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INFORMATION GATHERING, DATA REDUCTION, AND INFORMATION DISSEMINATION FOR RESIDENTIAL EXPERIMENT STATION OPERATIONS

September 1981

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Lincoln Laboratory
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Prepared for
THE U.S. DEPARTMENT OF ENERGY
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ABSTRACT

The Residential Experiment Stations (RESs) of the Solar Photovoltaic Residential Project have been designed by MIT Lincoln Laboratory under Department of Energy sponsorship to develop residential photovoltaic systems and to disseminate information to the photovoltaic community, cognizant institutions and, ultimately, the public. This report pertains to the residential data systems that have been designed specifically for the RESs to gather and process the physical data required. It covers the specific reports which will be issued by the project and lists the contents of each report. A sample format for each report is also presented. The appendices describe the quantities that will be measured at the Monitored Houses, Prototype Systems and Initial System Evaluation Experiments. They also include a description of the data processing.

PREFACE

The U.S. Department of Energy's Solar Photovoltaic Residential Project, as outlined in the September 1979 draft Residential Application Implementation Plan, began with the development and evaluation of Prototype Systems at Residential Experiment Stations. These stations provide regional focuses for the project and include the following features deemed critical to the system development process:

- Systems designed and supplied by the private sector;
- Systems compared under identical meteorological, load and utility conditions; and
- Systems evaluated while exposed to near-extreme U.S. climates.

These features ensure public access to system designers and suppliers, unambiguous comparisons of system energy production and reliability, and provide assurances of system durability in most continental U.S. locations.

The Prototype Systems are complete photovoltaic energy systems integrated into unoccupied, residential "shells." The physical environment of a real residence is replicated for operating and evaluating the system. Based on studies of current and projected housing types, energy usage, utility rates and photovoltaic system performance and prices, the following criteria have emerged for residential photovoltaic systems:

- Roof-mounted flat-plate arrays of 40 m^2 to 80 m^2 area;
- Utility-interactive operation involving two-way power flows with an electric utility;
- No on-site electric energy storage;
- Overall conversion efficiency of at least 10 percent;
- Peak electric power rating (i.e., in full sunlight) in the range 4 to 8 kilowatts ;
- Site insolation greater than approximately 1200 $kWhm^{-2}$ per year;
- Total installed PV system cost in the range $1.60 to $2.20 per peak watt; and
- Useful life of the PV system of at least 30 years.

Candidate systems which offer promise of meeting (initially) most and (eventually) all of the above criteria are being evaluated at the Residential Experiment Stations for test periods of approximately one year duration. This test period was selected in order to provide an adequate time for verifying technical performance (power and energy production, efficiencies, ac power quality, noise generation, etc.) over the full range of a year's weather. It also is sufficiently long to determine whether the system design and manufacturing quality are consistent with good safety practices.

These evaluations will provide only limited information on long-term reliability (i.e., frequency of unscheduled outages and/or periods of reduced output) and durability (i.e., the accrual of gradual degradation in system performance as a function of operating time). Such information can come only from accelerated testing methods, which at present are not available, or by the sheer passage of time. Finally, the evaluations will provide limited information on the amount of maintenance and repair effort which must be expended on a system. Further information can be obtained only by extended, real-time operation, preferably in an actual user's environment.

The evaluation procedures used at Residential Experiment Stations are presented in two documents: Prototype Residential Photovoltaic Systems Evaluation Plan and Information Gathering, Data Reduction and Information Dissemination for Residential Experiment Station Operations. The first document describes special, short-duration test procedures which will be carried out on the Prototype Systems and their components. These tests will provide characterizations of the system and its components, and will verify proper operation of the systems when they are exposed to both normal and abnormal operating conditions.

The second document describes the routine operation of the Prototype Systems, the physical quantities measured, the date processing procedures, the validation of analytic methods for performance prediction, and the calculation of Prototype System energy production estimates for typical meteorological years at various U.S. cities. These performance estimates, in conjunction with city-specific utility rates, will be used to assess the worth of the PV systems to homeowners.

Collectively, these documents explain the "experiment" at each Residential Experiment Station and provide a means for gauging the significance of the results. The second document also describes a series of reports which are designed to address the informational needs of those individuals and institutions with specific interests in the performance of the Prototype Systems. Consistent with the role of the experiment stations in implementing the National Photovoltaic Program objective of resolving "...technical, institutional, legal, environmental and social issues involved in fostering widespread adoption of photovoltaic energy systems," * the audience for these reports extends beyond project management.

*National Photovoltaic Program, Multi-Year Program Plan, U.S. Department of Energy, Division of Solar Technology, Washington, DC 20585, 6 June 1979.

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1.0 OBJECTIVES

The Residential Experiment Stations (RESs) of the Solar Photovoltaic Residential Project have been designed to meet two basic objectives: (1) residential photovoltaic system development and (2) information dissemination to the photovoltaic community, cognizant institutions, and, ultimately, the public. Residential Data Systems (RDSs) have been designed to collect and process the physical data required in meeting these objectives.

This document pertains only to the RDS developed to gather physical data at the RESs. It first covers the specific reports which will be issued by the project and, in the appendices, outlines the use of the RDS for collecting and processing the information to be reported. Appendices A1, A2 and A3 describe the quantities that will be measured at the Monitored Houses, Prototype Systems and Initial System Evaluation Experiments. They also include a description of the data processing. A complementary document titled "Prototype Residential Photovoltaic System Evaluation Plan," is in preparation which will catalogue durability and reliability studies that will be performed on the prototype photovoltaic power systems. It, together with this document on the RDS, will form the bulwark by which prototype photovoltaic power systems will be evaluated.

2.0 DAILY REPORT ON RES OPERATIONS

A daily report summarizing the past day's performance (midnight to midnight) of each Monitored House (MH), Prototype System (PS) and Initial System Evaluation Experiment (ISEE) will be prepared and distributed to the management and selected staff of the Project. The objective of this brief (two-page) report is to provide up-to-date feedback on MH, PS and ISEE performance, together with meteorological information, so that any problems can be recognized quickly and corrected. It is also expected that such information will prompt the recognition of opportunities for performance enhancement even when no problem is perceived to exist.

The MH information will comprise the total electric energy usage, the usage between sunrise and sunset hours (henceforth this time between sunrise and sunset will be referred to as sun-hours), the average voltage, the peak

current and voltage, the peak load power and the time it occurred, and the number of valid data hours. (The last datum will identify incomplete records for the day.) Appendix A4 describes how some of the quantities furnished in the daily report are defined.

The PS information will comprise the photovoltaic (PV) array dc energy produced (both absolute kilowatt-hours and kilowatt-hours per array kilowatt peak rating), the array peak power, the insolation at the array tilt angle during sun-hours and during power-conditioning unit operation, the peak tilted insolation, the PV array energy conversion efficiency, the maximum and minimum panel temperature, a figure of merit for PV array operation (see Appendix A4 for definition), the power conditioner ac energy production and operation efficiency, the peak power from power conditioner, the number of operating hours of the power-conditioning unit, a figure of merit for power conditioner operation (see Appendix A4 for definition), the imposed total load and identity of the MH supplying the load, the energy supplied by the utility feed, the energy accepted by the utility feed, the number of hours monitored, and the system status (the last datum will identify inverter breakdowns, array washings, etc.).

The ISEEs information will comprise the same measures as the PSs and will also include the estimated passive solar heating gain, estimated energy gain from fireplace and wood stove heating, the estimated heat pump system heating or cooling, the ac energy input to heat pump, the ac energy to air blower, the solar and heat pump contribution to hot water production, the supplemental electric energy contribution to hot water production, the supplemental electric energy contribution to space heating and the number of degree days.

Meteorological information will comprise the tilted array insolation reported with each PS and ISEE, the total horizontal insolation at the RES, the peak and lowest outdoor temperature given with each ISEE and at the RES, and the average sunhour wind speed and precipitation at the RES. In addition, a "clearness index" (see Appendix A4), defined as the percent of maximum possible terrestrial horizontal insolation available for the day, will be calculated and presented for the RES together with the status of monitoring at both RES and ISEE.

A sample format for the daily operations report is given in Table I.

TABLE I

RESIDENTIAL EXPERIMENT STATION, SAMPLE DAILY REPORT

HERES DAILY REPORT: TUESDAY 6/30/81

PROTOTYPE AND ISEE PV ARRAY INFORMATION RATED POWER(KW)/TILT ANGLE(DEG.)	MITLL 6.8/45.	WEST 5.2/45.	GE 6.8/33.7	TRISC 4.8/45.	SOLRX 5.2/40.	CARLE 7.3/45.
PV DC ENERGY (KWH)	32.63	21.00	30.93	21.59	0.0	36.10
PV DC ENERGY / RATED POWER	4.80	4.04	4.55	4.51	0.0	4.95
ARRAY PEAK POWER (KW)	5.29	4.12	5.26	3.78	0.0	6.76
TOTAL TILT INSOLATION:SUNHOURS(KWH/M**2)	5.53	5.34	6.54	4.84	0.0	5.63
TOT TILT INSOL:PV SYSTEM ON(KWH/M**2)	5.53	4.25	0.0	4.84	0.0	5.62
PEAK INSOLATION LEVEL (KW/M**2)	0.89	0.87	0.98	0.90	0.0	0.96
PV ARRAY EFFICIENCY (%)	6.75	5.40	0.0	9.34	0.0	6.49
MAXIMUM PANEL TEMPERATURE (DEG.C)	51.23	47.58	59.21	44.87	0.0	63.93
MINIMUM PANEL TEMPERATURE (DEG.C)	7.73	5.08	6.75	18.34	0.0	10.12
FIGURE OF MERIT: PV ARRAY	91.12	99.91	0.0	100.61	0.0	87.93

PROTOTYPE AND ISEE PCU INFORMATION	MITLL	WEST	GE	TRISC	SOLRX	CARLE
POWER CONDITIONER AC OUTPUT (KWH)	29.09	17.02	0.0	19.70	0.0	32.93
PEAK POWER FROM POWER CONDITIONER (KW)	4.79	3.53	0.0	3.47	0.0	6.33
POWER CONDITIONER EFFICIENCY (%)	89.17	81.07	0.0	91.23	0.0	91.23
FIGURE OF MERIT: POWER CONDITIONER	100.00	100.00	0.0	100.00	0.0	0.0

PROTOTYPE AND ISEE AC ENERGY FLOW	MITLL	WEST	GE	TRISC	SOLRX	CARLE
NUMBER OF HOURS OF PV SYSTEM OPERATION	14:18	8:48	0: 0	10:54	0: 0	13:42
IMPOSED TOTAL LOAD (KWH)	14.97	1.56	16.69	9.97	0.0	40.19
WHICH MONITORED HOUSE SUPPLYING LOAD	0.0	0.0	0.0	0.0	0.0	0.0
ENERGY SUPPLIED TO UTILITY FEED (KWH)	22.07	17.26	0.0	15.29	0.0	13.04
ENERGY SUPPLIED BY UTILITY FEED (KWH)	8.12	1.24	0.0	5.74	0.0	20.58
HOURS OF DATA RECORDED	23:59	23:59	23:59	15:54	0: 0	23:59

STATUS
- -Prototype 1 is online. One of eight strings is shut off due to current leakage problems.
- -Prototype 2 is online. Imposed load does not match load data source.
- -Prototype 3 is online.
- -Prototype 4 is online.
- -Prototype 5 is offline.
- -ISEE is online.

TABLE I (Continued)

RESIDENTIAL EXPERIMENT STATION, SAMPLE DAILY REPORT

NERES DAILY REPORT: TUESDAY 6/30/81

SUNRISE- 4:16 SUNSET- 19:21 SOLAR NOON- 11:48 DAY LENGTH- 15:04 ZENITH ANGLE OF SUN AT SOLAR NOON- 19.3 DEG.

METEOROLOGICAL INFORMATION	RES	CABLE
MAXIMUM AMBIENT TEMPERATURE (DEG. C)	24.87	32.27
MINIMUM AMBIENT TEMPERATURE (DEG. C)	10.28	14.10
DEGREE DAYS (DEG. C DAY)	0.0	0.0
AVERAGE WIND VELOCITY (MPH)	5.28	*********
PRECIPITATION (IN)	*********	*********
TOTAL HORIZONTAL INSOLATION (KWH/M**2)	6.75	*********
PERCENT OF POSSIBLE HORIZ. INSOLATION	79.75	*********
HOURS OF DATA RECORDED DURING SUNHOURS	15: 0	15: 0

MONITORED HOUSE INFORMATION	MH1	MH2	MH3	MH4	MH5	MH6
TOTAL ELECTRICAL ENERGY USED (KWH)	0.0	22.76	21.78	6.36	25.97	20.97
ELECT. ENERGY USE DURING SUNHOURS (KWH)	0.0	11.00	12.87	5.11	18.56	13.77
INSTANT. PEAK CURRENT DRAWN BY HOUSE (A)	0.0	44.04	53.13	36.04	48.66	40.67
AVERAGE VOLTAGE (V)	0.0	232.14	247.79	244.17	244.73	240.96
INSTANT. PEAK VOLTAGE (V)	0.0	237.74	251.73	247.41	248.36	245.50
PEAK POWER DRAWN BY HOUSE (KW)	0.0	6.36	7.53	1.52	6.21	5.81
TIME PEAK POWER DRAWN (HR,MIN)	0: 0	21:41	19:47	8: 5	8:41	13:35
HOURS OF DATA RECORDED	0: 0	23:59	23:59	13:29	23:59	23:59

JSEE ENERGY FLOW	CABLE
EST. FIREPLACE + WOODSTOVE HEATING (KWH)	*********
EST. PASSIVE SOLAR HEATING GAIN (KWH)	*********
EST. HEAT PUMP HEATING OR COOLING (KWH)	*********
AC ENERGY INPUT TO HEAT PUMP (KWH)	*********
AC ENERGY TO AIR BLOWER (KWH)	*********
SOLAR AND HEAT PUMP HOT WATER PROD. (KWH)	*********
ELECT RESISTANCE HEATING FOR WATER (KWH)	0.0
ELECT RESISTANCE SPACE HEATING (KWH)	*********

3.0 MONTHLY REPORTS ON RES OPERATIONS

Three separate monthly data packages summarizing the past month's performance will be prepared and made available by the tenth day of the following month. Each will cover the operation of MHs, PSs and ISEEs. The first package will be an hour by hour tabulation of the various quantities measured. This package will be available for inspection at the RES. The second package is a report which will be a synopsis of the first package presenting the same quantities as an hour by hour tabulation for an average day. It will be distributed to the RES Consulting Committee, the other field centers in the PV program, the Jet Propulsion Laboratory Lead Center and the Department of Energy. The third package is also a report which will be a one-page summary presenting some of the quantities as net values for an average day. It will be available for distribution to the general public. The objective of these reports is to disseminate authoritative and accurate information concerning the performance of PSs and ISEEs and the typical loads which they serve. Such timely information is needed by the overall DOE PV program to ensure a uniform and correct understanding of the performance of these developmental systems. It is expected that the general availability of this information will temper unfounded and exaggerated claims concerning system performance. The information presented should be widely accepted and provide for a rational dialogue concerning the merits of residential PV power systems.

Information from the MHs will be presented for use by electric utilities and PV system designers. This information will be particularly useful in the numerical simulation of PV system performance as there is currently little hourly information available on actual residential loads.

The detailed data will contain hourly tabulations of the total electric energy usage for each day of the month (i.e., 31 days by 24 hours, or 744 entries). Hourly averages for a standard weekday and standard weekend or holiday will be included. A sample format for the detailed data is given in Table II. Maximum power levels, voltage, and current will also be reported for each hour and averaged for representative weekday and weekend values. Finally, load duration curves will be determined for each MH individually and for all

TABLE II

RESIDENTIAL EXPERIMENT STATION, DETAILED MONTHLY DATA FORMAT

MONTHLY REPORT FOR MONITORED HOUSES
MARCH 1981

MONITORED HOUSE 3

TOTAL ELECTRIC ENERGY USED (KWH)
ENERGY FOR EACH HOUR ENDING AT LOCAL STANDARD TIME

DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
1S	0.28	0.62	0.94	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.44
2M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.52	1.32	2.48	1.98	2.14	0.24	0.0	0.78	1.88	0.99	12.20
3T	0.74	2.01	0.72	1.05	0.79	1.01	3.07	5.48	1.04	1.17	0.76	0.75	1.68	1.65	1.14	0.0	0.0	2.15	3.40	3.04	4.37	3.96	1.73	1.79	43.48
4W	1.06	0.90	0.86	0.88	1.77	0.88	2.81	3.50	3.14	0.70	0.81	1.66	0.70	0.78	1.62	1.04	1.47	2.61	2.30	3.12	3.37	2.10	1.07	5.19	44.37
5T	0.97	0.59	1.77	0.80	0.73	1.69	1.59	4.12	5.07	0.85	0.74	1.56	0.84	0.77	1.45	1.48	0.98	2.86	3.35	4.18	1.86	1.78	1.10	1.48	42.61
6F	0.68	0.75	1.58	0.78	0.63	0.79	3.75	3.38	1.34	0.71	0.25	0.0	0.60	0.57	1.15	0.99	1.02	0.91	1.68	1.01	1.12	0.90	1.78	0.62	27.00
7S	0.86	0.71	1.15	1.30	1.45	0.0	1.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.47	0.0	0.0	0.0	0.0	0.0	0.0	8.30
8S	0.27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.44	0.0	0.0	0.0	1.71
9M	0.27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.31	1.33	0.44	1.22	0.75	0.56	4.01	4.13	1.00	2.10	2.40	5.51	2.31	1.50	0.67	29.51
10T	0.48	0.62	0.62	0.59	1.32	0.75	1.59	2.11	0.74	1.46	0.57	0.57	0.57	0.62	0.68	0.75	2.01	3.63	1.34	3.24	2.40	1.53	1.38	0.67	30.24
11W	0.89	0.61	0.11	0.0	0.31	0.62	1.42	4.80	0.72	0.58	0.53	0.40	0.60	0.56	0.85	1.05	2.01	1.73	3.44	1.05	1.07	1.99	0.59	1.14	27.08
12T	0.78	0.61	0.71	0.62	0.58	0.63	4.05	2.71	5.57	0.50	0.61	0.64	0.56	0.82	0.10	0.75	3.40	2.91	2.23	6.86	2.27	2.07	1.25	0.59	41.99
13F	0.65	0.61	0.59	1.47	0.64	0.60	1.46	3.47	1.31	1.66	1.47	0.0	0.94	1.40	1.41	0.81	0.72	0.99	2.70	2.83	3.20	0.78	0.74	0.72	31.19
14S	1.99	0.57	0.60	0.53	0.52	0.57	1.55	0.62	0.81	2.03	1.86	2.46	2.33	4.15	1.85	3.30	6.07	3.73	2.02	1.71	2.29	1.31	1.55	1.73	46.15
15S	0.81	0.84	0.81	0.85	1.70	0.77	0.80	0.91	1.46	3.85	3.84	1.87	2.17	3.86	2.22	1.57	1.98	4.00	1.39	1.24	3.39	4.35	1.03	1.60	47.21
16M	0.94	0.76	0.63	0.59	0.61	1.56	1.48	3.47	0.79	1.33	0.59	0.27	0.39	0.57	1.71	0.86	1.67	2.94	1.72	4.04	1.47	1.23	0.0	0.0	29.63
17T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.15	2.48	1.32	3.19	4.82	1.33	2.10	1.09	19.48
18W	1.13	1.18	1.19	1.21	2.12	1.19	2.43	4.02	6.07	1.30	0.42	0.0	0.0	1.22	0.94	3.72	1.72	2.29	1.56	3.33	1.77	1.77	1.96	1.20	45.76
19T	0.82	1.23	1.19	1.21	2.13	1.28	2.89	3.68	3.02	1.21	1.09	1.08	1.06	1.96	3.77	2.57	1.35	2.49	1.69	5.68	5.63	3.23	0.94	1.71	54.92
20F	0.68	0.63	0.59	0.66	0.0	0.0	0.0	0.0	0.0	0.57	0.69	0.74	0.67	0.77	1.19	1.32	0.80	2.15	2.41	3.57	1.18	5.70	1.94	0.85	27.16
21S	2.09	0.72	0.68	0.67	0.68	0.61	1.51	0.59	1.23	2.45	4.39	1.13	2.65	1.26	0.86	2.24	4.46	1.85	4.37	1.39	2.33	3.81	2.35	0.84	45.15
22S	0.96	0.65	0.77	1.69	0.56	0.78	0.65	0.94	2.46	1.38	3.65	1.19	5.74	1.03	1.86	0.95	1.90	1.20	4.25	1.21	5.04	4.01	0.91	1.76	45.54
23M	0.85	0.79	0.86	1.76	0.86	0.89	2.19	3.45	5.45	0.85	0.61	0.60	1.46	0.57	0.65	0.80	0.72	1.18	2.69	4.06	5.34	1.85	1.34	0.76	40.60
24T	0.82	0.90	0.96	1.90	0.93	0.94	2.34	2.37	5.30	2.48	0.84	0.58	0.59	0.59	1.39	1.19	1.49	2.58	1.47	2.28	3.37	1.82	1.00	1.90	42.02
25W	0.98	0.64	0.93	0.93	0.93	1.32	1.61	5.48	1.00	0.0	0.0	0.68	1.61	0.78	0.79	0.72	1.00	2.04	2.24	3.70	1.62	4.84	4.67	0.53	39.55
26T	1.06	1.81	0.86	0.65	0.86	0.84	2.56	2.70	2.87	0.39	0.57	0.40	0.56	1.42	2.40	3.11	0.58	4.46	2.70	4.33	4.44	2.47	2.66	0.48	45.21
27F	0.55	0.70	0.87	1.54	0.68	0.60	3.31	3.21	1.61	0.71	0.60	0.44	0.68	1.22	0.58	0.55	0.67	2.46	3.44	2.47	2.62	2.71	3.04	2.26	37.52
28S	2.30	2.21	2.27	3.18	2.28	2.31	2.32	2.30	4.07	4.90	2.19	3.54	0.88	0.73	1.50	0.93	0.82	1.90	2.38	1.92	1.32	1.86	0.78	0.82	50.20
29S	0.70	0.44	0.55	0.42	1.33	0.40	0.61	0.47	1.20	3.67	0.87	4.90	1.43	3.99	7.17	2.13	1.05	0.67	2.32	1.01	0.95	0.74	1.31	0.30	38.62
30M	0.31	0.25	0.27	0.40	0.26	0.40	2.14	3.32	1.48	1.55	0.35	1.26	0.59	0.53	1.34	0.80	0.62	2.04	1.35	1.06	2.49	0.72	0.49	0.29	24.84
31T	1.18	0.24	0.39	0.23	0.38	0.14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.46	0.56	0.71	0.78	1.33	3.49	1.79	1.08	0.62	0.39	0.61	14.39
WEEKDAY HOURLY AVERAGE	0.79	0.84	0.83	0.96	0.92	0.92	2.39	3.61	2.74	1.08	0.71	0.76	0.85	0.90	1.18	1.43	1.46	2.24	2.69	3.07	2.90	2.11	1.60	1.22	38.20
WEEKEND HOURLY AVERAGE	1.14	0.85	0.97	1.15	1.22	0.91	1.26	0.96	1.87	3.05	2.80	2.52	2.53	2.50	2.58	1.85	2.71	2.12	2.87	1.41	2.39	2.68	1.32	1.18	44.83
MONTHLY HOURLY AVERAGE	0.90	0.84	0.87	1.02	1.00	0.92	2.06	2.91	2.51	1.57	1.24	1.24	1.27	1.27	1.49	1.53	1.74	2.21	2.73	2.71	2.78	2.24	1.54	1.21	39.79

the MHs collectively. These load duration curves for the entire month will be calculated using the 5-second data base to provide new insights into residential peak loads. The synopsis report will present these data in tabular form for an average day. A sample format for the synopsis report is given in Table III. The summary report will, however, present total electrical usage only. Table IV shows a sample format for the summary report.

Information concerning the PSs will be addressed to PV system designers, electric utilities and the institutions represented on the RES Consulting Committees. It is expected that this information will provide a basis for understanding the performance implications for the various design differences among the PSs. In this section any problems encountered with the systems will also be described and corrective actions discussed.

The detailed data will have hourly tabulations in the standard format (see Table II). The data presented will be the dc array output, average array cell temperature, array tilt insolation, the ac inverter output (real energy), total harmonic distortion of inverter current, the load imposed on the system, and the exchange of energy with the utility. For each MH load, the typical weekday and weekend exchange of energy with the utility of each PS will be calculated and presented. In addition to these averaged energy exchanges, the maximum inverter ac power output which occurs during each hour of each day will be reported together with the tilted array insolation. The daily status for each PS for the entire month will also be reported. The synopsis report will present the same data in tabular form for an average day. The summary report will present the following values for an average day: array dc output, array peak power, total and peak tilt insolation, maximum and minimum panel temperatures, inverter ac output and peak power, imposed total load, and energy supplied to and by the utility feed.

Initial System Evaluation Experiment reporting will closely match the load reporting from MHs and system performance reporting from PSs. This reporting will be aimed primarily at electric utility and institutional observers.

TABLE III

RESIDENTIAL EXPERIMENT STATION, BRIEF MONTHLY REPORT FORMAT

MONTHLY REPORT FOR PROTOTYPES

MONTHLY HOURLY AVERAGE
APRIL 1981

DC ARRAY OUTPUT (KWH)
ENERGY FOR EACH HOUR ENDING AT LOCAL STANDARD TIME

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
PT1	0.00	0.00	0.00	0.00	0.00	0.04	0.36	1.00	2.03	2.78	3.17	3.36	3.42	2.88	2.34	1.72	0.92	0.23	0.01	0.00	0.00	0.00	0.00	0.00	24.57
PT2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	0.15	0.04	0.04	0.04	0.07	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56
PT3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT4	0.0	0.0	0.0	0.0	0.00	0.06	0.37	1.03	1.80	2.37	2.61	2.87	2.79	2.43	2.00	1.51	0.74	0.22	0.01	0.00	0.0	0.0	0.0	0.0	20.80
PT5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

MONTHLY HOURLY AVERAGE
APRIL 1981

AC INVERTER - REAL ENERGY OUTPUT (KWH)
ENERGY FOR EACH HOUR ENDING AT LOCAL STANDARD TIME

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
PT1	0.0	0.0	0.0	0.0	0.0	0.03	0.31	1.01	1.88	2.59	2.97	3.34	3.20	2.70	2.18	1.58	0.83	0.19	0.00	0.0	0.0	0.0	0.0	0.0	22.80
PT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.08	0.12	0.01	0.00	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.28
PT3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT4	0.0	0.0	0.0	0.0	0.0	0.03	0.30	0.92	1.64	2.17	2.39	2.63	2.55	2.23	1.82	1.37	0.65	0.17	0.00	0.0	0.0	0.0	0.0	0.0	18.89
PT5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE IV

RESIDENTIAL EXPERIMENT STATION, BRIEF MONTHLY REPORT FORMAT

NERES MONTHLY SUMMARY

Month: June Year: 1981

Site Location	NERES	ISEE-1
Latitude:	42.46°	42.53°
Longitude:	71.30°	71.36°

METEOROLOGICAL INFORMATION	NERES	CARLE
Average maximum ambient air temp.(°C)	26.8	N/A
Average minimum ambient air temp.(°C)	14.3	N/A
Average ambient air temp.(°C)	20.6	N/A
Average degree days(°C days/day)	0.0	N/A
Total precipitation(cm)	7.2	---
Average wind speed(m/s)	2.5	---
Average total horizontal insolation(kWh/m^2/day)	5.7	---

MONITORED HOUSE (MH) INFORMATION	MH1	MH2	MH3	MH4	MH5	MH6
Average total electric energy used(kWh/day)	----	18.4	26.4	17.04	32.6	22.6
Average electric energy in use during sunhours(kWh/day)	----	11.8	20.0*	10.74	22.8	14.0

PROTOTYPE AND ISEE PHOTOVOLTAIC ARRAY INFORMATION	MITLL	WEST	GE	TRISC	SOLRX	CARLE
Average PV DC energy(kWh/day)	31.2	20.4	28.5	20.4	----	29.2*
Average PV DC energy/rated power(kWh/day/kWp)	4.6	3.9	4.2	4.3	----	4.0*
Array peak power(kW)	6.7	4.6	6.3	4.4	----	6.2
Average array peak power(kW)	5.6	4.2	5.1	3.6	----	N/A
Average total tilt insolation: during sunhours (kWh/m^2/day)	4.93	4.59	5.85	4.64	----	4.47*
Average total tilt insolation: PV system on(kWh/m^2/day)	4.89	4.35*	N/A	4.63	----	4.45
Peak insolation(kW/m^2)	1.04	1.00	1.14	1.03	----	1.00
Average peak insolation(kW/m^2)	0.88	0.84	0.93	0.85	----	0.83
PV array efficiency(%)	7.4	6.3	N/A	9.4	----	6.7
Average maximum panel temp(°C)	57.8	51.7	63.1	47.8	----	57.2
Average minimum panel temp.(°C)	12.8	10.2	11.4	11.0	----	8.9

PROTOTYPE AND ISEE POWER CONDITIONING UNIT (PCU) INFORMATION	MITLL	WEST	GE	TRISC	SOLRX	CARLE
Average PCU AC energy output(kWh/day)	28.1	16.6	23.1*	18.4	----	26.3
Average PCU AC peak power output(kW)	5.2	3.6	4.2*	3.3	----	5.6
PCU peak power output(kW)	6.2	3.9	5.3	4.1	----	7.0
PCU efficiency(%)	90.1	81.3	81.0*	90.1	----	90.1*

PROTOTYPE AND ISEE AC ENERGY FLOW	MITLL	WEST	GE	TRISC	SOLRX	CARLE
Average imposed load(kWh/day)	20.2	0.0	14.5	0.0	----	18.8
Average energy supplied to utility feed(kWh/day)	21.0	16.6	19.0*	18.4	----	17.6
Average energy supplied by utility feed(kWh/day)	13.4	0.0	11.0*	0.0	----	10.2
NUMBER OF DAYS OF DATA COLLECTED	25	12	16	27	0	19

+The load data source for the imposed load was changed from MH3 to MH4 on 6/12

* Estimated

Notes: MITLL had between 5 and 8 of 8 strings online. One string had current leakage problems.
WEST was down between 6/5 and 6/22 due to inverter malfunction.
GE came online 6/9.
TRISC was online full month
SOLRX was not online
CARLE was online full month.

The detailed data will present hourly tabulations of ISEE data (see Table II for sample format) for total electricity usage, domestic hot water usage, estimated heat pump heating or cooling, estimated passive solar gain, estimated energy gain from wood stove and fireplace heating, PV array dc output, average cell temperature, array tilt insolation, inverter real energy output, energy exchange with the electric utility, and maximum and minimum power levels at the utility feed interface during each hour of each day. (Minimum levels can be large negative values representing power fed into the grid.) A monthly load duration curve will be calculated. Finally, total insolation at the array tilt angle will be tabulated together with the daily system status. The synopsis report will present the same data in tabular form for an average weekday (and weekend, where appropriate). The summary report, however, will only provide average day values for the same quantities as presented for the prototypes.

The detailed data will present meteorological data (Table II) comprised of the tilted array insolation given with each ISEE and PS, the total horizontal insolation at the RES, the daily sun-hour maximum, the minimum and average temperatures at the RES, the daily sun-hour average temperature at each ISEE, the wet-bulb temperature, the daily precipitation, the sun-hour average, and the maximum wind speed at the RES. Finally, the percent possible total horizontal insolation will be calculated and presented in the hourly format for the RES. The synopsis report will present these data with hourly tabulations replaced by values for an average day. The summary report will present average day values for ambient temperature, precipitation, wind speed and total horizontal insolation.

4.0 ANNUAL REPORT ON RES OPERATIONS

An annual report will be issued by each RES, summarizing the monthly average weekday and weekend/holiday MH, PS, ISEE and meteorological data. It will be prepared in such a way as to include the detailed monthly reports as appendices. The report will also include results of reliability and durability studies performed on the prototype systems.

A critical feature of this report will be two assessments. The performance of the collective PSs and ISEEs vis-à-vis the price goals and milestones of the National Photovoltaics Program will be reviewed and a summary of institutional responses to residential PV systems will be presented. These assessments will be used to provide direction to the overall DOE efforts to develop residential PV systems.

5.0 PROTOTYPE SYSTEM PERFORMANCE REPORT

At the conclusion of a one-year test period beginning with system acceptance, a report will be issued on the measured and predicted performance of each PS. This report will be written for the PV community and the institutions represented in the consulting committees, especially the electric utilities. It will summarize the measured performance of the system, present an analytic model of the system which will have been verified by the measured data, and will provide estimates of system performance based on SOLMET Typical Meteorological Year (TMY) data for various cities within the region of the RES and for loads varying from minimal to extreme electric energy usage.

This report will also summarize the results of the reliability, durability, and safety studies performed on the system. These studies will be conducted through a sequence of tests which are catalogued in a complementary document in preparation titled "Prototype Residential Photovoltaic Systems Evaluation Plan."

In addition, the report will assess the potential manufacturing cost of and installation cost for the system and, together with performance predictions, will assess the system's potential cost effectiveness for a homeowner.

6.0 REPORTS, BROCHURES AND TAPE DATA DISTRIBUTION

A primary objective of the residential project is to provide accurate data and information to interested individuals, institutions and companies concerning the performance of the MHs and developmental PV systems.

The daily operations report is intended primarily for internal use. Upon request, however, it will be available to the PS and ISEE subcontractors, the members of the Consulting Committees, and the organizations within the PV program.

Monthly operations reports will be distributed to all staff personnel in the RESs, all Consulting Committee members, all organizations in the DOE Photovoltaics Program, all PS and ISEE subcontractors, major institutions which have expressed an interest in receiving these reports and the Department of Energy Technical Information Center distribution category UC-63. In addition, copies of these reports will be available at RESs for public inspection.

The Annual Report on RES operations will be distributed to the same individuals and organizations as the monthly reports. In addition a brochure will be made available at the RESs.

Prototype System performance reports are designed primarily for the photovoltaics community including the institutions represented on the Consulting Committees, especially electric utilities, and the PV manufacturers. These documents will also serve as final reports to DOE on each PS and, accordingly, will be distributed by DOE's Technical Information Center, through category UC-63.

Tapes of the archived six-minute data will be made available on request to organizations with a legitimate interest in and need for the data. This will be done as a service providing the interested organization provides a blank tape for the purpose.

APPENDICES

A1 MONITORED HOUSE

Measurements

The quantities noted here are measured every 5 seconds, averaged over six minute periods and recorded 24-hours a day:

1. Utility ac bus RMS voltage
2. Utility ac RMS current
3. Utility ac power (peak, average)
4. Temperature of room housing instruments

A listing of the accuracy of the instruments readings will be available on file at the RES. To ensure the validity of the measured values, the instruments will be calibrated periodically.

Data Processing

The quantities are measured by the Monitored House Data Acquisition Controller (RDAC) and the information is transmitted by telephone lines every five seconds to a Data Concentrator Unit (DCU) at the RES. The values are accumulated and then fed every six minutes to a Hewlett Packard 9845 computer that reformats and averages the data over the six-minute interval and stores the averaged data. The stored data is transcribed on a magnetic tape and also in core memory of a second Hewlett Packard 9845 computer. Data stored on the magnetic tape is carried from the RES to a main frame computer for processing various reports. The second Hewlett Packard 9845 stores the six-minute data on a 24-hour revolving basis. This computer will generate the daily reports and will be available daily to review and process the 24-hour data base for special tasks and purposes.

The magnetic tapes carry data for periods ranging from part of a day to several days. The data is brought onto the main frame system and split and spliced into segments of 24 hours, midnight to midnight. The daily segments or "files" thus made are transcribed onto a master tape. It is envisioned that a full year of data for all MHs, PSs and ISEEs can be accommodated on four to eight (2400 feet, 6250 bpi) tapes. Copies of the master tapes are kept for archival purposes.

The data on the master tape used in conjunction with appropriate Fortran programs will yield all the information for daily, monthly and annual reports. Initially the daily report will be generated on the main frame computer; at a later date this will be done at the RES on a second Hewlett Packard 9845 computer.

Figure 1 schematically outlines the information gathering, data reduction and information dissemination process for the Residential Experiment Station.

A2 PROTOTYPE SYSTEMS

Measurements

The quantities noted here are measured every five seconds, averaged over six-minute periods and recorded 24 hours a day:

1. Array dc bus voltage
2. Array dc bus current
3. Array bus power
4. System ac bus voltage (RMS)
5. Inverter real power output (if inverter includes an isolation transformer the measurement is made downstream of it)
6. Inverter current harmonic distortion
7. Load real power consumption
8. Utility ac current (RMS)
9. Utility real power
10. Module temperature at four array locations
11. Inverter room temperature
12. Attic space temperature
13. Total insolation at the tilt of the PV modules.

A listing of the accuracy of the instruments reading will be available on file at the RES. To ensure the validity of the measured values, the instruments will be calibrated periodically.

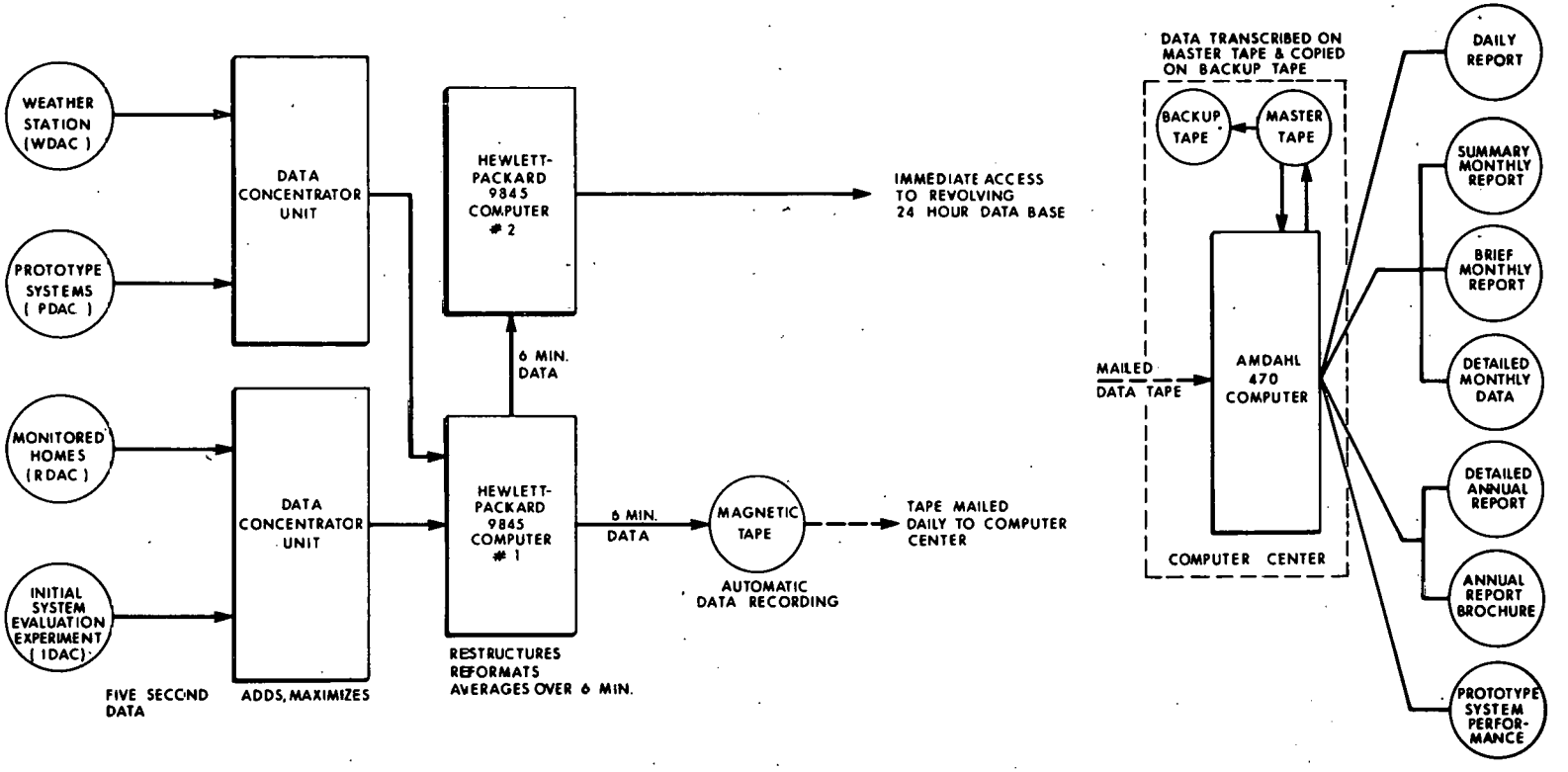

Fig. 1. Flow chart for data acquisition and reporting of RES and ISEE operations.

Data Processing

This is identical to the routine for processing data from the MHs. In fact the data for all four classes of instrumented sites is simultaneously taken and recorded together.

A3 METEOROLOGICAL STATIONS

Measurements

The quantities noted here are measured every five seconds, averaged over six-minute periods and recorded 24 hours a day:

1. Total horizontal insolation
2. Total direct normal insolation
3. Ambient temperature
4. Wind velocity
5. Precipitation
6. Ambient dew point temperature.

A listing of the accuracy of the instruments, readings will be available as on file at the RES. To ensure the validity of the measured values, the instruments will be calibrated periodically.

Data Processing

This is identical to the routine for processing data from the MHs.

A4 INITIAL SYSTEM EVALUATION EXPERIMENT

Measurements

The quantities noted here are a special list for the Carlisle House and the list may vary with ISEEs depending on their special needs. They are measured every five seconds, averaged over six-minute periods and recorded 24 hours a day:

1. Total insolation at the tilt of the PV array
2. Ambient temperature
3. Array bus dc voltage

4. Array bus dc current
5. Inverter ac voltage (RMS)
6. Inverter real power output
7. Load real power consumed
8. Utility real power
9. Module temperature at four array locations
10. Indoor temperature at two locations
11. Domestic hot water flow rate
12. Cold water temperature going to tank
13. Hot water temperature leaving tank
14. Resistive electrical power supplied to hot water tank
15. Heat pump freon pressure at compression side (of compressor)
16. Heat pump freon pressure at suction side (of compressor)
17. Electrical power (real) to heat pump compressor
18. Electrical power (real) to heat pump air blower
19. Heat pump resistance heater power
20. Floor slab temperature at six locations (two different depths and three locations)
21. Temperature difference across a south-facing window
22. Total insolation flux through a south-facing window
23. Temperature of the flue gas exiting the wood stove
24. Temperature of the flue gas exiting the fireplace.

A listing of the accuracy of the instruments readings will be available on file at the RES. To ensure the validity of the measured values, the instruments will be calibrated periodically.

Data Processing

This is identical to the routine for processing data from the MHs

A5 DEFINITIONS AND RATIONALE FOR USE OF SOME QUANTITIES PRESENTED IN VARIOUS REPORTS

1. Clearness Index: The daily clearness index is defined as the ratio of the measured daily horizontal terrestrial radiation to

the calculated* daily horizontal terrestrial radiation for "clear skies." It is a measure of how cloudy and smoggy the day has been.

2. Sunhour: This is the period of time between sunrise and sunset.
3. Figure of Merit for PV Array: It is defined as the ratio of the measured daily dc energy production to a corresponding value calculated with measured insolation, array temperatures and voltages and is given by,

$$\text{Figure of merit} = \frac{\int dt\ P}{\int dt\ I\eta_r\ [1 - \Delta(T_c - T_r)]}$$

Here P, I, T_c are the measured dc power produced, total insolation incident on array and average array cell temperature, η_r is the reference array efficiency at the measured voltage and reference array cell temperature, T_r; Δ is the cell temperature coefficient and the integrals are with respect to time over the period of 24 hours. The value of the figure of merit should be close to unity and will serve as a diagnostic tool to verify that the array is operating as the weather conditions dictate.

4. Figure of Merit for Power Conditioner Operation: It is defined as the ratio of the daily ac energy produced by the power conditioner to the corresponding calculated value and is given by,

$$\text{Figure of merit} = \frac{\int dt\ P_a}{\int dt\ \eta_p P}$$

Here the integrals are again with respect to time over the period of 24 hours, P_a is the ac power produced by the power conditioner, P is the dc power produced by the array, and η_p is the power conditioner efficiency available as a function of incoming dc energy into the power conditioner and its operating voltage.

*See for example, F. Kreith and J. F. Kreider, Principles of Solar Engineering, McGraw-Hill Book Company, 1978, pp. 41-45.

The figure of merit should be close to unity and serves as a diagnostic tool to verify that the power conditioner is operating at conditions dictated solely by the PV array output.