	N.A.	N.A.	N.A.

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

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