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CONTRACTOR REPORT

SAND81-7085/5
Unlimited Release
UC-63d

MASTER

Intermediate Photovoltaic System Application Experiment Operational Performance Report

Volume 5
for Lovington Square Shopping Center
Lovington, NM

Boeing Computer Services, Inc
Seattle, WA 98124

SAND--81-7085/5

DE82 006877

Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department of Energy
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Index of Available Reports for Photovoltaic System at Lovington Square Shopping Center

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Foreword

Beginning with this volume, the monthly reports will include this narrative section to provide information not easily included in the computer-generated modules.

* * * * *

Software problems resulted in the loss of fourteen days of data during September. A new version of the ODAS program solved most of the previous problems, and although some ODAS failures still occurred, data was collected every day for the month of October. Because of the loss of certain data elements in September, some of the parameters in the computer-generated report modules were obviously incorrect. Those parameters were corrected by hand, whenever possible, and the corrected values are flagged with an asterisk. A brief discussion of some of the affected parameters follows.

In report Module 3, Item 1, the total electrical energy produced in September is listed as 6,392 kWh. Both power conditioner units (PCUs) at Lovington have mechanical-type watt-hour meters which measure input dc energy and operate independently of the ODAS. During September, the "A" PCU recorded 7,767 kWh of dc input and the "B" PCU recorded 7,926. The data in report Module 4 indicates that the PCUs operated with an average efficiency of 90.4 percent, inferring that $(7,767 + 7,926) \times .904 = 14,186.5$ kWh of ac output energy was generated during the month.

Similarly, during October, the mechanical meters recorded 7,869 kWh for the "A" subfield and 7,369 kWh for the "B" subfield. Using the average PCU efficiency of 89.04 percent calculated for October, infers that the total ac output for the month was 13,567.9 kWh. It should be noted that the difference in the two subfield outputs is a result of different tilt angles. Subfield "A" is tilted at an angle of 40°, whereas the tilt of subfield "B" was changed from 40° to 30° on July 31, 1981.

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Photovoltaic Monthly Report

Report Module No. 3 :PV Array System

Shopping Center
Lovington, NM
September, 1981

1. Electrical energy: Total electrical energy produced by PV array field during the month	6392 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	132255. 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	3.95 %
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

*See foreword, p.ii

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
September, 1981

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

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
September, 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

Shopping Center
Lovington, NM
September, 1981

PLOT 3.3: PV ARRAY FIELD ENERGY PRODUCTION AS A FUNCTION OF
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PLOT 3.4: PV ARRAY FIELD ENERGY PRODUCTION AS A FUNCTION OF
PV ARRAY FIELD VOLTAGE FOR THE MONTH

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

Photovoltaic Month Report

Shopping Center
Lovington, NM
September, 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

Shopping Center
Lovington, NM
September, 1981

Power Conditioner Unit No. 1

1. Power conditioner input: Total energy input into the power conditioner during the month	3189 kWh*
2. Power conditioner output: Total energy output from the power conditioner during the month	2889 kWh*
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	90.6%*
4. Power conditioner output: Average output power factor	Not Available

*See foreword, p.ii

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
September 1981

Report Module No. 4 : Power Conditioning System

Power Conditioner Unit No. 2

1. Power conditioner input: Total energy input into the power conditioner during the month	3203 kWh*
2. Power conditioner output: Total energy output from the power conditioner during the month	2889 kWh*
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	90.2%*
4. Power conditioner output: Average output power factor	Not Available

*See foreword, p.ii

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
September 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	6392 kWh*
2. Power conditioner output: Total energy output from the power conditioner during the month	5778 kWh*
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	90.4%*
4. Power conditioner output: Average output power factor	Not Available

*See foreword, p.ii

Photovoltaic Monthly Report

Report Module No. 8 : System Relationships

Shopping Center
Lovington, NM
September, 1981

1. PV system-load energy: Total electrical energy supplied by the PV system to the load during the month	Not Available
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	Not Available
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	3.57% *
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	40.38 %

*See foreword, p.ii

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
September, 1981

PLOT 8.2: DAILY PV SYSTEM AVAILABILITY DURING THE MONTH

Photovoltaic Monthly Report

Report Module No. 9 : Meteorological Data

Shopping Center
Lovington, NM
September, 1981

1. Solar insolation: Monthly average solar insolation incident on a horizontal surface during the month during daylight hours	408. W/m ²
2. Solar insolation: Monthly average plane-of-array insolation during the month during daylight hours	471. 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	535. 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	14.° C Days
7. Cooling need: Total actual cooling degree days for the month	40.° C Days
8. Heating need: Long term average heating degree days for the month	0.° C Days
9. Cooling need: Long term average cooling degree days for the month	132.° C Days
10. Temperature: Average ambient temperature for the month	20.° C
11. Wind: Average wind speed for the month	2.1 m/sec
12. Number of freeze/thaw cycles during the month	0.
13. Adverse weather conditions	None

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
September, 1981

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

PLOT 9.2: WIND DIRECTION DISTRIBUTION FOR THE MONTH

Photovoltaic Monthly Report

Report Module No. 10: Energy Summary

Shopping Center
Lovington, NM
September, 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	132255. kWh
3. Solar energy: Total measured incident solar energy on a horizontal surface during the month	115975. kWh
4. Solar energy: Long term average incident solar energy on a horizontal surface for the month	6.54 $\frac{\text{kWh}}{\text{m}^2\text{-day}}$
5. Electrical energy: Total electrical energy produced by PV array field during the month	5231. 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	
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	Not Available
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

Shopping Center
Lovington, NM
September, 1981

Report Module No. 11 : Efficiency Summary

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	3.95 %
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	Not Available
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	3.57%*
6. PV system efficiency: As a ratio of net PV system output to total measured direct normal solar energy during the month	Not Applicable

*See foreword, p.ii

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
September, 1981

—— (A) BASED ON PLANE-OF-ARRAY SOLAR ENERGY

----- (B) EFFICIENCY ADJUSTED TO OPTIMUM CELL TEMPERATURE OF 28°C

PLOT 11.1: DAILY FV ARRAY FIELD EFFICIENCY

Photovoltaic Monthly Report

Report Module No. 3 :PV Array System

Shopping Center
Lovington,NM
October, 1981

1. Electrical energy: Total electrical energy produced by PV array field during the month	13148. 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	228469. 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	5.76 %
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

Shopping Center
Lovington, NM
October, 1981

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

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
October, 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

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

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

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

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
October, 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

Shopping Center
Lovington, NM
October, 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 6700 kWh
2. Power conditioner output: Total energy output from the power conditioner during the month 5968. kWh
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month 89.07 %
4. Power conditioner output: Average output power factor Not Available

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
October, 1981

Report Module No. 4 : Power Conditioning System

Power Conditioner Unit No. 2

1. Power conditioner input: Total energy input into the power conditioner during the month	6448 kWh
2. Power conditioner output: Total energy output from the power conditioner during the month	5739. kWh
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	89.00 %
4. Power conditioner output: Average output power factor	Not Available

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
October, 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	13148. kWh
2. Power conditioner output: Total energy output from the power conditioner during the month	11707. kWh
3. Power conditioner efficiency: As a ratio of total power conditioner output to input energy for the month	89.04%
4. Power conditioner output: Average output power factor	Not Available

Photovoltaic Monthly Report

Report Module No. 8 : System Relationships

Shopping Center
Lovington, NM
October, 1981

1. PV system-load energy: Total electrical energy supplied by the PV system to the load during the month	11707. 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	5.12 %
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	47.43 %

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
October, 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

PLOT 8.2: DAILY PV SYSTEM AVAILABILITY DURING THE MONTH

Photovoltaic Monthly Report

Report Module No. 9 : Meteorological Data

Shopping Center
Lovington, NM
October, 1981

1. Solar insolation: Monthly average solar insolation incident on a horizontal surface during the month during daylight hours	337. W/m ²
2. Solar insolation: Monthly average plane-of-array insolation during the month during daylight hours	444. 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	477. 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	156.° C Days
7. Cooling need: Total actual cooling degree days for the month	13.° C Days
8. Heating need: Long term average heating degree days for the month	62.° C Days
9. Cooling need: Long term average cooling degree days for the month	29.° C Days
10. Temperature: Average ambient temperature for the month	15.° C
11. Wind: Average wind speed for the month	2.8 m/sec
12. Number of freeze/thaw cycles during the month	1.
13. Adverse weather conditions	None

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
October, 1981

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

Photovoltaic Monthly Report

Shopping Center
Lovington, NM
October, 1981

PLOT 92: WIND DIRECTION DISTRIBUTION FOR THE MONTH

Photovoltaic Monthly Report

Report Module No. 10: Energy Summary

Shopping Center
Lovington, NM
October, 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	228469. kWh
3. Solar energy: Total measured incident solar energy on a horizontal surface during the month	176173. kWh
4. Solar energy: Long term average incident solar energy on a horizontal surface for the month	5.38 $\frac{\text{kWh}}{\text{m}^2\text{-day}}$
5. Electrical energy: Total electrical energy produced by PV array field during the month	13148. 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	11707. 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	11707. 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	0. kWh*

*See foreword, p.ii

Photovoltaic Monthly Report

Report Module No. 11 : Efficiency Summary

Shopping Center
Lovington, NM
October, 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 5.76 %
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 89.04%
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 5.12 %
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

Shopping Center
Lovington, NM
October, 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

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