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CONTRACTOR REPORT

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MASTER

Intermediate Photovoltaic System Application Experiment Operational Performance Report

**Volume 4
for Beverly High School
Beverly, MA**

SAND--81-7088/4

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**Boeing Computer Services, Inc
Seattle, WA 98124**

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FOREWORD

This volume, which includes both the November and December reports, contains two new pages. This new foreword page is intended to provide information not easily incorporated in the computer-generated modules. The second new entry is a plot of time of day versus data acquisition mode (Plot 3 of the monthly Operational Performance Report and an unlabeled plot in the Executive Summary). Four modes are possible. In mode 0, no data was acquired, inferring that the ODAS was inoperative. Mode 1 corresponds to nighttime when only weather data is collected. Mode 2 occurs between sunrise and sunset when the photovoltaic system is inoperative due to insufficient solar insolation or equipment malfunction. Weather data plus insolation is recorded during Mode 2. Mode 3 occurs when the photovoltaic system is in operation. Data collected in Mode 3 is that collected in Modes 1 and 2, plus system performance data. This new plot shows at a glance when the system or the ODAS was inoperative.

The November operational performance report for Beverly shows a bimodal distribution in the plot of energy produced versus power level. An examination of data in the DRC data base showed that of the 16 days when Mode 3 operation was recorded, power conditioning unit #2 was inoperative during 8 of those days. Thus the plot shows a peak below half maximum

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power, corresponding to one PCU in operation, and a second peak near maximum power, corresponding to both PCUs in operation.

The time-of-day versus mode plot for December shows that the PV system was inoperative most of the month. Presumably, adverse weather and the tendency of the PCUs to trip on minor ground faults can explain the lack of operation.

Index of Available Reports for Photovoltaic System
at Beverly High School

I. General

<u>Report</u>	<u>Contents</u>
1. DOE/ET/23062-1	Final contractor report initial design
2. SAND81-7088/1	Project description, list of participants, system specifications

II. Monthly Performance Reports

1. SAND81-7088/2	Data for July 1981
2. SAND81-7088/3	Data for Sept. & Oct. 1981
3. SAND81-7088/4	Data for Nov. & Dec. 1981

III. Executive Summaries

1. SAND81-7102/1	Data for July 1981
2. SAND81-7102/2	Data for Sept. & Oct. 1981
3. SAND81-7102/3	Data for Nov. & Dec. 1981

Photovoltaic Monthly Report**High School
Beverly, Mass.
November, 1981** **PLOT 3.0: DATA ACQUISITION MODE AND RECORDING INTERVAL PLOT.**

Photovoltaic Monthly Report

Report Module No. 3 :PV Array System

High School
Beverly, Mass.
November, 1981

1. Electrical energy: Total electrical energy produced by PV array field during the month	4419. kWh
2. Thermal energy: Total thermal energy produced by PV array field during the month	Not Applicable
3. Solar energy: Total measured incident solar energy in the plane of the collector during the month	123498. kWh
4. Solar energy: Total measured direct normal solar energy during the month	Not Available
5. Array efficiency: Average PV array field efficiency for the month, as a ratio of array electrical output energy to total measured incident plane-of-array solar energy	3.58 %
6. Array efficiency: Average PV array field efficiency for the month, as a ratio of array electrical output energy to total measured direct normal solar energy	Not Applicable
7. Parasitic energy: Energy used by the control, tracking, and cooling subsystems during the month	0
8. Percentage parasitic loss: As a ratio of system parasitic energy (control, tracking, and cooling subsystems) to total power conditioning unit output energy	Not Applicable

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 3.1: DAILY PV ARRAY FIELD ELECTRICAL ENERGY PRGDUCTION
COMPARED WITH INCIDENT PLANE-OF-ARRAY SOLAR ENERGY

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 3.2: DAILY PV ARRAY FIELD EFFICIENCY

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 3.3: PV ARRAY FIELD ENERGY PRODUCTION AS A FUNCTION OF
POWER LEVEL FOR THE MONTH

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 3.4: PV ARRAY FIELD ENERGY PRODUCTION AS A FUNCTION OF
PV ARRAY FIELD VOLTAGE FOR THE MONTH

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 3.5: VARIATION OF PV ARRAY FIELD ENERGY PRODUCTION
WITH CELL TEMPERATURE DURING THE MONTH

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 3.6: TOTAL MONTHLY PV ARRAY FIELD ELECTRICAL ENERGY
PRODUCTION COMPARED WITH AVERAGE HOURLY INCIDENT SOLAR
ENERGY DURING THE MONTH (LOCAL STANDARD TIME)

Photovoltaic Monthly Report

Report Module No. 4 : Power Conditioning System

High School
Beverly, Mass.
November, 1981

Power Conditioner Unit No. 1

1. Power conditioner input: Total energy input into the power conditioner during the month	2913. kWh
2. Power conditioner output: Total energy output from the power conditioner during the month	2466. kWh
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	84.67 %
4. Power conditioner output: Average output power factor	Not Available

Photovoltaic Monthly Report

Report Module No. 4 : Power Conditioning System

High School
Beverly, Mass.
November, 1981

Power Conditioner Unit No. 2

1. Power conditioner input: Total energy input into the power conditioner during the month	1508. kWh
2. Power conditioner output: Total energy output from the power conditioner during the month	1363. kWh
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	90.00 %
4. Power conditioner output: Average output power factor	Not Available

Photovoltaic Monthly Report

Report Module No. 4 : Power Conditioning System

High School
Beverly, Mass.
November, 1981

Total Power Conditioner Units

1. Power conditioner input: Total energy input into the power conditioner during the month	4422. kWh
2. Power conditioner output: Total energy output from the power conditioner during the month	3830. kWh
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	86.62 %
4. Power conditioner output: Average output power factor	Not Available

Photovoltaic Monthly Report

Report Module No. 8 : System Relationships

High School
Beverly, Mass.
November, 1981

1. PV system-load energy: Total electrical energy supplied by the PV system to the load during the month	3830. kWh
2. Grid-load energy: Total electrical energy used by the load that was drawn from the local utility grid during the month	Not Available
3. PV system-grid energy: Total electrical energy supplied by the PV system to the local utility grid during the month	0. kWh
4. PV system efficiency: As a ratio of total PV system output energy to total measured incident plane-of-array solar energy during the month	3.10 %
5. PV system efficiency: As a ratio of total PV system output energy to total measured direct normal solar energy during the month	Not Applicable
6. Dollar value: Of electrical energy supplied by the PV system to the load during the month	Not Available
7. Dollar value: Of net electrical energy supplied by the PV system to the local utility grid during the month	Not Available
8. Dollar value: Of thermal energy produced by the PV system during the month	Not Applicable
9. Dollar value: Of the base load peak demand supplied by the PV system to the load and grid during the month	Not Available
10. Capacity factor: As a ratio of the monthly PV array field output energy to the rated system capacity during the month	34.17 %

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 8.1: COMPARISON OF ENERGY RELATIONSHIPS BETWEEN THE PV SYSTEM, THE LOAD AND THE LOCAL UTILITY GRID ON A DAILY BASIS DURING THE MONTH

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 8.2: DAILY PV SYSTEM AVAILABILITY DURING THE MONTH

Photovoltaic Monthly Report

Report Module No. 9 : Meteorological Data

High School
Beverly, Mass.
November, 1981

1. Solar insolation: Monthly average solar insolation incident on a horizontal surface during the month during daylight hours	163. W/m ²
2. Solar insolation: Monthly average plane-of-array insolation during the month during daylight hours	326. W/m ²
3. Solar insolation: Monthly average direct normal insolation during the month during daylight hours	Not Available
4. Solar insolation: Long term average horizontal insolation for the month during daylight hours	331. W/m ²
5. Solar insolation: Long term average direct normal insolation during daylight hours	Not Applicable
6. Heating need: Total actual heating degree days for the month	401.° C Days
7. Cooling need: Total actual cooling degree days for the month	0.° C Days
8. Heating need: Long term average heating degree days for the month	330.° C Days
9. Cooling need: Long term average cooling degree days for the month	0.° C Days
10. Temperature: Average ambient temperature for the month	5.° C
11. Wind: Average wind speed for the month	2.7 m/sec
12. Number of freeze/thaw cycles during the month	13.

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 9.1: OPERATING ENVIRONMENT: AMBIENT TEMPERATURE,
CELL TEMPERATURE, WIND SPEED AND INCIDENT
SOLAR INSOLATION (LOCAL STANDARD TIME)

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

PLOT 9.2: WIND DIRECTION DISTRIBUTION FOR THE MONTH

Photovoltaic Monthly Report

Report Module No. 10 : Energy Summary

High School
Beverly, Mass.
November, 1981

1. Solar energy: Total measured direct normal solar energy during the month	Not Available
2. Solar energy: Total measured incident solar energy in the plane of the collector during the month	123498. kWh
3. Solar energy: Total measured incident solar energy on a horizontal surface during the month	62270. kWh
4. Solar energy: Long term average incident solar energy on a horizontal surface for the month	1.68 $\frac{\text{kWh}}{\text{m}^2\text{-day}}$
5. Electrical energy: Total electrical energy produced by PV array field during the month	4419. kWh
6. Thermal energy: Total thermal energy produced by PV array field during the month	Not Applicable
7. Power conditioning unit output: Total energy output from the power conditioning unit during the month	3830. kWh
8. Battery charge: Total energy supplied to charge batteries during the month	Not Applicable
9. Battery discharge: Total energy withdrawn from batteries during the month	Not Applicable
10. PV system-load energy: Total electrical energy supplied by the PV system to the load during the month	3830. kWh
11. Grid-load energy: Total electrical energy supplied to the load by the local utility grid during the month	Not Available
12. PV system grid energy: Total electrical energy supplied by the PV system to the local utility grid during the month	Not Available
13. Energy use: Total load energy consumption during the month	Not Available

Photovoltaic Monthly Report

Report Module No. 11 : Efficiency Summary

High School
Beverly, Mass.
November, 1981

1. Array efficiency: Average PV array field efficiency for the month, as a ratio of array electrical output energy to total measured incident plane-of-array solar energy	3.58 %
2. Array efficiency: Average PV array field efficiency for the month, as a ratio of array electrical output energy to total measured direct normal solar energy	Not Applicable
3. Power conditioner efficiency: As a ratio of power conditioner output to input energy for the month	84.67 %
4. Battery efficiency: As a ratio of total discharge energy to charge energy for the month	Not Applicable
5. PV system efficiency: As a ratio of net PV system output energy to total measured incident plane-of-array solar energy during the month	3.10 %
6. PV system efficiency: As a ratio of net PV system output to total measured direct normal solar energy during the month	Not Applicable

Photovoltaic Monthly Report

High School
Beverly, Mass.
November, 1981

— (A) BASED ON PLANE-OF-ARRAY SOLAR ENERGY
- - - (B) EFFICIENCY ADJUSTED TO OPTIMUM CELL TEMPERATURE OF 28°C

PLOT 11.1: DAILY PV ARRAY FIELD EFFICIENCY

Photovoltaic Monthly Report

Report Module No. 3 :PV Array System

High School
Beverly, Mass.
December, 1981

1. Electrical energy: Total electrical energy produced by PV array field during the month	403. kWh
2. Thermal energy: Total thermal energy produced by PV array field during the month	Not Applicable
3. Solar energy: Total measured incident solar energy in the plane of the collector during the month	93330. kWh
4. Solar energy: Total measured direct normal solar energy during the month	Not Available
5. Array efficiency: Average PV array field efficiency for the month, as a ratio of array electrical output energy to total measured incident plane-of-array solar energy	0.43 %
6. Array efficiency: Average PV array field efficiency for the month, as a ratio of array electrical output energy to total measured direct normal solar energy	Not Applicable
7. Parasitic energy: Energy used by the control, tracking, and cooling subsystems during the month	0
8. Percentage parasitic loss: As a ratio of system parasitic energy (control, tracking, and cooling subsystems) to total power conditioning unit output energy	Not Applicable

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 3.0: DATA ACQUISITION MODE AND RECORDING INTERVAL PLOT

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 3.1: DAILY PV ARRAY FIELD ELECTRICAL ENERGY PRODUCTION
COMPARED WITH INCIDENT PLANE-OF-ARRAY SOLAR ENERGY

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

— (A) BASED ON PLANE-OF-ARRAY SOLAR ENERGY
- - - (B) EFFICIENCY ADJUSTED TO OPTIMUM CELL TEMPERATURE OF 28°C

PLOT 3.2: DAILY PV ARRAY FIELD EFFICIENCY

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 3.3: FV ARRAY FIELD ENERGY PRODUCTION AS A FUNCTION OF
POWER LEVEL FOR THE MONTH

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 3.4: PV ARRAY FIELD ENERGY PRODUCTION AS A FUNCTION OF
PV ARRAY FIELD VOLTAGE FOR THE MONTH

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 3.5: VARIATION OF PV ARRAY FIELD ENERGY PRODUCTION
WITH CELL TEMPERATURE DURING THE MONTH

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 3.6: TOTAL MONTHLY PV ARRAY FIELD ELECTRICAL ENERGY PRODUCTION COMPARED WITH AVERAGE HOURLY INCIDENT SOLAR ENERGY DURING THE MONTH (LOCAL STANDARD TIME)

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

Report Module No. 4 : Power Conditioning System

Power Conditioner Unit No. 1

1. Power conditioner input: Total energy input into the power conditioner during the month	396. kWh
2. Power conditioner output: Total energy output from the power conditioner during the month	310. kWh
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	78.23 %
4. Power conditioner output: Average output power factor	Not Available

Photovoltaic Monthly Report

Report Module No. 4 : Power Conditioning System

High School
Beverly, Mass.
December, 1981

Power Conditioner Unit No. 2

1. Power conditioner input: Total energy input into the power conditioner during the month	7. kWh
2. Power conditioner output: Total energy output from the power conditioner during the month	5. kWh
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	72.00 %
4. Power conditioner output: Average output power factor	Not Available

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

Report Module No. 4 : Power Conditioning System

Total Power Conditioner Units

1. Power conditioner input: Total energy input into the power conditioner during the month	403. kWh
2. Power conditioner output: Total energy output from the power conditioner during the month	315. kWh
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	78.12 %
4. Power conditioner output: Average output power factor	Not Available

Photovoltaic Monthly Report

Report Module No. 8 : System Relationships

High School
Beverly, Mass.
December, 1981

1. PV system-load energy: Total electrical energy supplied by the PV system to the load during the month	315. kWh
2. Grid-load energy: Total electrical energy used by the load that was drawn from the local utility grid during the month	Not Available
3. PV system-grid energy: Total electrical energy supplied by the PV system to the local utility grid during the month	0. kWh
4. PV system efficiency: As a ratio of total PV system output energy to total measured incident plane-of-array solar energy during the month	0.34 %
5. PV system efficiency: As a ratio of total PV system output energy to total measured direct normal solar energy during the month	Not Applicable
6. Dollar value: Of electrical energy supplied by the PV system to the load during the month	Not Available
7. Dollar value: Of net electrical energy supplied by the PV system to the local utility grid during the month	Not Available
8. Dollar value: Of thermal energy produced by the PV system during the month	Not Applicable
9. Dollar value: Of the base load peak demand supplied by the PV system to the load and grid during the month	Not Available
10. Capacity factor: As a ratio of the monthly PV array field output energy to the rated system capacity during the month	13.08 %

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 8.1: COMPARISON OF ENERGY RELATIONSHIPS BETWEEN THE PV SYSTEM, THE LOAD AND THE LOCAL UTILITY GRID ON A DAILY BASIS DURING THE MONTH

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 8.2: DAILY PV SYSTEM AVAILABILITY DURING THE MONTH

Photovoltaic Monthly Report

Report Module No. 9 : Meteorological Data

High School
Beverly, Mass.
December, 1981

1. Solar insolation: Monthly average solar insolation incident on a horizontal surface during the month during daylight hours	118. W/m ²
2. Solar insolation: Monthly average plane-of-array insolation during the month during daylight hours	235. W/m ²
3. Solar insolation: Monthly average direct normal insolation during the month during daylight hours	Not Available
4. Solar insolation: Long term average horizontal insolation for the month during daylight hours	289. W/m ²
5. Solar insolation: Long term average direct normal insolation during daylight hours	Not Applicable
6. Heating need: Total actual heating degree days for the month	595.° C Days
7. Cooling need: Total actual cooling degree days for the month	0.° C Days
8. Heating need: Long term average heating degree days for the month	551.° C Days
9. Cooling need: Long term average cooling degree days for the month	0.° C Days
10. Temperature: Average ambient temperature for the month	1.° C
11. Wind: Average wind speed for the month	2.9 m/sec
12. Number of freeze/thaw cycles during the month	17.
13. Adverse weather conditions	None

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 9.1: OPERATING ENVIRONMENT: AMBIENT TEMPERATURE,
CELL TEMPERATURE, WIND SPEED AND INCIDENT
SOLAR INSOLATION (LOCAL STANDARD TIME)

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 92: WIND DIRECTION DISTRIBUTION FOR THE MONTH

Photovoltaic Monthly Report

Report Module No. 10: Energy Summary

High School
Beverly, Mass.
December, 1981

1. Solar energy: Total measured direct normal solar energy during the month	Not Available
2. Solar energy: Total measured incident solar energy in the plane of the collector during the month	93330. kWh
3. Solar energy: Total measured incident solar energy on a horizontal surface during the month	46446. kWh
4. Solar energy: Long term average incident solar energy on a horizontal surface for the month	1.38 $\frac{\text{kWh}}{\text{m}^2\text{-day}}$
5. Electrical energy: Total electrical energy produced by PV array field during the month	403. kWh
6. Thermal energy: Total thermal energy produced by PV array field during the month	Not Applicable
7. Power conditioning unit output: Total energy output from the power conditioning unit during the month	315. kWh
8. Battery charge: Total energy supplied to charge batteries during the month	Not Applicable
9. Battery discharge: Total energy withdrawn from batteries during the month	Not Applicable
10. PV system-load energy: Total electrical energy supplied by the PV system to the load during the month	315. kWh
11. Grid-load energy: Total electrical energy supplied to the load by the local utility grid during the month	Not Available
12. PV system grid energy: Total electrical energy supplied by the PV system to the local utility grid during the month	Not Available
13. Energy use: Total load energy consumption during the month	

Photovoltaic Monthly Report

Report Module No. 11 : Efficiency Summary

High School
Beverly, Mass.
December, 1981

1. Array efficiency: Average PV array field efficiency for the month, as a ratio of array electrical output energy to total measured incident plane-of-array solar energy 0.43 %
2. Array efficiency: Average PV array field efficiency for the month, as a ratio of array electrical output energy to total measured direct normal solar energy Not Applicable
3. Power conditioner efficiency: As a ratio of power conditioner output to input energy for the month 78.23 %
4. Battery efficiency: As a ratio of total discharge energy to charge energy for the month Not Applicable
5. PV system efficiency: As a ratio of net PV system output energy to total measured incident plane-of-array solar energy during the month 0.34 %
6. PV system efficiency: As a ratio of net PV system output to total measured direct normal solar energy during the month Not Applicable

Photovoltaic Monthly Report

High School
Beverly, Mass.
December, 1981

PLOT 11.1: DAILY PV ARRAY FIELD EFFICIENCY

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