Measured Impact of a Roof Top Photovoltaic System

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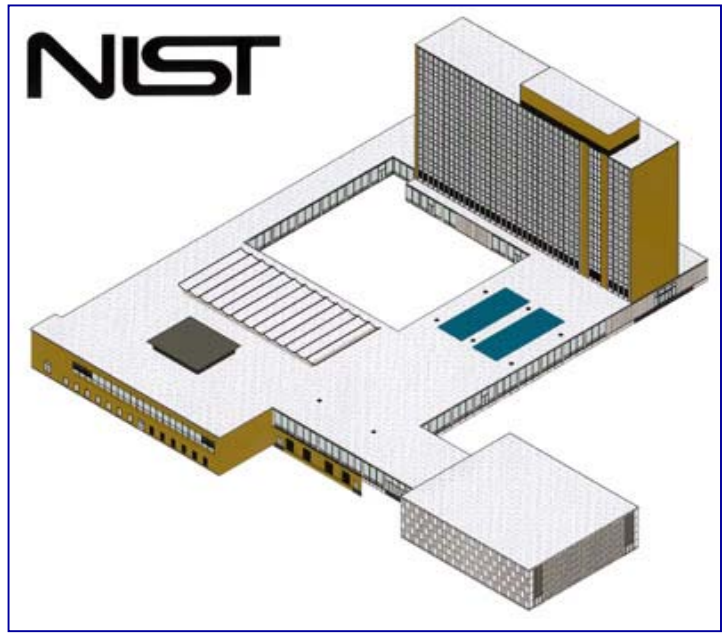
NIST's Roof Top Photovoltaic System

- Objective
  - Quantify Energy and Economic Impact Associated with NIST's 35 kW Photovoltaic System
- Presentation Overview
  - System Description
  - Monitoring Equipment
  - Experimental Results
    - Solar Radiation Measurements
    - Delivered Energy
    - Conversion Efficiency
  - Economic Results
    - Energy Savings
    - Peak Demand Savings
    - Savings Associated with Enhanced Thermal Insulation

NIST's Roof Top Photovoltaic System



Size – 35 kW DC (Standard Rating Conditions)

Total Installed Cost - $239,945 or $6.86 per DC Watt

Installation Date – September 11-14, 2001

Photovoltaic System Specifications

Module Specifications

- Stabilized Power = 150 W DC
- Open Circuit Voltage = 43.4 V
- Voltage at Peak Power = 34.0 V
- Short Circuit Current = 4.8 A
- Current at Peak Power = 4.4 A
- Dimensions = 1054 mm x 1194 mm

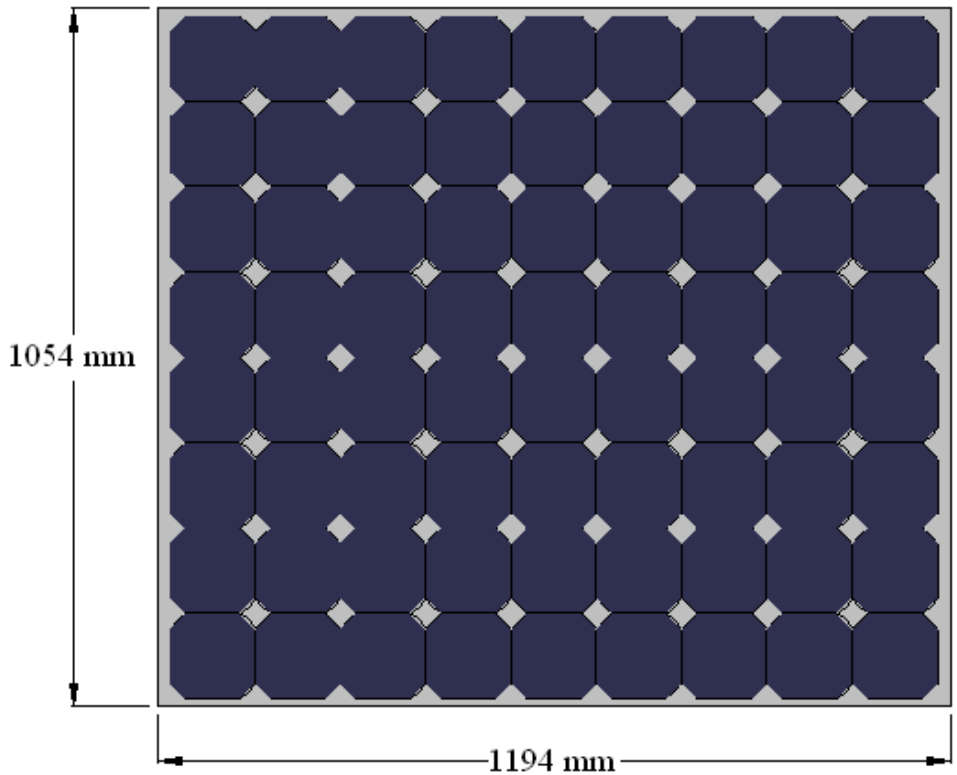
Array Specifications

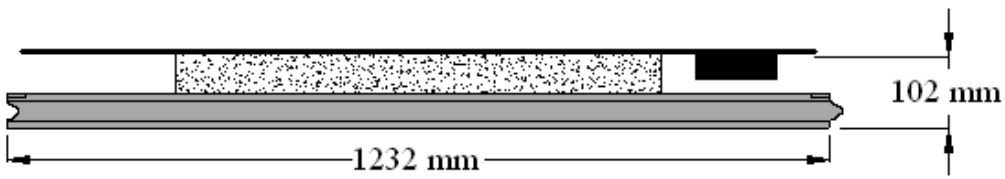
- No. of Modules in Series-Wired String = 13
- No. of Parallel Strings in Source Circuit = 18
- No. of Source Circuits = 1
- Total Number of Modules = 234
- Stabilized Power = 35 kW DC
- Open Circuit Voltage = 564 V
- Voltage at Peak Power = 442 V
- Short Circuit Current = 86 A
- Current at Peak Power = 79 A

Inverter Specifications

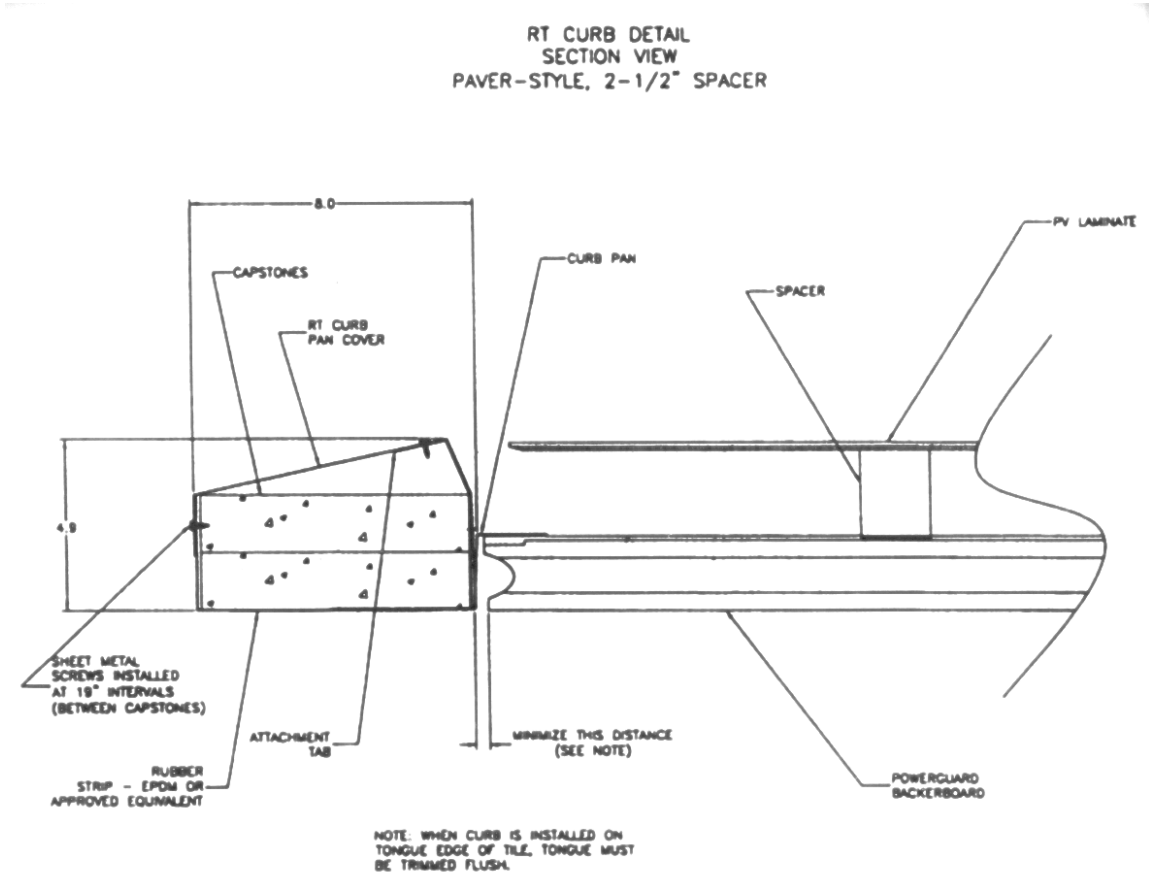
- Nominal AC Line Voltage = 208 VAC
- PV Maximum Voltage = 600 VDC
- PV Minimum Voltage = 300 VDC
- Continuous AC Power = 30 KVA
- Maximum PV Current = 100 ADC

Photovoltaic Module





Mounting Details



NIST's Rooftop Photovoltaic System

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Monitoring Equipment

- Manufacturer Supplied
  - Ambient Temperature Sensor
  - Anemometer
  - Silicon Photovoltaic Sensor
  - Programmable Sealed Data Logger
  - AC kWh Meter with Pulse Output
- NIST Supplied
  - 4 Precision Spectral Pyranometers
  - PC Driven Data Acquisition System

Results

- Solar Radiation Measurements
- Delivered Energy
- Conversion Efficiencies
- Economic Savings

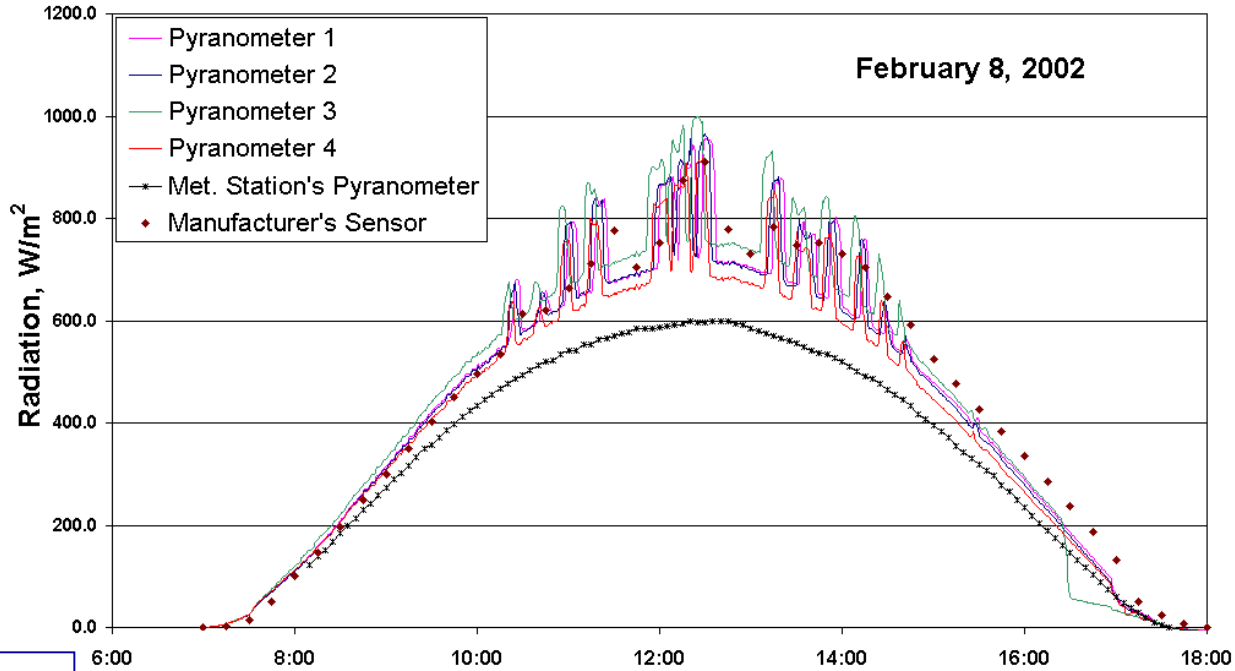
Solar Radiation Measurements

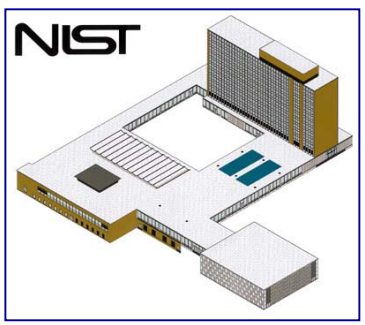
- Manufacturer's Sensor

- Precision Spectral Pyranometers

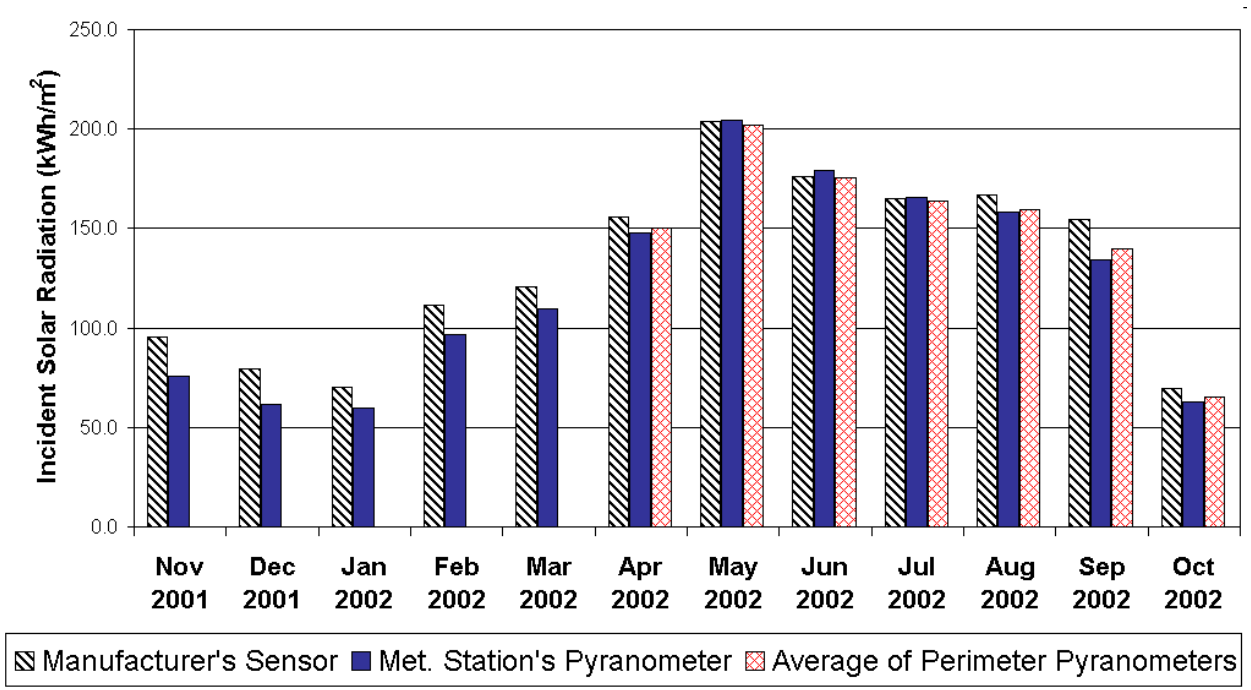
- NIST's BIPV Meteorological Station

Solar Radiation Measurement Comparison

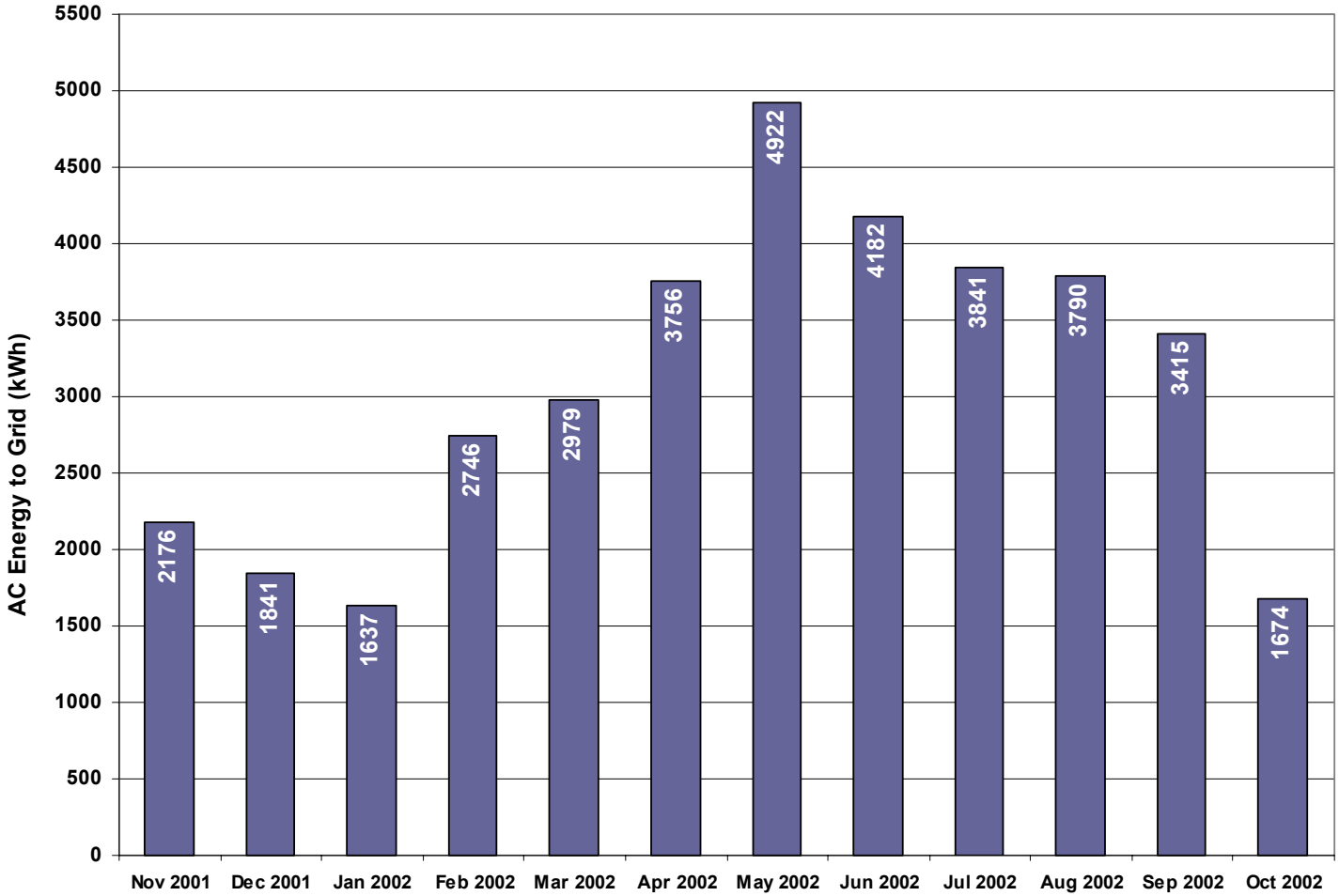




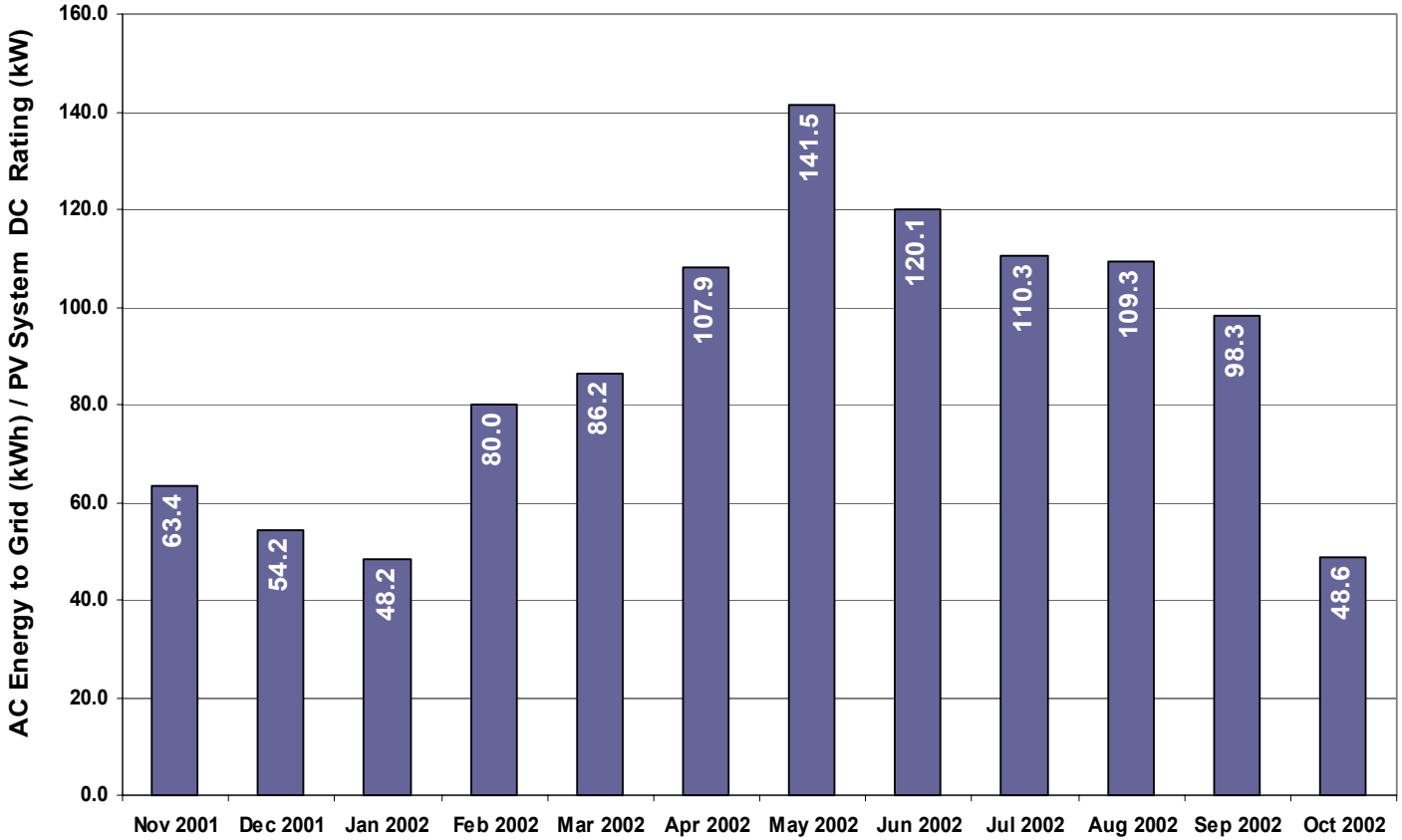
Monthly Solar Radiation Measurement Comparisons



Energy Delivered to Electrical Grid



Energy Delivered to Grid Per kW of System Rating



Conversion Efficiency

$$\eta_c = \frac{\int_o^\tau P_o \, d\tau}{A \int_o^\tau H_T \, d\tau}$$

where

A is a representative area, m^2,

H_T is the incident solar radiation, W/m^2,

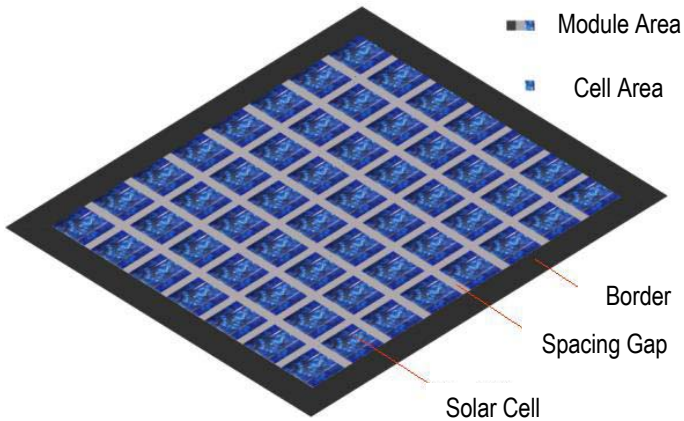
P_o is the inverter's electrical power output, W

and τ is the selected time interval, h.

Areas Used to Compute Conversion Efficiency

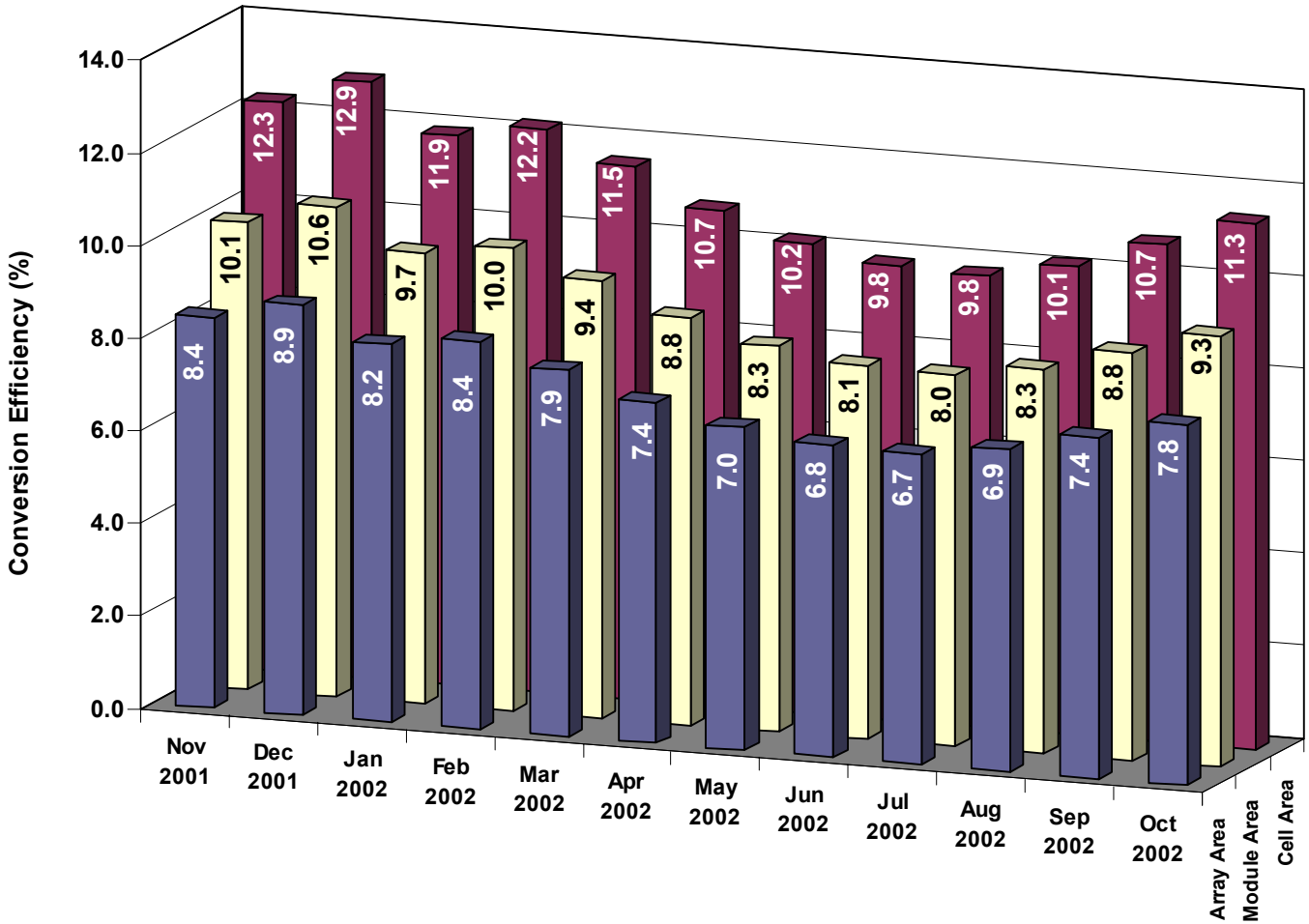
Cell Area - Number of cells times the area of each cell

Module Area - Number of modules times glazed area of each module

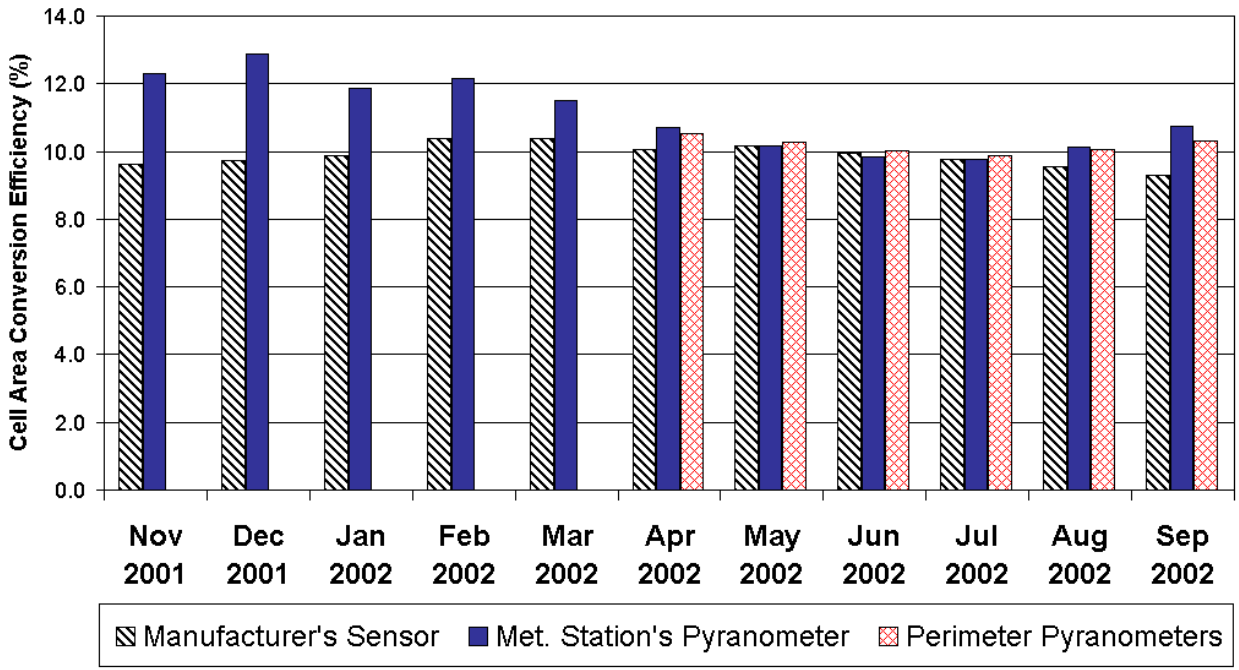


Footprint Area - Combined Area of modules, perimeter curbing system, and electrical inter-connect boxes

System Efficiencies Associated with Cell, Module, and Footprint Areas



Monthly Cell Conversion Efficiencies Using Various Solar Radiation Instruments



NIST Electric Utility Billing Schedule

		Summer Jun-Oct		Winter Nov-May	
Distribution					
Kilowatt-hour Charge		0.590¢	per kwhr	0.590¢	per kwhr
Kilowatt Charge					
	On Peak	$1.7738	per kw		
	Maximum	$0.7350	per kw	$0.7350	per kw
Transmission					
Kilowatt-hour Charge		0.265¢	per kwhr	0.265¢	per kwhr
Kilowatt Charge					
	On Peak	$0.7154	per kw		
	Maximum	$0.2940	per kw	$0.2940	per kw
Generation Service					
Kilowatt-hour Charge					
	On Peak	3.994¢	per kwhr	3.265¢	per kwhr
	Intermediate	3.323¢	per kwhr	2.708¢	per kwhr
	Off Peak	1.745¢	per kwhr	1.438¢	per kwhr
Peak Demand Charges					
	On Peak	$7.390	per kw		
	Maximum	$3.040	per kw	$3.040	per kw
NOTE:	On Peak (12 PM to 8 PM) Intermediate (8 AM to 12 PM) Off Peak (12 AM to 8 AM)				

Thermal Energy Savings

Reduction in Heat Loss/Gain Through Roof

$$Q = A\left[\frac{1}{R_o} - \frac{1}{R_{PV}}\right]\int_o^{\tau}(t_o - t_a)\,d\tau$$

where

t_o = outdoor ambient
t_a = assumed indoor temperature (77 ºF)
A = roof area occupied by the PV system
R_o = original roof thermal resistance (R-23)
R_{PV} = combined original roof and PV system insulation (R-33)

and τ = time

$$\text{Savings Cooling} = \frac{Q}{R_c} = \$\text{kWh}$$

$$\text{Savings Heating} = \frac{Q}{R_h} = \$\text{Natural Gas}$$

R_c = efficiency of cooling system
R_h = efficiency of heating system

Economic Savings Associated with Photovoltaic System

Billing Period	Energy Savings	Max Peak Demand Savings	On-Peak Demand Savings	Thermal Savings	Total Savings
Nov 01	71.49	1.77	-	5.09	78.35
Dec 01	61.43	37.39	-	9.57	108.38
Jan 02	54.47	50.10	-	8.52	113.09
Feb 02	94.84	56.71	-	8.47	160.01
Mar 02	104.19	75.28	-	6.56	186.03
Apr 02	132.77	63.33	-	3.17	199.27
May 02	166.18	79.92	-	1.66	247.75
Jun 02	164.24	38.40	75.95	0.60	279.19
Jul 02	154.17	81.12	196.95	0.87	433.12
Aug 02	148.62	56.71	137.68	0.81	343.81
Sep 02	140.58	56.97	138.31	0.16	336.02
Oct 02	67.35	31.09	90.14	4.35	192.92
Total $	1360.32	628.76	639.03	49.83	2677.94

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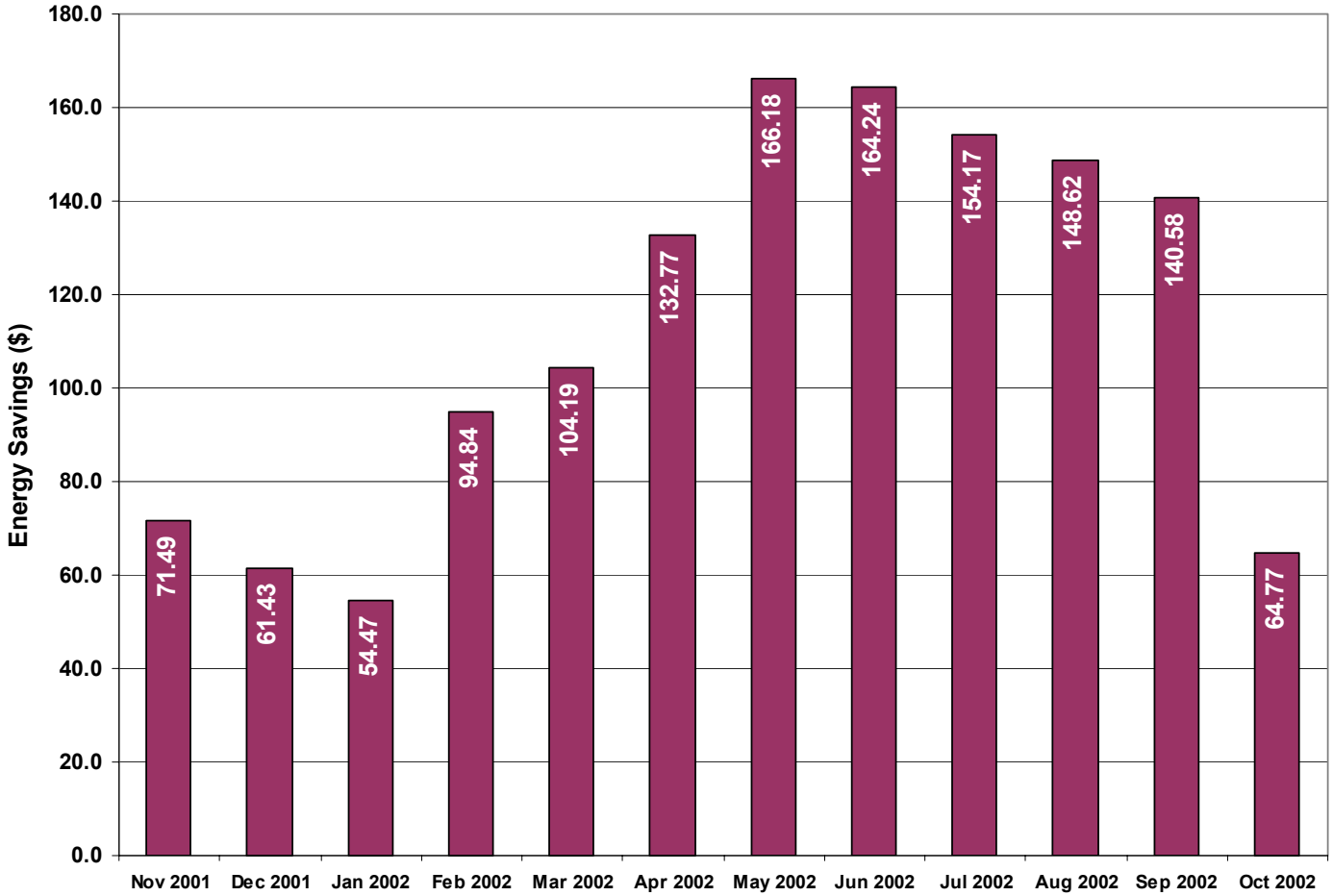

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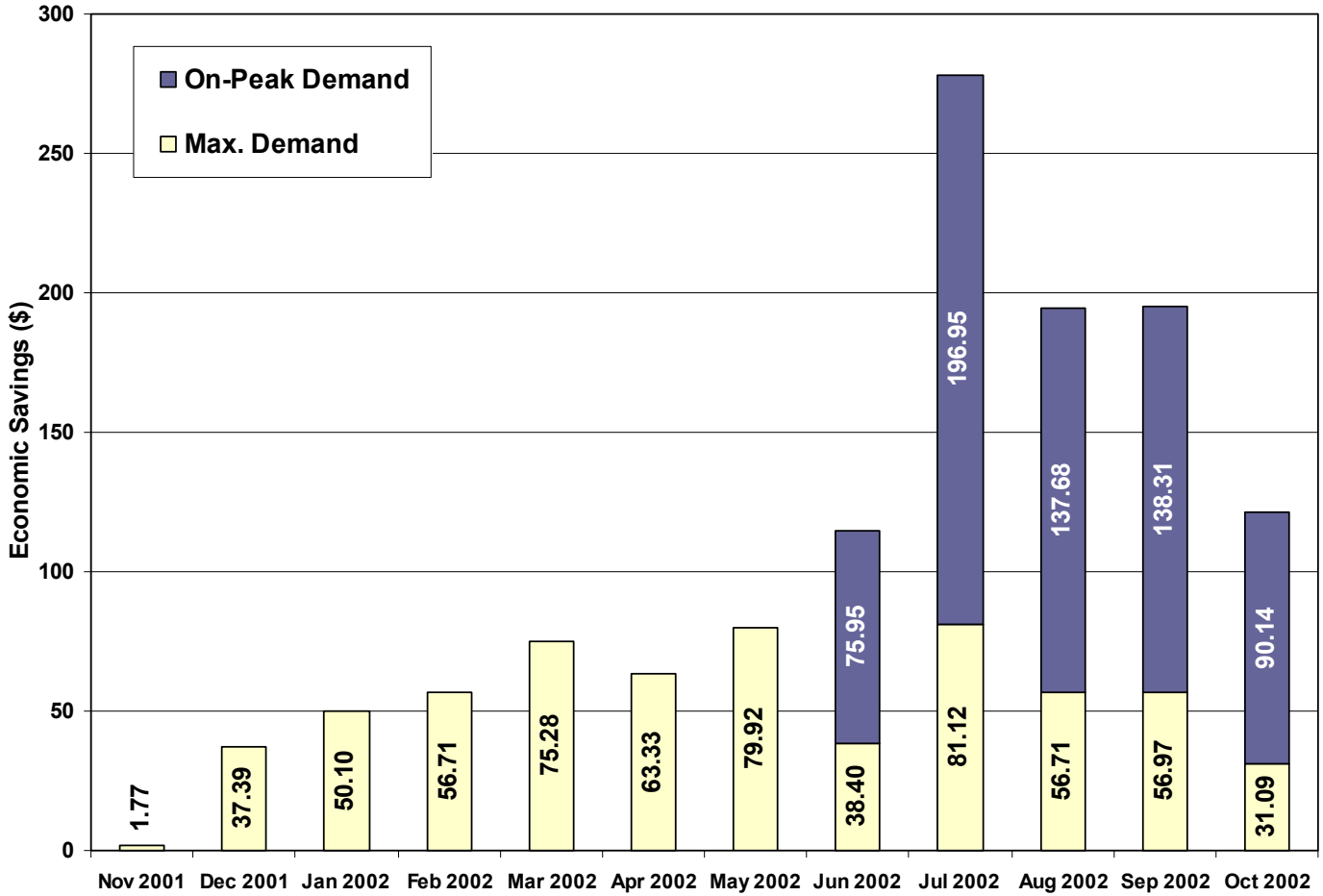

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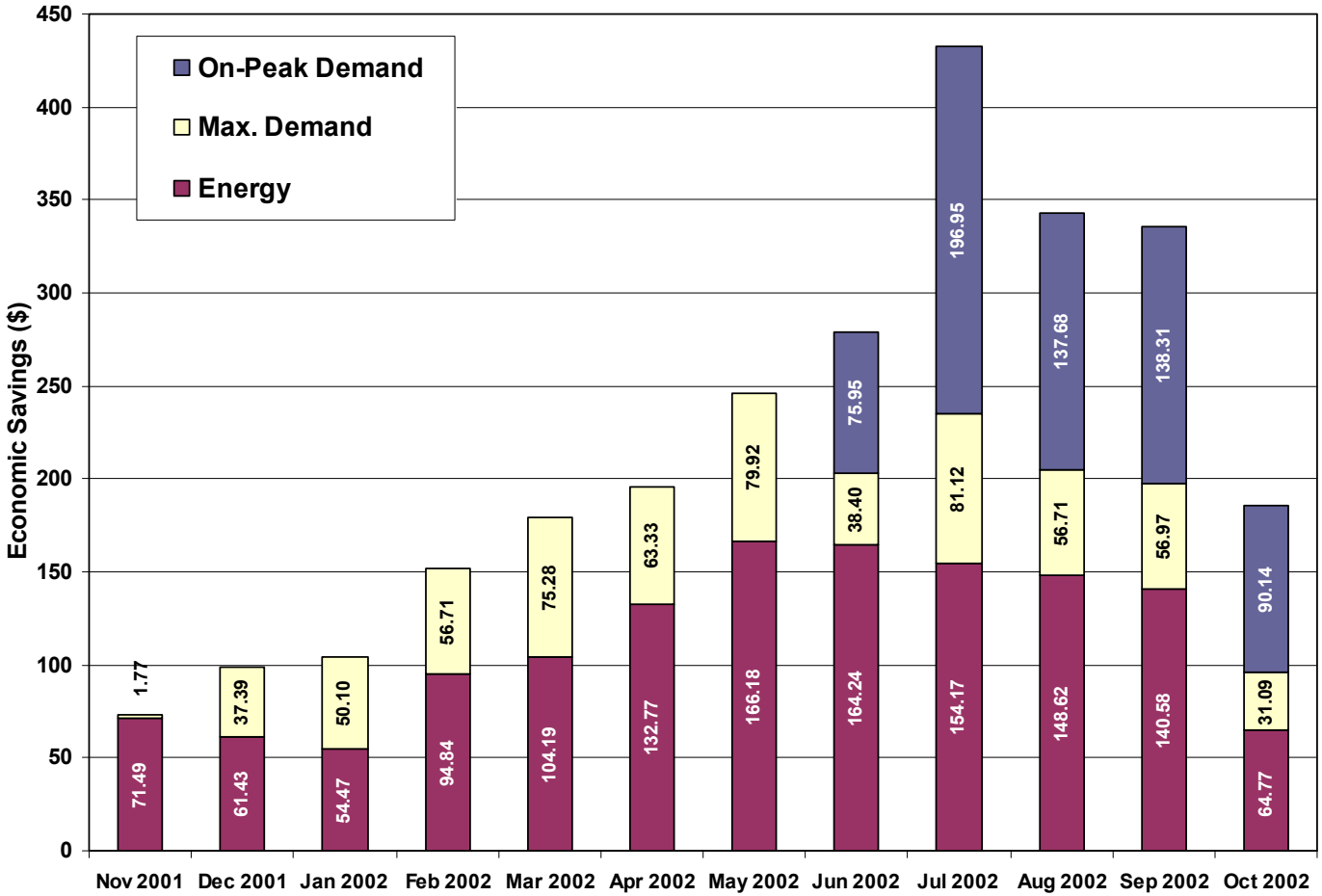

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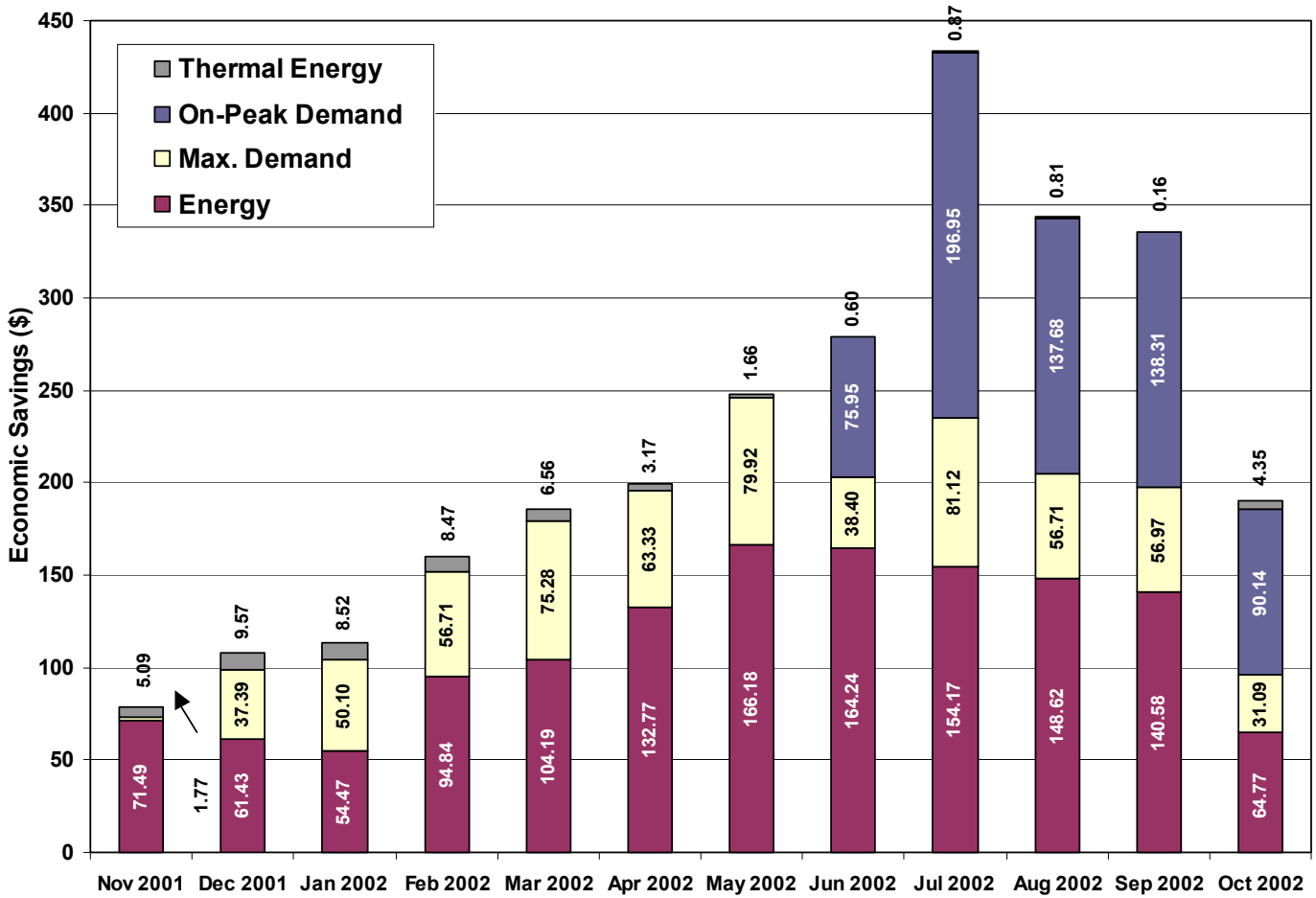

Summary

- Costs
  - $239,945
  - $6.86 per DC Watt
- Benefits
  - Annual Electric Utility Savings – Total = $2578.65
    - $607.57 Peak Demand
    - $615.81 Maximum Demand
    - $1355.27 Energy
  - Annual Avoided Emissions
    - 321 kg SO_2
    - 134 kg NO_x
    - 52.6 metric tons CO_2
- No Operation Problems Experienced to Date

Building Integrated Photovoltaic Program

Located at the following URL: http://www.bfrl.nist.gov/863/bipv/