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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

BELL TELEPHONE OF PENNSYLVANIA

West Chester, Pennsylvania
November 1979 through March 1980
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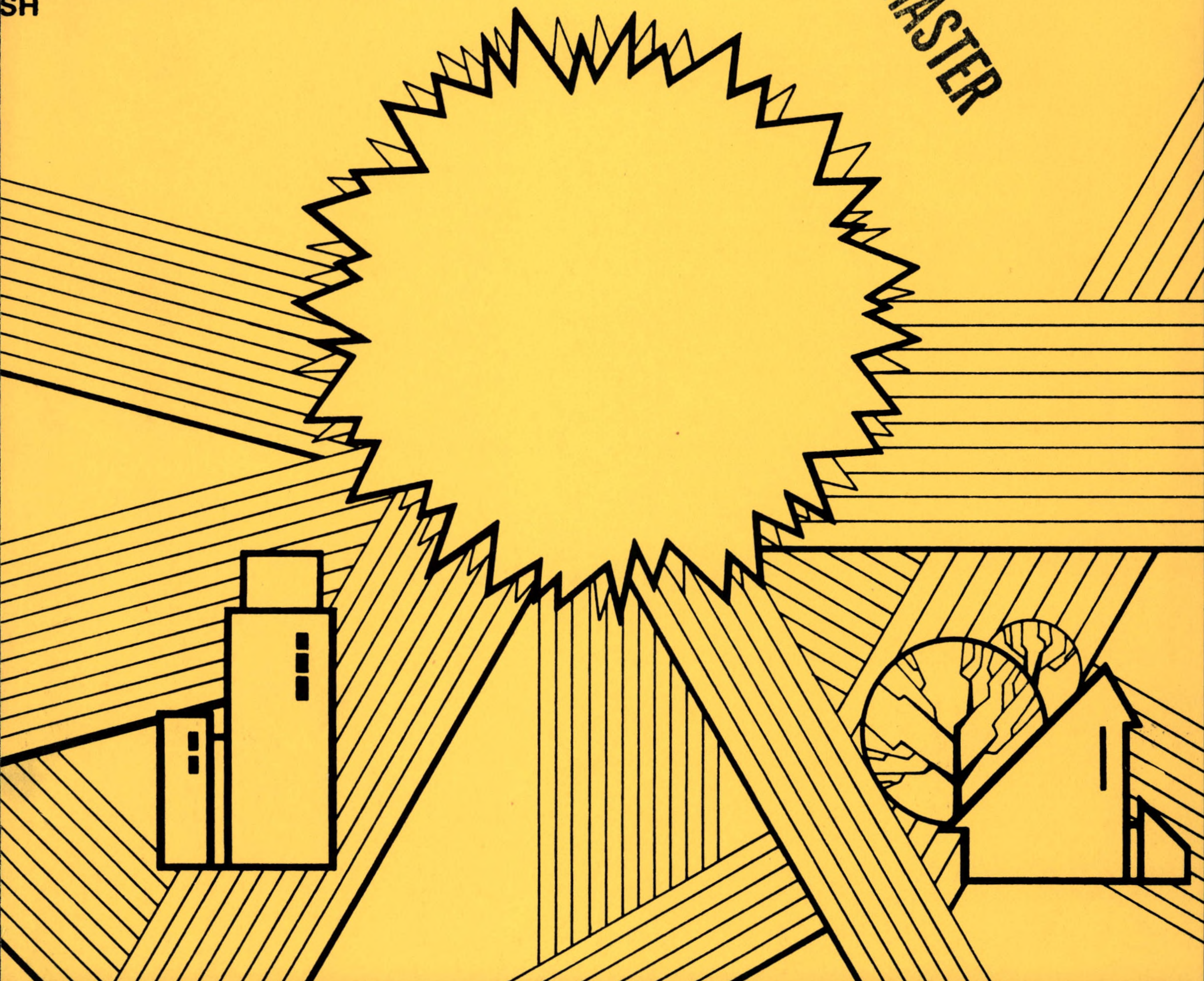

U.S. DEPARTMENT OF ENERGY

NATIONAL SOLAR DATA PROGRAM

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SOLAR/2012-80/14

BELL TELEPHONE OF PENNSYLVANIA

WEST CHESTER, PENNSYLVANIA

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

NOVEMBER 1979 THROUGH MARCH 1980

Prepared by Steven J. Frock

Approved: for
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Program Manager

Vitro Laboratories Division
Automation Industries, Inc.

The National Solar Data Network
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9700 South Cass Avenue
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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 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 reduce the use of nonrenewable fuels by encouraging the application of solar energy for heating, cooling, and domestic hot water. Vitro Laboratories Division operates the NSDN, under contract with the Department of Energy, to collect daily data 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, Hawaii and Puerto Rico. 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.

In addition to these "Seasonal" Reports, NSDN information is disseminated for each operational site via Monthly Performance Reports, and special reports.

BELL TELEPHONE OF PENNSYLVANIA

BELL TELEPHONE OF PENNSYLVANIA

The Bell Telephone Company of Pennsylvania site is an office building in West Chester, Pennsylvania. The solar system was put into operation in October 1977 and is designed to supply the following:

Seasonal Design Factors[1]
(Million BTU)

	Total Load	Solar Contribution	% Solar
Heating	234	134	57

The system is equipped with:

Collector	2,112 square feet, manufactured by Heliotherm
Storage	4,600 gallon steel tank, located aboveground
Auxiliary	Electric boiler - manufactured by Trane Co.

1.

	Total Design Load	Solar Contribution	Solar Fraction %
NOV	31.01	26.88	87
DEC	56.27	25.60	45
JAN	57.71	23.20	40
FEB	47.12	26.89	57
MAR	41.62	30.93	74

The Total Design Load, Solar Contribution, and Solar Fraction are all based on a 0-72°F design temperature. Design information obtained from: Report No. COO-2688-2; January 28, 1976; Preliminary Design West Work Center; Intertechnology Division, Warrenington, Virginia.

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BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

Solar Fraction[1]	46%
Solar Savings Ratio[2]	44%
Conventional Fuel Savings[3]	19,300 kw
System Performance Factor[4]	0.33
Solar System COP[5]	30

Seasonal Energy Requirements
November 1979 through March 1980
(million BTU)

	Total Load	Solar Contribution	% Solar
Heating	143.58	65.79	46

Environmental Data

	Measured Average	Long-Term Seasonal Average
Heating degree-days	772	818
Average incident solar energy	1,080 BTU/ft^2	1,062 BTU/ft^2

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

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

3. Uses solar energy delivered to heating load only (see Solar Energy Utilization).

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

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

1.1 SUMMARY AND CONCLUSIONS

The Bell Telephone of Pennsylvania solar energy system supplied 46% of the space heating required for this commercial building during the heating season of November 1979 through March 1980. Although Bell Telephone of Pennsylvania experienced problems with an automatic collection control device, the system did perform well by collecting 92.15 million BTU that otherwise would not have been supplied to the seasonal heating load requirement of 143.58 million BTU. (See Site History, Problems, Changes in Solar System.) The small electrical operational energy required for the solar collection subsystem contributed to a net energy savings of 63.70 million BTU for the season. This can be expressed as an electrical savings of 18,658 kwh. At an estimated current price of five cents per kwh, an approximate monetary value of savings would yield $933.00 for the season.

The system at Bell Telephone of Pennsylvania experienced sizeable thermal losses that must be accounted. A total of 84.10 million BTU of solar and auxiliary energy was lost throughout the system. The losses occurred at valves and other pipe fittings where insulation is missing. The thermal losses, in general, do contribute to the space heating load but are not included in the performance tables because of the difficulty in accurately determining their contribution. (See Solar Energy Utilization.)

The solar space heating system at Bell Telephone of Pennsylvania was operational from September 1979 through April 1980. During the heating season, November 1979 through March 1980, the solar system did save electrical energy while operating manually until January 21, 1980. The solar system successfully achieved an average solar fraction of 46% for that season. The malfunction of the solar collection controller necessitated the site staff to operate the collection system by manual means, limited to normal working days only. The system did not benefit from the available solar energy during the weekends and holidays. The system probably would have increased the collected energy of 92.15 million BTU if it had been fully automatic for that five-month period. (See Site History, Problems, Changes in Solar System.)

The solar system allows auxiliary electric energy from the boiler to enter the solar storage tank. Some of this auxiliary energy is transferred to another series of auxiliary energy devices, the heat pumps. The elevated tank temperature from the addition of auxiliary energy caused a decreased collector efficiency. Smaller auxiliary energy flows to storage were observed after the collector controller was repaired in January.

The solar energy used by the heating load cannot be directly measured due to the auxiliary energy added to storage, as the measured energy flows contain a mixture of solar and auxiliary energy. An actual measurement of the solar contribution to the heating load from storage can be found by establishing estimated fractional proportions. The solar fractional proportions enable calculation of the "pure" or "solar unique" energy used from storage to the heating load. (See Solar Energy Utilization.)

There was an 84.10 million BTU loss of solar and auxiliary energy throughout the system for the season. The losses that do not contribute to heating the building are not solar unique. They would occur even if no solar energy was supplied to the system. The energy savings computed with the assumptions that all losses apply to the load would be 92.15 million BTU which is equivalent to the solar energy collected. However, it is estimated that 10 to 20 million BTU of auxiliary and solar energy do not contribute to the heating of the building (See Solar Energy Utilization.) Better estimates should be possible during the next heating season.

The solar system was operational from September 1979 to April 1980. Simultaneous heating and cooling by the heat pumps occurred during the months of September, October and April. Since the instrumentation does not allow differentiation between cooling and heating, a complete analysis of space heating subsystems from these months was not possible.

1.2 OVERALL SYSTEM PERFORMANCE

The flow of solar energy through the Bell Telephone of Pennsylvania site for the reporting period from November 1979 through March 1980 is presented in Figure 1. This Energy Flow Diagram shows the amount of energy collected, transported, stored, consumed or lost at each point in the system.

The overall thermal performance of the solar energy system is presented in Table 1 and shown graphically in Figure 2. The overall system thermal performance was good with respect to the design information.

In Figure 1, the energy from storage to the heat pumps and the energy delivered to the heat pumps from storage was estimated (see Subsystem Performance, Storage). The electrical compressor and fan energy to the heat pumps was estimated by theoretically proportioning the measured electrical power from sensor, EP407 (see Schematic on Page A-3). The negative loss (-1.28 million BTU) going from the energy collection subsystem to the storage subsystem is within the expected measurement error.

In Table 1 and Figure 2, the solar energy used is the estimated solar energy that is delivered to the heating load. The auxiliary energy supplied to the space heating load is estimated using the same technique (see Solar Energy Utilization). The nonoperational energy is obtained from an energy balance of the measured energy flows and does not include the operation energy. The thermal losses contain a mixture of auxiliary and solar energy.

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 Bell Telephone of Pennsylvania functioned at a reporting period weighted average COP value of 30 for the period November 1979 through March 1980.

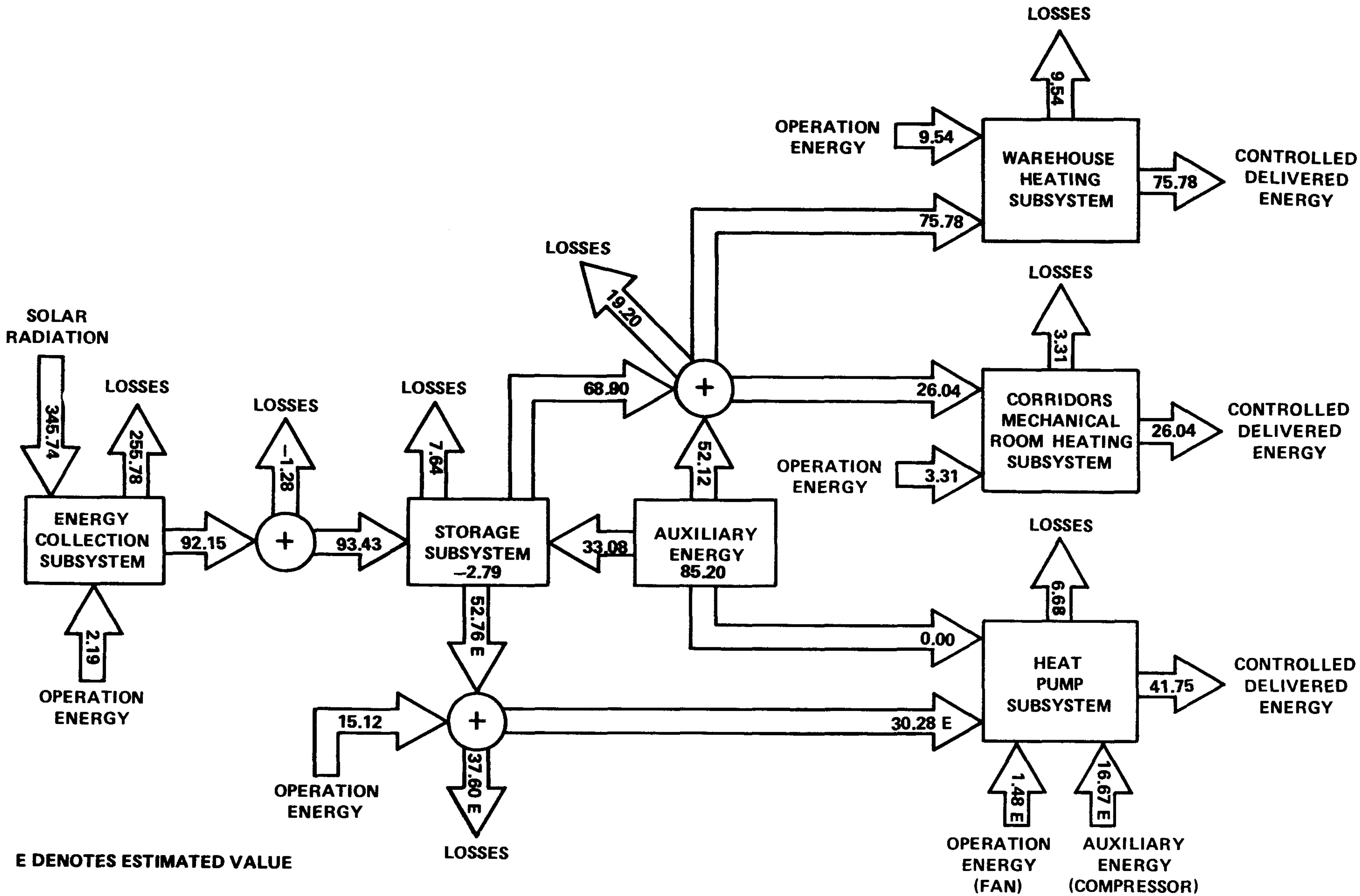


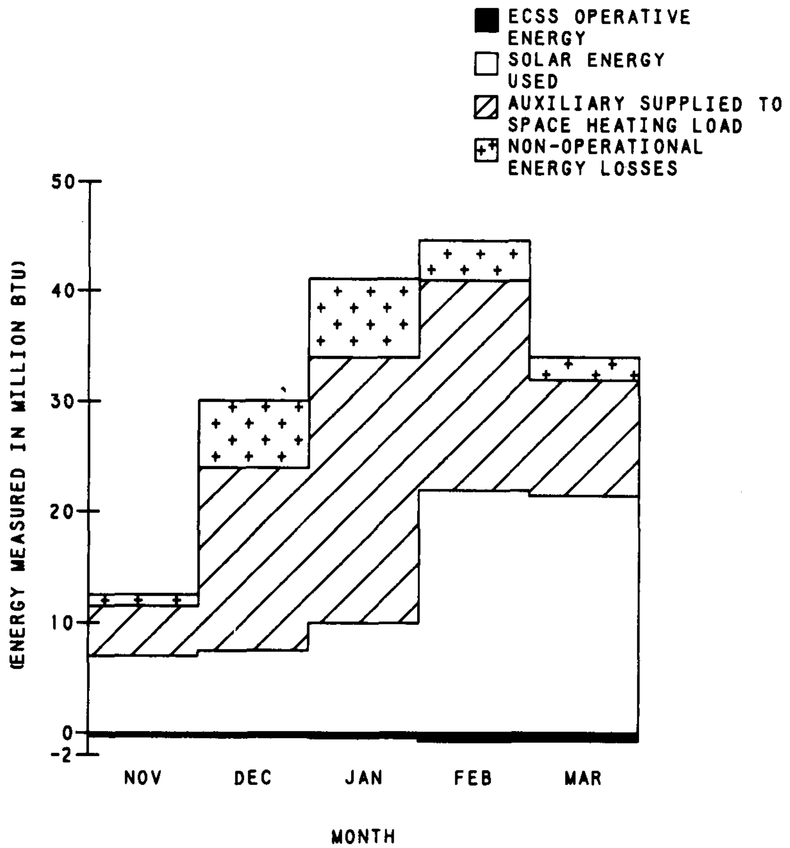
Figure 1. Energy Flow Diagram for Bell Telephone of Pennsylvania
November 1979 through March 1980
(Figures in million BTU)

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED MEASURED	AUXILIARY ENERGY ELECTRICAL	OPERATING ENERGY	ENERGY SAVINGS ELECTRICAL	SOLAR FRACTION (PERCENT) MEASURED
NOV	8.91	11.31	6.17	6.88	0.22	6.17	55
DEC	12.27	24.26	7.73	23.36	0.28	7.73	32
JAN	14.49	34.65	8.96	33.23	0.37	8.96	26
FEB	29.45	41.40	21.99	24.05	0.70	21.99	53
MAR	27.03	31.96	21.05	14.03	0.62	21.05	66
TOTAL	92.15	143.58	65.89	101.55	2.19	65.89	-
AVERAGE	18.43	28.72	13.18	20.31	0.44	13.18	46



Operating energy for the system is considered a system penalty and is plotted as a negative value below the origin.

Figure 2. System Thermal Performance
Bell Telephone of Pennsylvania
November 1979 through March 1980

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

MONTH	SOLAR ENERGY SYSTEM[1]	COLLECTOR SUBSYSTEM[2]	SPACE HEATING SUBSYSTEM[3]
NOV	28.0	40.5	1.89
DEC	27.6	43.9	1.32
JAN	24.2	39.2	1.48
FEB	31.4	42.1	3.06
MAR	33.9	43.6	3.26
AVERAGE	30.1	41.8	2.20

[1]COP for solar energy system is defined as:

$$\frac{\text{The Solar Energy Used}}{\text{ECSS Operating Energy}}$$

[2]COP for the collector subsystem is defined as:

$$\frac{\text{The Total Solar Energy Collected}}{\text{The Collector Operational Energy}}$$

[3]COP for space heating solar is defined as:

$$\frac{\text{The Solar Energy Used}}{\text{The Space Heating Operational Energy}}$$

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, November 1979 to March 1980, are presented in Table 3 and shown graphically in Figure 3. For this five-month period, the total electrical savings were 63.70 million BTU, for a monthly average of 12.74 million BTU. This is approximately 18,658 kwh of electricity. An electrical energy expense of 2.19 million BTU was incurred during the reporting period for the operation of solar energy components. These savings are based on the estimated solar energy used by the heating load. These savings do not include the effect of losses on the building heating.

Table 3. ENERGY SAVINGS

BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	SOLAR ENERGY SAVINGS ATTRIBUTED TO SPACE HEATING ELECTRICAL	ECSS OPERATING ENERGY	NET ENERGY SAVINGS ELECTRICAL
NOV	6.17	6.88	0.22	5.95
DEC	7.73	23.36	0.28	7.45
JAN	8.96	33.23	0.37	8.59
FEB	21.99	24.05	0.70	21.29
MAR	21.05	14.03	0.62	20.43
TOTAL	65.89	101.55	2.19	63.70
AVERAGE	13.18	20.31	0.44	12.74

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

A large percentage of the thermal losses contribute to heating the building (see Solar Energy Utilization). As a consequence, alternate interpretation of energy savings are possible when considering the total energy going to heat the building. An alternate interpretation must include the fact that some of the losses in the ceiling crawlspace (estimated 15% to 20%, including solar and auxiliary energy) do not contribute to heating the building. If an estimated 80% of the observed losses from the energy flow diagram were applied to the space heating load, an increased solar fraction of 65% would result. The energy savings would increase by 67.52 million BTU. A better estimate of the building heating from thermal losses is expected for the 1980-1981 heating season. The ambient environment of the mechanical room will be measured (see Solar Energy Utilization).

The auxiliary source at the Bell Telephone of Pennsylvania site consists of a Weil McLean electric boiler. This unit is considered to be 100% efficient for computational purposes.

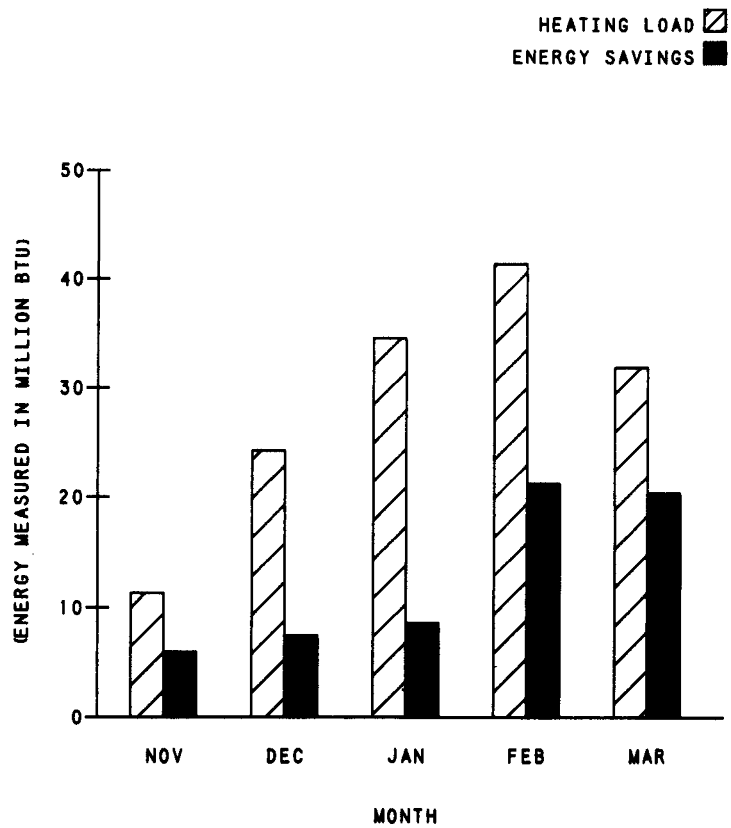


Figure 3. Combined Thermal Energy Savings Compared to Load
Bell Telephone of Pennsylvania
November 1979 through March 1980

1.4 SOLAR ENERGY UTILIZATION

Figure 4 shows the use of solar energy and the percent of losses.

The losses of solar energy at the different stages through the system, from incident radiation to the loads, are also presented in Table 4.

Large losses from the pipes occur during the distribution of energy from storage to the heating load (or terminal devices). The pipes are located in the mechanical room, which is heated, and the crawlspace above a drop ceiling. The ceiling crawlspace is an unconditioned space. Losses occurring in the mechanical room contribute to the building heating. Part of the losses in the crawlspace contribute to the building heating by decreasing the building losses through the roof. Effectively, part of the crawlspace losses do go to the exterior environment and do not contribute to the building heating. Approximate estimations using the building structure suggest that 15% to 25% of the thermal losses do not contribute to building heating. The estimates

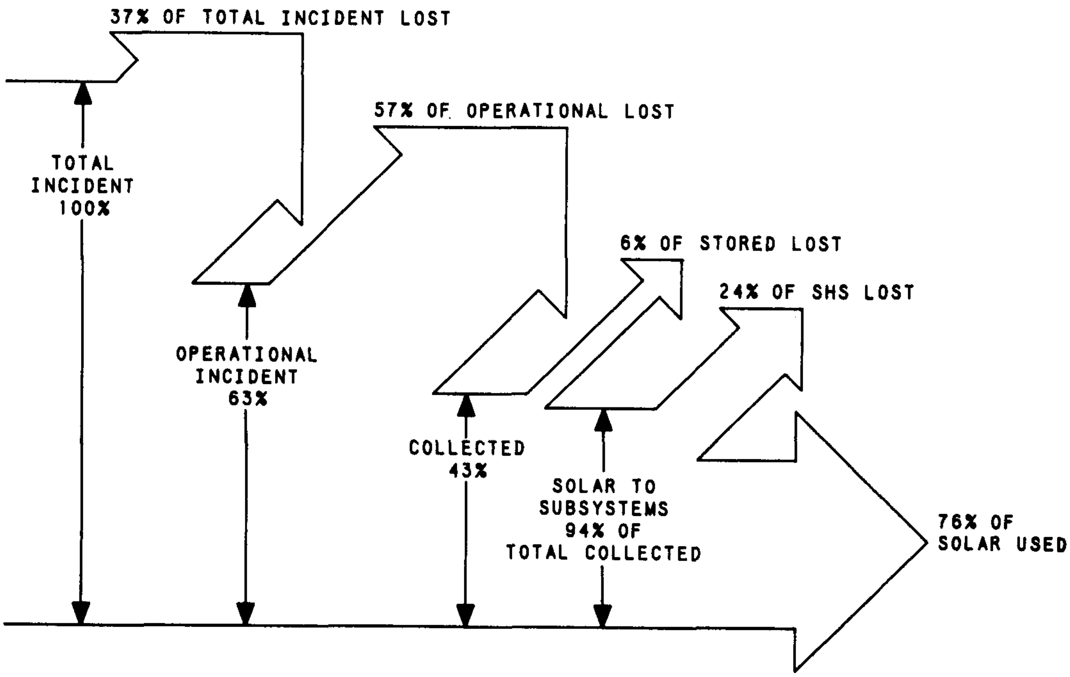


Figure 4. Solar Energy Use
Bell Telephone of Pennsylvania
November 1979 through March 1980

Table 4. SOLAR ENERGY LOSSES

BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

	NOV	DEC	JAN	FEB	MAR
1. SOLAR ENERGY (SE) COLLECTED - SE DIRECTLY TO LOADS (million BTU)	0.07	0.70	1.50	0.68	0.23
2. SE TO STORAGE (million BTU)	9.07	12.43	14.66	29.78	27.49
3. LOSS - COLLECTOR TO STORAGE (%)	N/A	N/A	N/A	N/A	N/A
4. CHANGE IN STORED ENERGY (million BTU)	−1.88	−0.02	−0.02	−0.51	−0.38
5. SOLAR ENERGY - STORAGE TO SPACE HEATING SUBSYSTEM (million BTU)	7.02	9.55	10.05	22.95	22.30
6. TOTAL LOSS FROM STORAGE (%)	18	5	6	5	4
7. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million BTU)	6.17	7.73	8.96	21.99	21.05
8. TOTAL NONOPERATING ENERGY LOSSES	6.14	10.53	12.13	11.60	8.94

are uncertain because the air temperatures where the losses occur are not known. Better estimates should be possible in the 1980-1981 season because the mechanical room air temperature will be measured.

A site visit in February confirmed that air temperatures in the crawlspace are lower than the building temperature and the recirculation loop temperature. It was also learned that the mechanical room temperature was much lower than the measured building temperature due to a heater failure.

The solar energy used by the heating load (terminal devices) cannot be directly measured. Electric auxiliary energy is added to storage and large losses occur between the electric auxiliary boiler and the heating load. It was determined from a site visit to Bell Telephone of Pennsylvania in February that heat pump recirculation line losses are occurring in an unconditioned crawlspace near the roof. The pipe losses could be reduced by completely insulating all of the crawlspace piping. The measured energy flow at the terminal devices (air handler, forced flow heaters, and heat pumps) contain a mixture of auxiliary and solar energy. The solar energy used is estimated by multiplying the measured load with proportions (or solar fractions) based on solar and auxiliary energy inputs into the particular energy flow. For solar energy leaving storage and arriving at the heat pumps, the energy absorbed by the heat pump is multiplied by a proportion (see Site Equations) that is based on solar energy into storage and electric boiler energy into storage. For solar energy leaving storage and arriving at the air handler unit and the forced fan unit, the measured energy flow at these terminal devices is multiplied by a proportion (see Site Equations) that is based on the measured solar and auxiliary energy flow from storage and the auxiliary added by the electric boiler.

1.5 SOLAR SYSTEM AVAILABILITY

The solar system was operational from September 1979 to April 1980. Solar energy was collected by manual operation of the collector controls from September until January 21. (See Summary and Conclusions and Site History, Problems, Changes in Solar System).

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The Bell Telephone of Pennsylvania collector array is composed of 88 Model DC24SC Heliotherm flat-plate collectors which use water as the heat transfer fluid.

Collector subsystem performance for the Bell Telephone of Pennsylvania site is presented in Table 5.

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY %	OPERATIONAL INCIDENT ENERGY	OPERATIONAL COLLECTOR EFFICIENCY %	ECSS OPERATING ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE °F
NOV	61.20	8.91	15	24.20	37	0.22	9.07	53
DEC	69.24	12.27	18	26.73	46	0.28	12.43	41
JAN	58.47	14.49	25	34.48	42	0.37	14.66	35
FEB	83.21	29.45	35	70.02	42	0.79	29.78	33
MAR	73.62	27.03	37	61.26	44	0.62	27.49	43
TOTAL	345.74	92.15	-	216.69	-	2.19	93.43	-
AVERAGE	69.15	18.43	26	43.34	42	0.44	18.69	41

Bell Telephone of Pennsylvania was reported on from November 1979 through March 1980. The incident solar energy measured was 345.74 million BTU with 216.69 million BTU incident with the collector pump active. The total solar energy collected was 92.15 million BTU corresponding to a 42% operational collector performance efficiency. The overall collector subsystem efficiency was 26%. The subsystem efficiency is low due to a collector controller problem. The automatic collector controller was inoperative from September through January because antifreeze protection devices were being added to regulate fill and drain-down procedures. During this time period, the system collected solar energy by manual means. The collected solar energy transferred to storage was 93.43 million BTU, of which 65.89 million BTU of solar unique were transferred directly to the load from storage. The ECSS operational energy was 2.19 million BTU.

2.2 STORAGE

Storage performance data for the site for the reporting period are shown in Table 6.

During the reporting period, total solar energy delivered to storage was 93.43 million BTU and auxiliary energy contribution to storage was 33.08 million BTU. There were 129.49 million BTU delivered from storage to the space heating subsystems. Energy loss from storage was 7.64 million BTU. This loss represented eight percent of the energy delivered to storage. The storage efficiency was 92%. (See Footnote 1.)

The flow meters W413 and W411 are impact type meters and are incapable of measuring the typical small flows from storage to the heat pump recirculation loop. As a consequence, the energy flow from storage to the heat pump recirculation loop is estimated by a net energy balance at storage. To obtain a net energy balance, the conductive losses from storage were estimated by an overall heat transfer coefficient for storage times the temperature difference between the tank and the building. The coefficient was determined by observing the tank temperature decay over times when there was no liquid into and out of the tank. The coefficient used was 50.33 BTU/hr-°F.

Unfortunately, the temperature in the utility room where storage is located was not always the same as the building temperature in the 1979-1980 heating season. This is, in part, due to the failure of the mechanical room heater. To obtain a more accurate estimate of losses in the mechanical room, T473 was removed from its thermowell and will measure the room temperature during the 1980 to 1981 heating season.

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

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

Where:
STEFF = Storage efficiency
STECH = Change in stored energy
STEO = Energy removed from storage
STEI = Energy added to storage

Effective storage heat loss coefficient (c) for the storage subsystem can be defined as follows:

$$c = (STEI-STEO-STECH)/\ (T_s - T_a) \times t \quad \frac{BTU}{Hr\ ^\circ F}$$

Where:
c = effective storage heat loss coefficient
T_s = average storage temperature
T_a = average ambient temperature in the vicinity of storage
t = number of hours in the month

Table 6. STORAGE PERFORMANCE

BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY %	AVERAGE STORAGE TEMP (°F)	LOSS FROM STORAGE
NOV	11.54	11.30	-1.88	82	129	2.13
DEC	24.43	23.03	-0.02	95	107	1.16
JAN	26.20	24.66	-0.02	94	107	1.62
FEB	33.60	32.57	-0.52	95	110	1.53
MAR	30.76	29.93	-0.40	96	108	1.20
TOTAL	126.53	121.49	-2.84	-	-	7.64
AVERAGE	25.31	24.30	-0.57	92	112	1.53

2.3 SPACE HEATING

The space heating performance for the Bell Telephone of Pennsylvania site for the reporting period is shown in Table 7 and presented graphically in Figure 5.

According to design specifications, the space heating subsystem performed well although automatic collection was not possible.

In Table 8, the sum of solar energy collected and the auxiliary thermal energy is more than the measured space load due to large losses (see Solar Energy Utilization). The losses that do not include the effect of operation energy are included in Figure 5. Thermal losses are computed by taking the difference of measured energy flows, assuming that there is no thermal input from pumps.

The space heating load of 143.58 million BTU was satisfied by 65.89 million BTU of solar unique energy and 77.69 million BTU of auxiliary energy. The solar fraction of this load was 46% with an operating energy expense of 28.78 million BTU.

The electrical energy savings were 65.89 million BTU. The average building temperature for the season was 68°F.

Table 7. SPACE HEATING SUBSYSTEM

BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	ENERGY CONSUMED COLLECTED SOLAR	AUXILIARY THERMAL	AUXILIARY ELECTRICAL	OPERATING ENERGY	SOLAR FRACTION %	BUILDING TEMPERATURE °F
NOV	11.31	8.91	6.37	6.88	3.27	55	70
DEC	24.26	12.27	22.35	23.36	5.84	32	68
JAN	34.65	14.49	32.18	33.23	6.04	26	66
FEB	41.40	29.45	22.71	24.05	7.18	53	66
MAR	31.96	27.03	13.03	14.03	6.45	66	68
TOTAL	143.58	92.15	96.64	101.55	28.78	-	-
AVERAGE	28.72	18.43	19.33	20.31	5.76	46	68

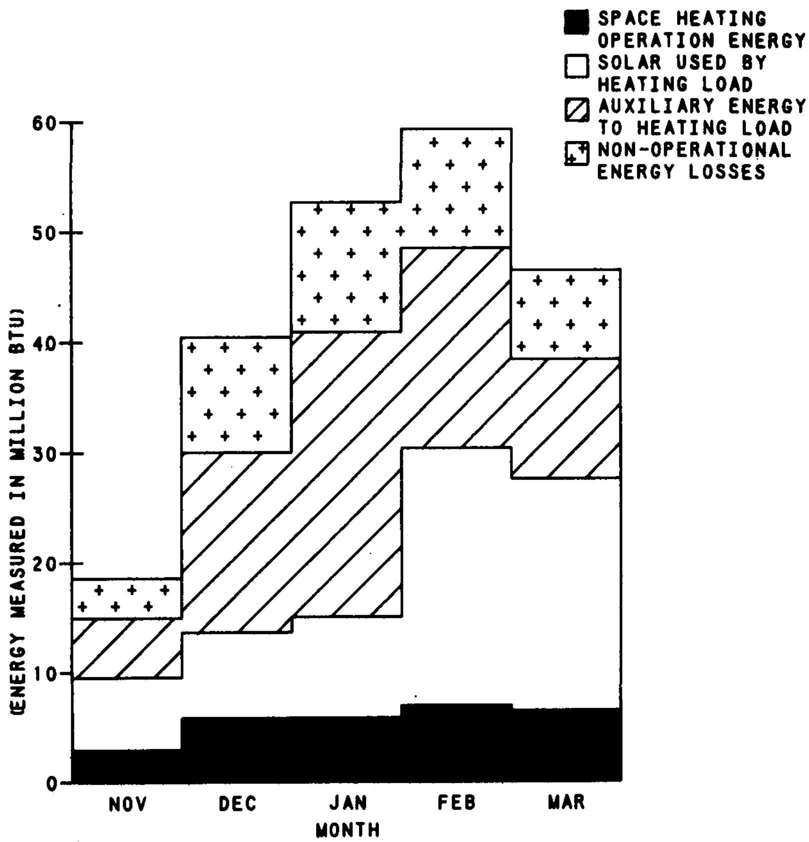


Figure 5. Space Heating Performance
Bell Telephone of Pennsylvania
November 1979 through March 1980

SECTION 3

OPERATING ENERGY

Measured monthly values of the Bell Telephone of Pennsylvania solar energy system and subsystem operating energy for the report period are presented in Table 8. A total 30.97 million BTU of operating energy was consumed by the entire system during the reporting period. A distribution of this operating energy among the subsystems is illustrated in Figure 6.

Total system operating energy for the Bell Telephone of Pennsylvania site is the electrical energy required to support the space heating subsystem.

Table 8. OPERATING ENERGY

BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	SHS OPERATING ENERGY	TOTAL SOLAR UNIQUE OPERATING ENERGY	TOTAL SYSTEM OPERATING ENERGY
NOV	0.22	3.27	0.22	3.49
DEC	0.28	5.84	0.28	6.12
JAN	0.37	6.04	0.37	6.41
FEB	0.70	7.18	0.70	7.88
MAR	0.62	6.45	0.62	7.07
TOTAL	2.19	28.78	2.19	30.97
AVERAGE	0.44	5.76	0.44	6.19

Heat Pump Recirculation Pump Power Subsystem

Pump P2 is located within the heat pump recirculation line. It supplies a constant supply of hot water to the heat pumps. The recirculation pump used 44% of the total operational energy of 34.30 million BTU.

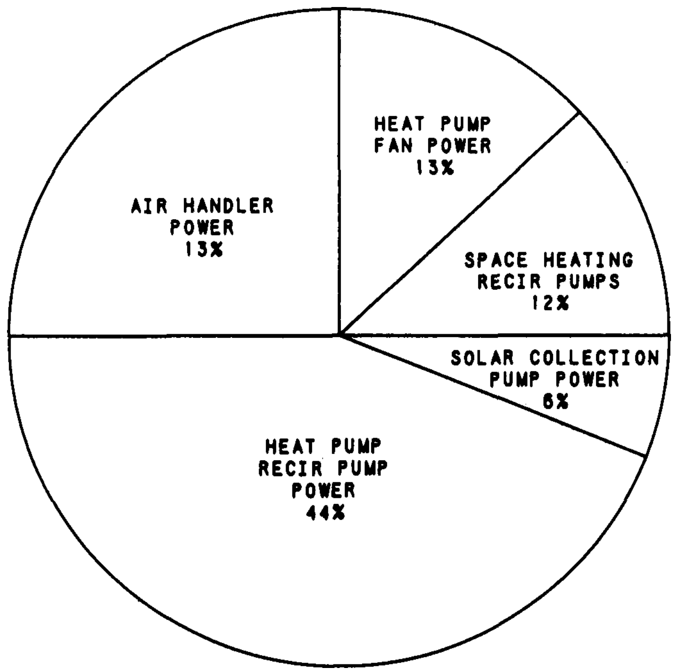


Figure 6. Total Operating Energy
Bell Telephone of Pennsylvania
November 1979 through March 1980

Air Handling Power Subsystem

Fan power, F1, is responsible for circulating conditioned air to the warehouse. Fan power for the season represented 25% of the total operational energy consumed.

Heat Pump Fan Power Subsystem

Heat pump fans, monitored by EP407, are contained in all of the twenty heat pumps located in the offices. Two of the 20 fans were on continuous operation in large reception areas. The fans used 13% of the total operational energy.

Space Heating Recirculation Pump Power

Pumps P3 and P4 are used to supply hot water to the air handling unit and the force fan unit heaters are found in the corridors and mechanical room heating subsystems. The pumps consumed 12% of the 34.30 million BTU used for operational energy.

SECTION 4

WEATHER CONDITIONS

The Bell Telephone of Pennsylvania site is located in West Chester, Pennsylvania at 40 degrees N latitude and 76 degrees W longitude.

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

Table 9. WEATHER CONDITIONS

BELL TELEPHONE of PENNSYLVANIA
NOVEMBER 1979 THROUGH MARCH 1980

	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS	
MONTH	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
NOV	966	1,041	51	46	425	564
DEC	1,058	859	39	35	805	924
JAN	893	979	33	32	983	1,014
FEB	1,359	1,162	31	34	892	817
MAR	1,124	1,296	41	42	754	716
TOTAL	5,400	5,337	-	-	3,859	4,089
AVERAGE	1,080	1,067	39	38	772	818

During the period from November 1979 to March 1980, the average daily total incident solar radiation on the collector array was 1,080 BTU per square foot per day. This radiation was slightly above the estimated average daily solar radiation for this geographical area during the reporting period of 1,067 BTU per square foot per day for a south-facing plane with a tilt of 55 degrees to the horizontal. During the period, the highest monthly average insolation was 1,359 BTU per square foot per day during February. The average ambient temperature during the reporting period was 39°F as compared with the long-term average of 38°F. The highest monthly average ambient temperature was 51°F during November and the lowest monthly average ambient temperature was 39°F during December. The number of heating degree-days for the period based on a 65°F reference was 3,960 as compared with the long-term average of 4,090. The range of heating degree-days was from a high of 65°F during November to a low of 19°F during March.

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

This parameter quantifies the effects of cloudiness and atmospheric transmission on the insolation received at the earth's surface. The clearness index ranged from a high of 46% during March to a low of 39% during December.

	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
Extra-terrestrial Insolation	1,439	1,205	1,332	1,796	2,397
TTL INS / EXT INS (%)	43	39	42	44	46

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

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

SECTION 5

REFERENCES

*1. National Solar Data Network, Department of Energy, prepared under Contract Number DE-AC01-79CS30027, Vitro Laboratories, Silver Spring, Maryland, January 1980.

2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.

3. E. Streed, et al, Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.

4. Mears, J. C., Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.

5. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.

*6. ASHRAE Standard 94-77, Methods of Testing Thermal Storage Devices Based on Thermal Performance, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.

*6A. User's Guide to Monthly Performance Reports, June 1980, SOLAR/0004-80/18, Vitro Laboratories, Silver Spring, Maryland.

*6B. Instrumentation Installation Guidelines July 1980, Parts 1, 2, and 3, SOLAR/0001-80/15, Vitro Laboratories, Silver Spring, Maryland.

*7. Monthly Performance Report, Bell Telephone of Pennsylvania, November 1979, SOLAR/2011-79/11, Vitro Laboratories, Silver Spring, Maryland.

*8. Monthly Performance Report, Bell Telephone of Pennsylvania, January 1980, SOLAR/2011-80/01, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Bell Telephone of Pennsylvania, February 1980, SOLAR/2011-80/02, Vitro Laboratories, Silver Spring, Maryland.

*10. Monthly Performance Report, Bell Telephone of Pennsylvania, March 1980, SOLAR/2011-80/03, 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

APPENDIX A

SYSTEM DESCRIPTION

The Bell Telephone of Pennsylvania site is a one-story office and warehouse building in West Chester, Pennsylvania. The solar energy system is designed to supply approximately 62% of the annual space heating requirements for the building. The site has an array of Heliotherm flat-plate collectors (DC-24SC) with a gross area of 2,112 square feet which faces south at an angle of 55 degrees from the horizontal. Solar-heated water is stored in a 6,000-gallon capacity tank, but is believed to contain only 4,600 gallons. The tank is located above ground in the mechanical room. Thermal energy is distributed to the loads by circulating water from the storage tank through forced-air heat exchangers and through 20 individual heat pump evaporators. When solar energy is insufficient to meet the requirements for space heating, auxiliary energy is supplied to the circulating water by electric resistance heating in the boiler. The system, shown schematically, has three instrumented modes of solar operation.

Mode 1 - Collector-to-Storage - This mode is entered when the sensed collector absorber plate temperature exceeds the temperature in the middle of storage by at least 18 degrees. Water from the tank is then circulated through the collectors until this temperature differential is less than three degrees. The collector subsystem has a drain-down feature to prevent freezing. Overheat protection is provided by automatic draining of the collector array whenever the collector output temperature exceeds 190°F.

Mode 2 - Storage-to-Space Heating - This mode is entered with a demand for heating from manually preset thermostats in either the office corridors or the warehouse area. Water is circulated by pumps P3 and P4 between the storage tank and the air-handling unit (AHU) heat exchangers and the forced flow heater (FFH) units. The AHU and the FFH units are activated to provide heat to the warehouse area and the corridors, respectively. Pumps P3 and P4 are deactivated whenever the space heating demands are satisfied at each respective area.

Mode 3 - Storage-to-Space Heating (Heat Pumps) - This mode is entered when there is a demand for space heating from individual offices and the sensed temperature of the water to the heat pumps is below a nominal 70°F. Valve V10 blends water from the storage tank with the heat pump return flow as required. Flow from the storage tank ceases when the heat pump fluid operating temperature again reaches the 70°F set point. When the sensed storage tank temperature is less than 70°F, the boiler becomes the thermal energy source for the heat pumps by the opening of valve V8 and the closing of valve valve V9.

SUBSYSTEMS

Collector

The gross collector array area is 2,112 ft^2. The collectors face in a southerly direction at an azimuth angle of zero degrees of South. The collectors are tilted to an altitude angle of 55 degrees from the horizontal. Orientation of the collectors is the optimum orientation for a system of this type, at a site latitude of 40 degrees North. Optimum collector orientation at this site is estimated to be zero degrees South at a tilt of 55 degrees. Optimum orientation was predicted based on an f-Chart simulation sensitivity analysis.

The collector panels have a single, 0.10 inch thick cover and a selective surface manufactured by Heliotherm. The absorber surface has a solar absorptivity of 0.95 and an infrared emissivity of 0.10. Total solar transmissivity of the glazing is 0.92. The absorber surface is composed of 0.04 inch roll-bond CDA 122 copper by Olin Brass Co. The fluid circulated through the collectors is water. The collector panels are 0.10 inches thick covered with plexiglass "G" by Rohm & Haas.

Storage

Solar energy storage is provided by a steel storage tank located in the building. The storage has three inches of polystyrene on the top, sides and bottom. Water is used as the medium to transfer solar energy to the space heating subsystem.

Space Heating

The space heating subsystem consists of forced fan units heaters, air handling equipment, and heat pumps designed to utilize solar energy through heat exchangers and blower coils. Documentation of the space heating load and design specifications were unobtainable.

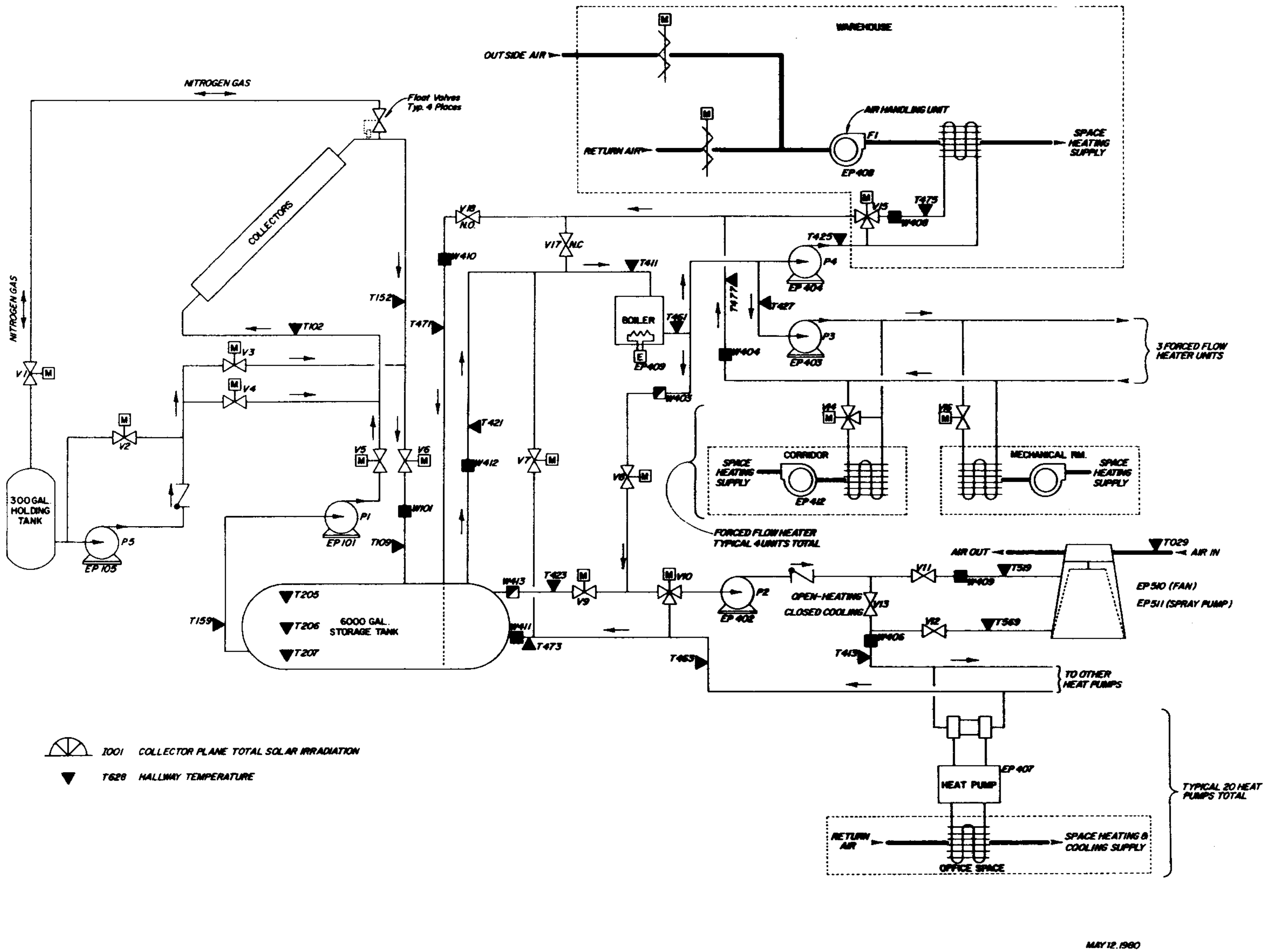


Figure A-1. Bell Telephone of Pennsylvania Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Bell Telephone of Pennsylvania 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.

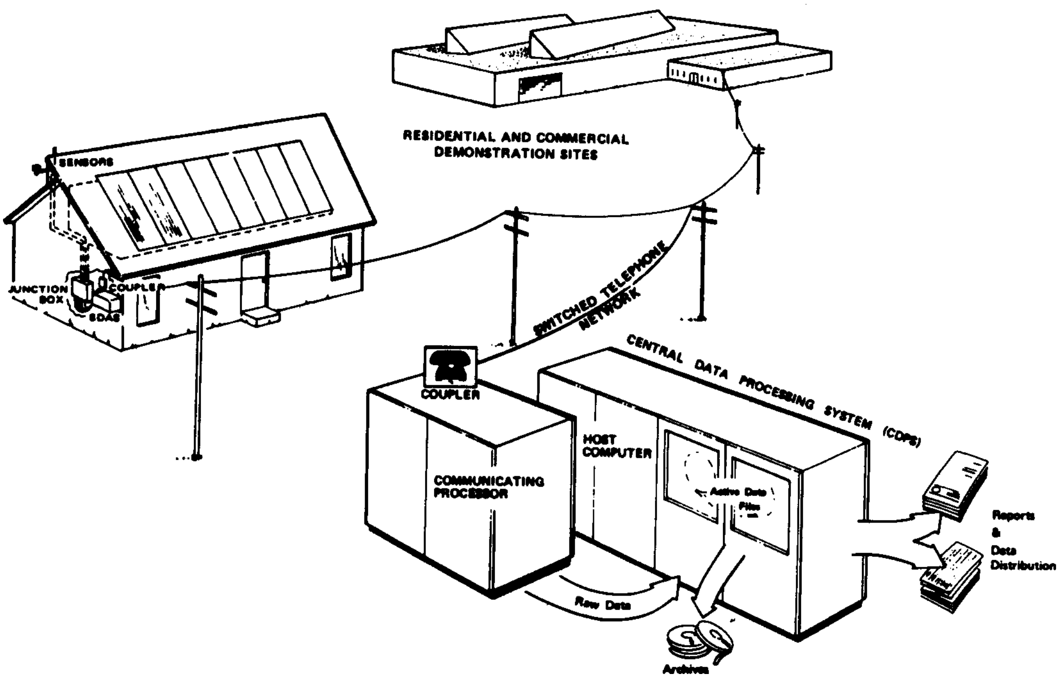


Figure B-1. The National Solar Data Network

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 micro-processor 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 five minutes (actually 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 five-minute period, and the average value is recorded in the tape.

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

The data received by the System 7 are in the form of digital counts in the range of 0-1023. 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, and these tabulations are also called "tab data." The CDPS is also capable of transforming this data into plots or graphs.

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 five-minute period. The site software produces as output a set of performance factors; on an hourly, daily, and monthly basis.

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 the Bell Telephone of Pennsylvania solar energy system from November 1979 through March 1980 was analyzed during the heating season, and Monthly Performance Reports were published for the months when sufficient valid data were available. 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. The month of December was a month where there was a lack of sufficient valid data and yielded a narrative report.

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

August 1978, SOLAR/2012-78/08
November 1978, SOLAR/2012-78/11
December 1978, SOLAR/2012-78/12
January 1979, SOLAR/2012-79/01
February 1979, SOLAR/2012-79/02
March 1979, SOLAR/2012-79/03
November 1979, SOLAR/1011-79/11
January 1980, SOLAR/2012-80/01
February 1980, SOLAR/2012-80/02
March 1980, SOLAR/2012-80/03

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

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

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. Appendix C includes the symbol, 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 abbreviations used in this report.

SECTION 1. PERFORMANCE FACTOR DEFINITIONS

SYMBOL	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.
CAREF	Collector Array Efficiency	Ratio of the collected solar energy to the incident solar energy.
CAT	SCS Auxiliary Thermal Energy	Amount of energy provided to the SCS by a BTU heat transfer fluid from an auxiliary source.
* CL	Space Cooling Subsystem Load	Energy required to satisfy the temperature control demands of the space cooling subsystem.
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.
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.

* Primary Performance Factors

SYMBOL	NAME	DEFINITION
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

SYMBOL	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	Energy required to satisfy the temperature control demands of the building service hot water system.

* Primary Performance Factors

SYMBOL	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

SYMBOL	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.
* 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

SYMBOL	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

SYMBOL	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.
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 to the system heat transfer fluid expands and contracts to prevent excessive pressure from developing and causing damage.

F-Curve — The collector instantaneous efficiency curve. Used in the "F-curve" procedure for collector analysis (see Instantaneous Efficiency).

Figure of Merit, FMS — A calculated number showing the relative net fraction of the system load supplied from solar energy.

$$FMS = \frac{\text{Solar Energy}}{\text{Supplied to Load}} - \frac{\text{Solar System}}{\text{Operating Energy}}$$

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	The solar energy received by a surface.
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.

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: $\frac{Ti-Ta}{I}$ $\frac{°F \times hr. \times sq.\ ft.}{BTU}$
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 that converts energy to useful thermal energy for heating without the use of collector circulating fluid.
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 param eter in a system, such as temperature or flow rate, for the purpose of measurement or control.
Solar Conditioned Space	The area in a building that depends on solar energy to provide a fraction of the heating and cooling needs.
Solar Fraction	The fraction of the total load supplied by solar energy. The ratio of solar energy supplied to loads divided by total load. Often expressed as a percentage.
Solar Savings Ratio	The ratio of the solar energy supplied to the load minus the solar system operating energy, divided by the system load.
Storage Efficiency, N_s	Measure of effectiveness of transfer of energy through the storage subsystem taking into account system losses.
Storage Subsystem	The assembly of components used to store solar-source energy for use during periods of low insolation.
Stratification	A phenomenon that causes a distinct thermal gradient in a heat transfer fluid, in contrast to a thermally homogeneous fluid. Results in the layering of the heat transfer fluid, with each layer at a different temperature. In solar energy systems, stratification can occur in liquid storage tanks or rock beds, and may even occur in pipes and ducts. The temperature gradient or layering may occur in a horizontal, vertical or radial direction.
System Performance Factor	Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
Ton of Refrigeration	The heat equivalent to the melting of one ton (2,000 pounds) of ice at 32°F in 24 hours. A ton of refrigeration will absorb 12,000 BTU/hr, or 288,000 BTU/day.
Tracking Collector	A solar collector that moves to point in the direction of the sun.
Zone	A portion of a conditioned space that is controlled to meet heating or cooling requirements separately from the other space or other zones.

SECTION 3. ABBREVIATIONS

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

APPENDIX D

PERFORMANCE EQUATIONS

BELL TELEPHONE OF PENNSYLVANIA

INTRODUCTION

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

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

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

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

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

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

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

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 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.

* 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	=	Specific Heat
D	=	Direction or Position
EE	=	Electric Energy
EP	=	Electric Power
F	=	Fuel Flow Rate
I	=	Incident Solar Flux (Insolation)
N	=	Performance Parameter
P	=	Pressure
PD	=	Differential Pressure
Q	=	Thermal Energy
T	=	Temperature
TD	=	Differential Temperature
V	=	Velocity
W	=	Heat Transport Medium Mass Flow Rate
TI	=	Time

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

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \Sigma(T029) \times \Delta\tau$$

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times I(T628) \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$TDA = (1/360) \times \Sigma(T029) \times \Delta\tau$$
for ± three hours from solar noon

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 collector loop is active

SOLAR ENERGY TO STORAGE (BTU)

$$STEIS = \Sigma[M101 \times HWD\ (T109-T159) \times \Delta\tau]$$

AUXILIARY ENERGY TO STORAGE

$$STEIFB = \Sigma[M410 \times HWD\ (T471-T421) \times \Delta\tau] \text{ where } T471 > T421$$

ENERGY TO HEAT PUMPS

$$HWTHP2 = \Sigma[(104 \times EP407) \times \Delta\tau]$$

ENERGY TO AIR HANDLER AND FORCED FAN UNITS

$$STEO1 = \Sigma[M410 \times HWD\ (T421-T471) \times \Delta\tau]$$

$$HL = \Sigma[M408 \times HWD\ (T475-T425) \times \Delta\tau]$$

$$HLFFH = \Sigma[M404 \times HWD\ (T477-T427) \times \Delta\tau]$$

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma[M101 \times HWD\ (T152-T102)\ \Delta\tau]$$

TOTAL SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma(STEIS + STEIFB)$$

SOLAR FRACTION AT STORAGE

$$SFSTOR = STEIS/(STEIFB + STEIS)$$

SOLAR USED AT HEAT PUMP

$$HPHSE = SFSTOR \times HWTHP2$$

SOLAR FRACTION FOR AIR HANDLER AND FORCED FAN

$$SFAF = SFSTOR \times STEO1/[STEO1 + (HAE2-STEIFB)]$$

SOLAR UNIQUE ENERGY TO WAREHOUSE

$$WHHSE = SFAF \times HL1$$

SOLAR UNIQUE ENERGY TO CORRIDORS AND MECHANICAL ROOM

$$MECHSE = SFAF \times HLFFH$$

SOLAR ENERGY USED FOR SPACE HEATING

$$HSE = HPHSE + WHHSE + MECHSE$$

SPACE HEATING SOLAR FRACTION

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

SPACE HEATING ENERGY SAVINGS

$$HSVE = HSE$$

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TST = \Sigma[(T205 + T206 + T207)/3 \times \Delta\tau \times 1/60]$$

ENERGY FROM STORAGE TO HEAT PUMP LOOP

$$STEOHP = (STEIS + STEIFB) - STEO1 + STECH + (TST-TB) \times 50.3$$

50.3 is overall heat loss coefficient for the storage tank

ENERGY DELIVERED FROM ECSS TO SPACE HEATING SUBSYSTEM (BTU)

$$CSEO = STEO1 + STEOHP$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = \Sigma[EPCONST \times (EP105 + EP101)]$$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = \Sigma[(EPCONST \times (EP403 + 404) \times (EP402 + EP408 + EP412 + EP107)]$$

when system is in the storage-to-space heating mode

SPACE HEATING SUBSYSTEM AUXILIARY ELECTRICAL FUEL ENERGY (BTU)

$$HAE = \Sigma(HAE1 + HAE2)$$

$$HAE1 = \Sigma[EPCONST \times EP407\ (1.0\text{-}FANPWRF)]$$

$$HAE2 = \Sigma[EPCONST \times EP409]$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = HAE2 + 0.7 \times HAE1$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = (HL1 + HLFFH + HWTHP2 + 0.7 \times HAE1)$$

$$HL1 = \Sigma[M408 \times HWD\ (T425\text{-}T475)]$$

$$HLFFH = \Sigma[M404 \times HWD\ (T427\text{-}T477)]$$

$$HWTHP2 = (104 \times EP407)$$

104 is the design heat absorption rate for the heat pumps BTU/kw-hr/min

BUILDING TEMPERATURE (°F)

$$TOFF = \Sigma[1/60 \times (\ T628) \times \Delta\tau]$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

$$CAREF = SECA/SEA$$

CHANGE IN STORED ENERGY (BTU)

$$STECH\ 1 = \Sigma[STOCAP \times CP(TSTI) \times RHO\ (TSTI) \times (TSTI)]$$

$$STECH = STECH1 - STECH1_p$$

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

STORAGE EFFICIENCY

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

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

$$SEL = HSE$$

ESCC SOLAR CONVERSION EFFICIENCY

$$CSCEF = HSE/SEA$$

SYSTEM LOAD (BTU)

$$SYSL = HL$$

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

$$SFR = HSFR$$

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

$$AXT = HAT$$

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

$$AXE = HAE$$

SYSTEM OPERATING ENERGY (BTU)

$$SYSOPE = HOPE + CSOPE$$

TOTAL ENERGY CONSUMED (BTU)

$$TECSM = SYSOPE + AXE + SECA$$

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

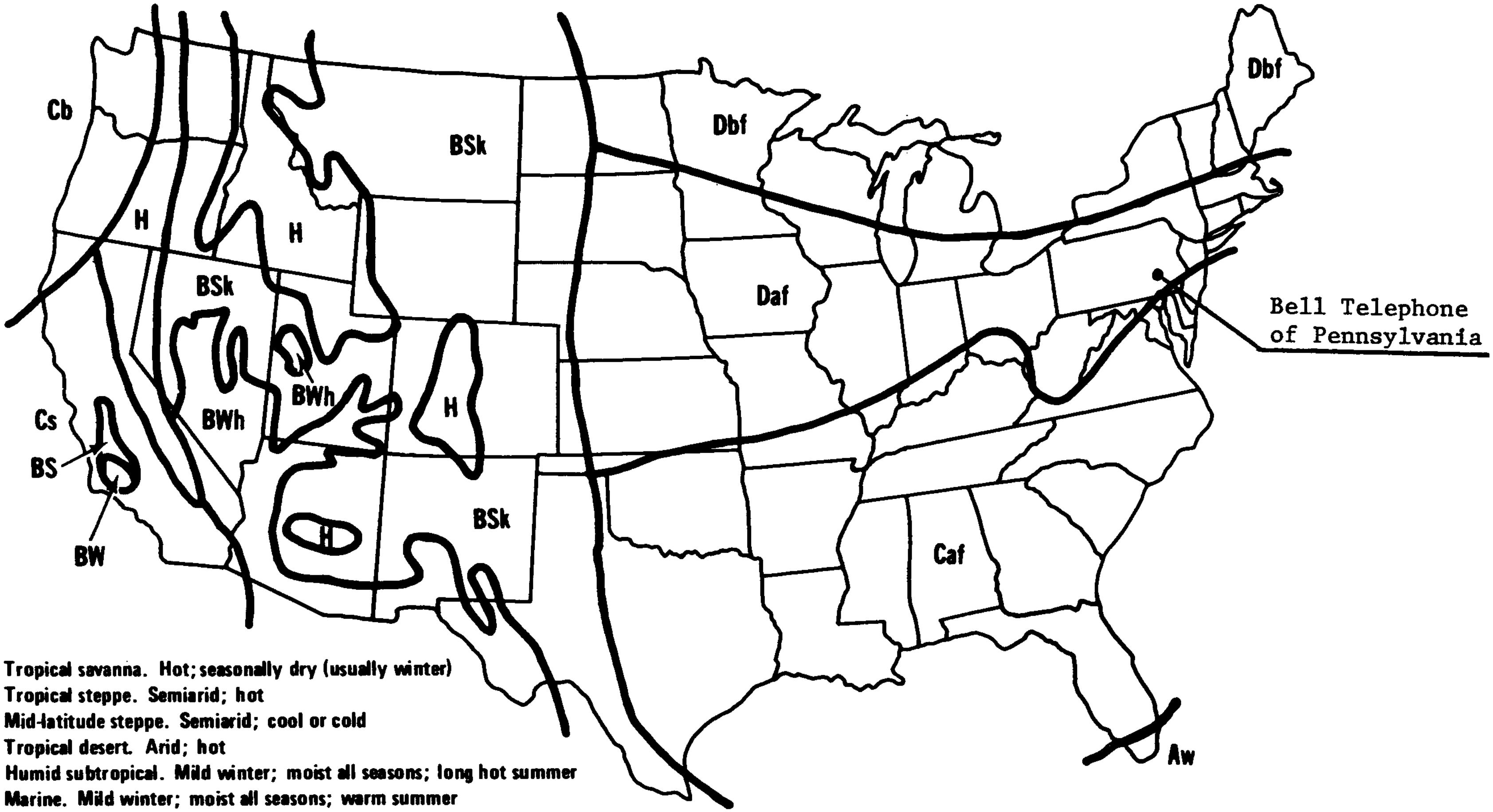
$$TSVE = HSVE - CSOPE$$

SYSTEM PERFORMANCE FACTOR

$$SYSPF = SYSL/[(AXE + SYSOPE) \times 3.33]$$

APPENDIX E

METEOROLOGICAL CONDITIONS



KEY

Aw	Tropical savanna. Hot; seasonally dry (usually winter)
BS	Tropical steppe. Semiarid; hot
BSk	Mid-latitude steppe. Semiarid; cool or cold
BWh	Tropical desert. Arid; hot
Caf	Humid subtropical. Mild winter; moist all seasons; long hot summer
Cb	Marine. Mild winter; moist all seasons; warm summer
Cs	Coastal Mediterranean. Mild winter; dry summer; short warm summer
Daf	Humid continental. Severe winter; moist all seasons; long, hot summer
Dbf	Humid continental. Severe winter; moist all seasons; short warm summer
H	Undifferentiated highland climates

Trewartha, G.T. The Earth's Problem Climates. University Wisconsin Press, Madison, WI, 1961.

Figure E-1. Meteorological Map of the United States Showing Bell Telephone of Pennsylvania Location

ENVIRONMENTAL DATA

Between November 1979 and March 1980, Bell Telephone of Pennsylvania was occupied. The average ambient temperature for the reporting season was 39°F. There were 772 heating degree-days which fell below the long-term average of 818 degree-days. The total daily average of incident solar energy per unit area was 1,080 BTU per foot squared a day. The long-term average was 1,067 BTU per foot squared a day.

BELL TELEPHONE OF PENNSYLVANIA LONG-TERM WEATHER DATA

COLLECTOR TILT: 55 DEGREES
LATITUDE: 40 DEGREES

LOCATION: WEST CHESTER COUNTY, PENNSYLVANIA
COLLECTOR AZIMUTH: 0 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
NOV	1,439	619	0.43043	1.681	1,041	564	0	46
DEC	1,205	472	0.39160	1.820	859	924	0	35
JAN	1,332	557	0.41802	1.758	979	1,014	0	32
FEB	1,796	796	0.44342	1.459	1,162	871	0	34
MAR	2,397	1,110	0.46305	1.168	1,296	716	0	42

LEGEND:

HOBAR - Monthly average daily extraterrestrial radiation (ideal) in BTU/day-Ft^2.

HBAR - Monthly average daily radiation (actual) in BTU/day-Ft^2.

KBAR - Ratio of HBAR to HOBAR.

RBAR - Ratio of monthly average daily radiation on tilted surface to that on a horizontal surface for each month (i.e., multiplier obtained by tilting).

SBAR - Monthly average daily radiation on a tilted surface (i.e., RBAR x HBAR) in BTU/day-Ft^2.

HDD - Number of heating degrees days per month.

CDD - Number of cooling degrees days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

MONTHLY REPORT: BELL TELEPHONE OF PENNSYLVANIA
NOVEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1638	55	60
2	661	64	68
3	240	49	48
4	1852	46	50
5	1853	46	50
6	1212	48	52
7	281	50	52
8	689	46	49
9	560	55	57
10	38	60	61
11	34	50	51
12	560	48	50
13	36	48	49
14	584	44	44
15	1040	42	43
16	1500	43	44
17	1843	47	53
18	1737	52	57
19	1553	53	57
20	952	54	55
21	1689	55	56
22	1043	55	57
23	836	58	62
24	345	63	*
25	975	65	67
26	10	62	66
27	1608	52	55
28	1057	51	59
29	1051	34	36
30	1500	31	34
SUM	28977	-	-
AVG	966	51	53

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: BELL TELEPHONE OF PENNSYLVANIA
DECEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1516	34	36
2	931	32	35
3	1900	31	33
4	1322	38	42
5	1469	43	46
6	184	48	50
7	1605	45	45
8	1408	41	44
9	1219	34	36
10	1335	41	43
11	1626	48	52
12	994	54	57
13	4	44	44
14	948	36	38
15	1694	34	35
16	86	42	44
17	1896	26	22
18	1328	25	25
19	77	28	30
20	333	27	28
21	214	31	33
22	163	40	42
23	123	44	45
24	60	51	51
25	910	54	53
26	1180	41	43
27	1137	36	39
28	1801	40	43
29	1697	42	43
30	1781	43	46
31	1843	38	40
SUM	32783	-	-
AVG	1058	39	41

MONTHLY REPORT: BELL TELEPHONE OF PENNSYLVANIA
JANUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1108	37	38
2	402	35	35
3	231	35	37
4	395	28	29
5	151	28	28
6	1913	26	27
7	78	34	36
8	1213	33	33
9	185	31	32
10	1606	28	30
11	96	45	48
12	665	34	31
13	627	31	32
14	114	44	47
15	1663	46	48
16	1779	42	45
17	1003	40	41
18	61	42	43
19	477	40	41
20	1475	36	38
21	1721	32	34
22	*	*	*
23	510	35	38
24	1189	22	22
25	130	30	32
26	1843	30	32
27	1030	31	32
28	1711	33	34
29	971	28	31
30	1212	22	24
31	1233	21	23
SUM	27686	-	-
AVG	893	33	35

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: BELL TELEPHONE OF PENNSYLVANIA
FEBRUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1786	17	19
2	2129	19	21
3	2110	21	24
4	1956	26	28
5	2101	26	27
6	223	26	28
7	1157	30	33
8	2052	31	34
9	647	29	30
10	*	*	*
11	*	*	*
12	2055	29	29
13	1994	30	33
14	1254	36	41
15	973	36	37
16	140	34	37
17	1691	23	23
18	2024	26	30
19	1405	36	41
20	1553	41	48
21	1549	47	53
22	39	41	42
23	912	44	48
24	577	45	47
25	860	40	42
26	2187	28	27
27	740	30	33
28	363	25	27
29	2205	15	17
SUM	39397	-	-
AVG	1359	31	33

* DENOTES UNAVAILABLE DATA.

BELL TELEPHONE OF PENNSYLVANIA
MARCH 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1283	14	17
2	1595	17	19
3	2282	24	27
4	1488	37	42
5	177	44	45
6	2196	39	39
7	568	43	45
8	385	56	61
9	1996	44	45
10	1706	46	52
11	2144	35	33
12	2050	30	30
13	121	32	30
14	390	34	36
15	2319	37	38
16	2111	40	43
17	147	49	52
18	1780	46	44
19	1931	44	48
20	865	52	57
21	55	52	59
22	263	36	36
23	2236	43	46
24	290	46	51
25	105	43	42
26	756	41	43
27	2077	47	51
28	809	47	53
29	216	49	51
30	452	52	*
31	65	41	41
SUM	34859	-	-
AVG	1124	41	43

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

The Bell Telephone of Pennsylvania site was occupied for all of the reporting period. The system operated between September 1979 through April 1980. This system has been in operation since September 1977. Since being put into operation in September, there has been one major operational problem with the automatic collection controls.

Date	Event
9/79	Automatic Collection Control not functional

A new differential controller for the collector subsystem and a freeze protection alarm system was installed for the 1979-1980 heating season. Also, the collector refill system's automatic vents were replaced with solonoid valves. The automatic control system was turned on on January 21, 1980 when all of the above system changes were completed and tested.

APPENDIX G

CONVERSION FACTORS

APPENDIX G

CONVERSION FACTORS

Energy Conversion Factors[1]

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[2]	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil[3]	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	979.43×10^{-6} cubic feet/BTU
Electricity	3,413 BTU/kilowatt-hour	293.08×10^{-6} kwh/BTU

[1]Source information is from the Dept. of Energy "Monthly Energy Review" FEB 1980

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

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

APPENDIX H

SENSOR TECHNOLOGY

APPENDIX H

SENSOR TECHNOLOGY

Temperature Sensors

Temperatures are measured by a Minco Products S53P platinum Resistance Temperature Detector (RTD). Because the resistance of platinum wire varies as a function of temperature, measurement of the resistance of a calibrated length of platinum wire can be used to accurately determine the temperature of the wire. This is the principle of the platinum RTD which utilizes a tiny coil of platinum wire encased in a copper-tipped probe to measure temperature. The probes are designed to have a normal resistance of 100 Ohms at 32°F.

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 ducts or 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.

The RTDs are connected in a Wheatstone bridge arrangement to yield an output signal of 0-100 millivolts, which is measured by the SDAS. Different resistance values are used in the bridge, depending on the temperature range the sensor must measure. A third wire is brought out from the sensor and connected into the bridge to compensate for the resistance of the lead wires between the sensor and the SDAS.

The RTDs are individually calibrated by the manufacturer to National Bureau of Standards traceable standards. In addition, a five-point transmission system calibration check is done at the site to compensate for any deviation of the measurement system from nominal values.

The data-processing software takes these checks and calibrations into account, using a third-order polynomial curve fit to relate SDAS output to temperature.

Wind Sensor

Wind speed and direction are measured by a Model W101-P-DC/540 (or W102-P-DC/540) sensor made by the WeatherMeasure Corporation. This sensor is rugged, reliable and accurate and will withstand severe environments such as icing and hurricane winds.

Wind speed is measured by a four-bladed propeller vehicle coupled to a DC generator. The balanced propeller is fabricated from a special low-density, fiberglass-reinforced plastic to yield maximum sensitivity and strength. The DC generator has excellent linearity but somewhat higher threshold due to brush friction.

Dual-wiper, precious-metal slip rings are used to connect the wind speed generator signal (15 Volts DC at 100 miles per hour) to the data transmission lines. These generally provide trouble-free use for several years.

Wind direction is measured by means of a dual-wiper 1000-Ohm long-life conductive plastic potentiometer housed in the base of the sensor (0-540°). It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

The potentiometer is of high commercial grade and has sealed bearings. The conductive plastic resistance element has infinite resolution and a lifetime about 10 times that of wire-wound potentiometers. The base is of aluminum, and corrosion-resistant materials are used in the construction.

Humidity Sensors

Relative humidity is measured by a WeatherMeasure Corporation Model HM111-P/HM14-P sensor. This measurement is of particular importance in solar cooling systems.

This solid-state sensor measures relative humidity over the full range of 0-100%. Response of the sensing element is linear within approximately 1%, from 0-80% relative humidity, with small hysteresis and negligible temperature dependence.

The sensor is based upon the capacitance change of a 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. The thin polymer layer reacts very quickly and, therefore, the response time is very short (one second to 90% humidity change at 68°F).

The polymer material is resistant to most chemicals. Because the sensor response is based on "bulk" effect, under normal conditions dust and dirt do not easily influence its operation. For use outdoors, a sintered filter is used because sulphur dioxide absorbed on small particles can corrode the thin film electrodes of the sensor. The smaller the pore size of the filter, the greater the protection. The response time, however, is increased.

The sensor is mounted in a small probe which contains all the electronics necessary to provide a millivolt output. The output of the probe electronics is linear from 0-100% relative humidity. Because the capacitance change of the sensor is sensitive only to ambient water vapor, temperature compensation is not required in most situations.

Insolation Sensors

Eppley pyranometers and shadowband pyranometers are used to measure the amount of radiant energy incident on a surface. A standard pyranometer measures the total amount of solar energy available, including both the direct beam component and the diffuse component, while the shadow-band instrument is designed to measure the diffuse component only. The instruments are calibrated in the horizontal position, with an Eppley thermopile used as the signal generator of the sensor. The heating of the thermopile by the radiation of the sun generates the signal, with the response being linear over the operating range. Measurements are in BTU/ft^2-hr.

The addition of a shadow band to a pyranometer enables the instrument to record only the diffuse portion of the sunlight by shielding the sensor from the direct rays of the sun (the beam component). The amount of beam radiation available is readily calculated by subtracting the diffuse radiation measurement from the total radiation measured by the unshaded standard pyranometer. This beam radiation measurement is useful when working with focusing solar collectors. When using the shadowband pyranometer, the accuracy of its measurement depends on the correct adjustment of the shadow band to be certain that the sensor is shielded from the direct rays of the sun.

The pyranometer includes a circular multi-junction thermopile of the wire-wound type. The thermopile has the advantage of withstanding some mechanical vibration and shock. The receiver is circular, and coated with Parsons black lacquer. The instrument has a pair of removable precision ground and polished hemispheres of Schott optical glass. It also has a spirit level and a desiccator that can be readily inspected. The clear glass is transparent from a wave/length of about 285 to 2,800 nanometers. The temperature dependence is ±1% over the range of -4°F to 104°F. It has a response time of one second and a linearity of ±5% over the range of the instrument.

Flow Sensors

The Ramapo flowmeter is an accurate and sensitive liquid flow rate measuring device. The dynamic force of fluid flow, or velocity head of the approaching stream, is sensed as a drag force on a target (disc) suspended in the flow stream. This force is transmitted via a lever rod and flexure tube to an externally bonded, four active arm strain gauge bridge. This strain gauge bridge circuit translates the mechanical stress due to the sensor (target) drag into a directly proportional electrical output. Translation is linear, with infinite resolution, and is hysteresis free. The drag force itself is usually proportional to the flow rate squared. The electrical output is unaffected by variations in fluid temperature or static pressure head, within the stated limitations of the unit.

Power Sensors

A major component of the watt meter is a concentrating magnetic core (usually a toroid). The conductor carrying current to the load is passed through the window (eye) of the magnetic core one or more times. The magnetic field surrounding the conductor (load-carrying wire) is instantaneously proportional to the current flowing in the conductor. This field is intercepted by the magnetic core, producing a magnetic flux which is also instantaneously proportional to the current flowing in the conductor. A Hall effect transducer is cemented into a thin slot milled through the concentrating magnetic core.

In this position it intercepts nearly all of the magnetic flux present in the core. Two of the transducer's terminals provide a full scale output of 50MVDC. The remaining two terminals are referred to as a control input. The output of the Hall transducer is not only proportional to the magnetic flux passing through it but also to any EMF which appears across its control terminals. The load voltage is applied to the transducer's control terminals.

The resultant measurements of the watt meter are summarized below:

1. Output is directly proportional to the flux in the magnetic core which in turn is directly proportional to the load current (I).

2. Output is directly proportional to the load voltage (E).

3. Final output is directly proportional to the vector product of E, I, and cos ϕ (power factor angle). This output is read into the SDAS as an electrical power in watts.

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