

10 Kilowatt Photovoltaic Demonstration Project Final Report

Oakland University
Rochester, Michigan

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Table of Contents

Table of Contents 2
Executive Summary 3
Introduction 4
Project Team 4
Educational and Demonstration Components 5
Review of PV Materials, Products, & Projects 5
Design 8
 PV Material Selection 8
 Inverter Selection 9
 Site Selection 9
 Roof Layout 11
 Uni-Solar PV Material Performance 11
 Weather Review 12
 Shingle Counts 14
 Final Roof Layout 15
 Electrical Design 19
Installation 20
Instrumentation 25
System Performance 27
Conclusion 30

Executive Summary

In the spring of 2002, the Facilities Management Department of Oakland University was awarded a \$100,000 grant from the State of Michigan Energy Office to undertake a "Large Scale Solar Photovoltaic Demonstration Project".

The main objective of the grant is to publicly demonstrate PV technology in a local installation.

After a review of available PV technologies, a building integrated PV design was chosen which would attractively harmonize with the University architectural style. The selected PV material is produced by a local amorphous PV manufacturer, United Solar Ovonic, LLC.

After a campus-wide search for an appropriate installation site, a high visibility location was chosen at the new University Student Apartments. The selected site was a compromise between engineering concerns, high public visibility, and historical campus considerations.

The system was successfully installed and is performing within expectations. As data accumulates on the system performance and weather conditions, the Oakland University engineering department will assist with further study and analysis.

The public demonstration goals were also achieved. So far to date there have been five articles published in local and city newspapers covering the project. The open house and project web site have generated a fair number of inquiries and requests for more information.

The State of Michigan should continue to pursue additional public demonstration projects. But more importantly, the State should encourage additional solar and renewable energy investment through additional incentives such as direct project support through tax incentives and rebates, net metering, and a minimum state-wide renewable energy portfolio requirement.

Introduction

In the spring of 2002, the Facilities Management Department of Oakland University was awarded a grant from the State of Michigan Energy Office to undertake a “Large Scale Solar Photovoltaic Demonstration Project”. A total of \$200,000 was available to public or non-profit organizations to install one or more projects of 10 or more kilowatts of photovoltaics (PV) at one location. Both Oakland University and Michigan State University received one half of the available funding. Oakland University provided a financial match of 30%, for a total project budget of \$130,000.

The main objective of the grant is to publicly demonstrate PV technology in a local installation.

After a review of available PV technologies, a building integrated PV design was chosen which would attractively harmonize with the University architectural style. The selected PV material is produced by a local amorphous PV manufacturer, United Solar Ovonics, LLC.

After a campus-wide search for an appropriate installation site, a high visibility location was chosen at the new University Student Apartments. The selected site was a compromise between engineering concerns, high public visibility, and historical campus considerations.

The following sections will detail the formation of the project, the design process, the installation, and some early results from the functional system.

Project Team

A team of PV experts and educational coordinators was created to ensure project success and to integrate the completed system into local alternative energy education:

Project Manager & System Design	James Leidel Energy Manager Oakland University, Facilities Management
Design & Installation Consultant	Robert Pratt Consultant RGP Pro (formerly of Detroit Edison Company)
Educational Coordinator	Laila Guessous, PhD Professor of Mechanical Engineering Oakland University
Educational Coordinator	Debra Rowe, PhD Professor and Dean Oakland Community College
PV Manufacturer Representative & Design Consultant	Richard Blieden, PhD Director of Project Sales United Solar Ovonics LLC (Uni-Solar)

Educational and Demonstration Components

The long-term public demonstration portion of this project will be greatly enhanced by the two education team members. Professor Debra Rowe of Oakland Community College has been an active proponent and educator of alternative energy technologies for many years. One of her courses, AET 2010 Solar and Other Renewable Energy Systems, will make use of the system as a case study and/or research topic. Professor Laila Guessous of Oakland University is working on an upper division mechanical engineering course in alternative energy which will also make use of the completed project.

A public open house was held on October 3rd, 2003 to coincide with the 8th Annual National Solar Tour organized by the American Solar Energy Society (www.ases.org). The event was a success, with many OU staff, students, and the general public in attendance. The project's close proximity to the manufacturer, a large metropolitan area, and many architectural & engineering firms should ensure that this project will receive continued interest and attention in the coming years.

Lastly, a web site was developed to describe and publicize the project. The site will be further developed as new information on the system performance becomes available. (www.oakland.edu/energy/solar)

Review of PV Materials, Products, & Projects

PV Materials

The PV material with the most real experience "in-the-field" is the **mono-crystalline** cell variety. The long term performance of mono-crystalline PV has been proven over many decades of study and operation. Mono-crystalline PV cells are grown from molten silicon in a process almost identical to that used in computer chip manufacture. It is an energy intensive and costly process with little prospect at becoming more efficient through technological advances.

Poly-crystalline PV was developed as a lower cost manufacturing process and is becoming more common.

Amorphous PV is a newer technology where the active PV material is atomized or otherwise deposited on a substrate with a random structure. The efficiency of amorphous cells is much lower, but the promise of significantly reduced manufacturing cost has generated much interest. There is some concern in the PV industry as to the relative lack of long term reliability data of amorphous products. Also, the much expected drop in costs for amorphous PV has so far failed to materialize.

Building Integrated Design

A fundamental goal of this project was to demonstrate a completely building integrated design. Amorphous PV has been manufactured into roofing products, semi-transparent windows, and various other building façade materials. A local company located in Auburn Hills, Michigan (a mere three miles from the University) produces an innovative selection of amorphous roofing products. United Solar Systems was approached early on during the project development regarding their products, and they offered to provide

their product direct to the University with preferential pricing to help support the project. Therefore, the type of PV product was selected on the basis of a building integrated design approach and the involvement of the local manufacturer, United Solar.

PV Project Experience

A review of successful PV project management practices and past projects was undertaken. References from past installations of the United Solar System's roofing products were also sought out.

Successful PV Projects – TEAM-UP Report

An excellent project management document was published by the Solar Electric Power Association with funding by the US DOE¹. It reviewed 35 PV ventures and highlighted some lessons learned:

- #1 Establish clear program goals and realistic but flexible schedules
- #2 Secure support from upper management
- #3 Know what to expect from the technology
- #4 Integrating PV into new construction
- #5 Use experienced PV installers
- #6 Make interconnection simple
- #7 All systems should be monitored
- #8 Don't be afraid to ask for help

WisconSun.org Articles

Two easy-to-read white papers produced by WisconSUN (<http://www.wisconsun.org>) were useful in the formulation of this project. WisconSUN is a solar promotional organization sponsored by the non-profit Energy Center of Wisconsin. On their web site is a paper describing different options and products for building integrated PV². Another paper discusses the reliability of PV roofing products. It specifically discussed the United Solar shingles.³ The paper noted lamination problems with early United Solar products, but these were resolved.

¹ TEAM-UP Program, "Creating a Successful PV Program: What Every Energy Service Provider Needs to Know", Solar Electric Power Association, Washington DC, December 2001.

² N Wolter, "Options for Integrating PV into Your Building" Wisconsin Solar Use Network (WisconSUN), 1999, updated 2003

³ N Wolter, J Burdick, "Photovoltaic (PV) Roofing Products - Are They Reliable?", Wisconsin Solar Use Network (WisconSUN), April 2000.



Cass High School Installation

In early 2000, Cass High School installed a 2 kilowatt PV shingle array on plywood panels mounted on the school roof. The site was examined, and the science department chair was interviewed to assess the integrity of the Uni-Solar shingle product after multiple years of exposure to the elements. The system was operating well, and the shingle modules seemed to be weathering very nicely with no reported problems.

Fairfield University Project

Another project that was reviewed was a 12.5 kW shingle project installed in 2000 at Fairfield University located in Fairfield, CT. The project was headed by engineering professor, Dean Evangelos Hadjimichael. The design build installer, PS Design, was managed by Parker Coates. Both of these



individuals were contacted for information regarding their project. Nothing negative was reported with the shingles. Their system utilizes three separate models of DC to AC inverters in order to study and compare their operation.

Oakland Community College Installation

Close to OU was another installation of United Solar PV at Oakland Community College – Auburn Hills campus. It consisted of a 4 kW array of framed panels located on rack system mounted on the ground. This system showed evidence of deterioration from the weather. The problems were consistent with those reported in the WisconSUN paper. This project was constructed in 1987, and had over a decade of good service. However, the system had to be disconnected due to multiple shorts at the panels. Robert Pratt, formerly of Detroit Edison Company, wrote a paper describing the three year performance and reliability of this system⁴. He documented an annual efficiency swing caused by seasonal temperature changes inherent with amorphous PV.

Building Integrated PV – Architectural Design Sourcebook

A useful architectural guide book containing multiple case studies was published by the US Department of Energy⁵. Several of the projects described utilized the United Solar roofing products.

⁴ R Pratt, “Three Year Performance and Reliability Analysis of a 4kW Amorphous-Silicon Photovoltaic System in Michigan”, Presented at the Photovoltaic Module Reliability Workshop, Lakewood CO, October 25, 1990.

⁵ P Eiffert and G Kiss, “Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures – A Sourcebook for Engineers”, US DOE, Office of Power Technologies, NREL/BK-520-25272, February 2000.

Design

The following information describes the product selection, design process, including the selection of an appropriate, high visibility site on campus, PV material integration with the selected structure, physical layout, and electrical system design.

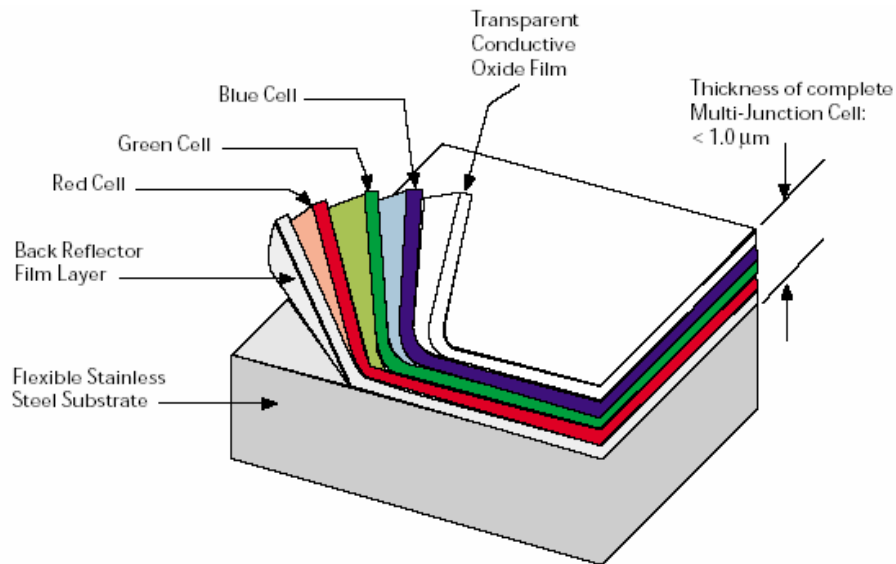
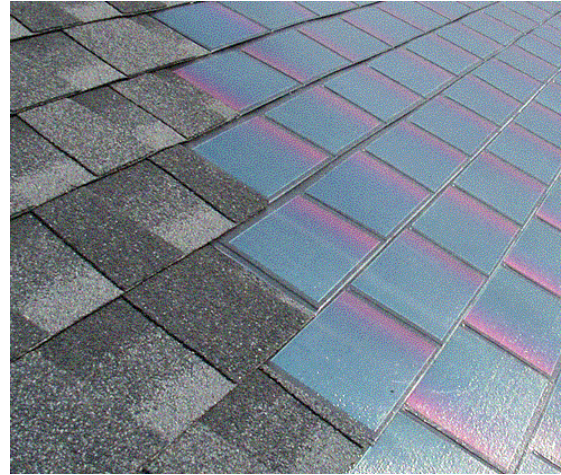
PV Material Selection

As stated above, the material was selected mainly on the basis of building integrated design approach and the preferential pricing and engineering support offered by the local manufacturer, United Solar Systems.

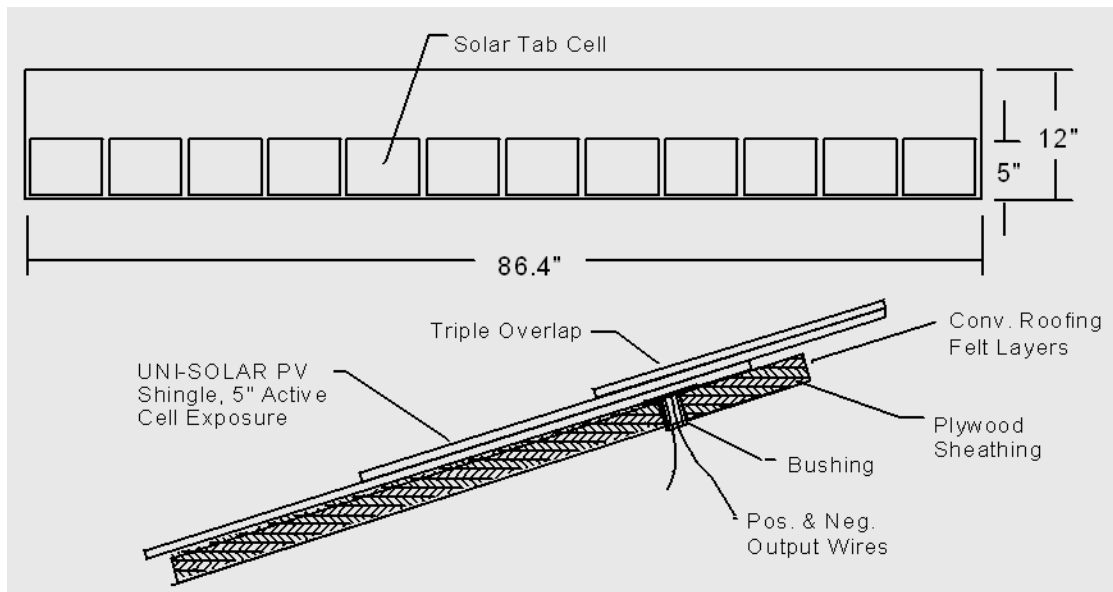
The selected product is the SHR-17 solar shingle which produces 17 Watts of power in full sun at 9 Volts DC and 1.9 Amps DC.

This product is covered by a 20 year warranty on electrical output. It includes product replacement, but not labor, if the power drops below 80% of its originally rated output.

The shingles consist of cut pieces of stainless steel which have multiple layers of different compounds atomized onto its surface. This “Triple Junction” coating is applied to a 16 inch wide piece of flexible stainless steel in a continuous manufacturing process moving through multiple deposition chambers. The entire production line is about the length of a football field.



Triple junction PV diagram



Dimensional diagram of the SHR-17 shingle module

Inverter Selection

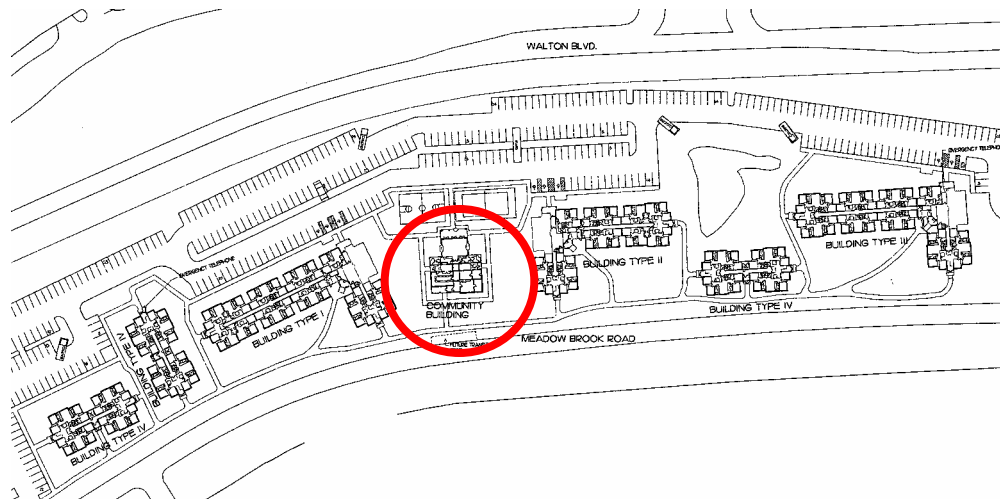
There were several design choices required regarding the electrical system. These choices determined the style of electrical DC to AC inverter required.

- Battery storage?
- Direct grid inter-tie?
- PV array DC voltage, high or low?

To avoid the cost and maintenance of batteries, a direct grid inter-tie system was selected. One of the most prolific inverters world wide is the SMA Sunny Boy. They have several UL listed models which utilize a high voltage DC design. The high voltage reduces the required DC wire size and therefore cost. (www.sma-america.com)

Site Selection

The desired site was to be highly visible by the general public and student population. There were multiple sites which looked promising, but had historical preservation issues requiring a potentially lengthy approval process. The best candidate turned out to be a newly constructed community / office building located at the center of our new University Student Apartments. It is a single story structure, located adjacent to a main campus thoroughfare and sidewalk.



Location of new apartment complex Community Building



Southwest view of the Community Building during construction

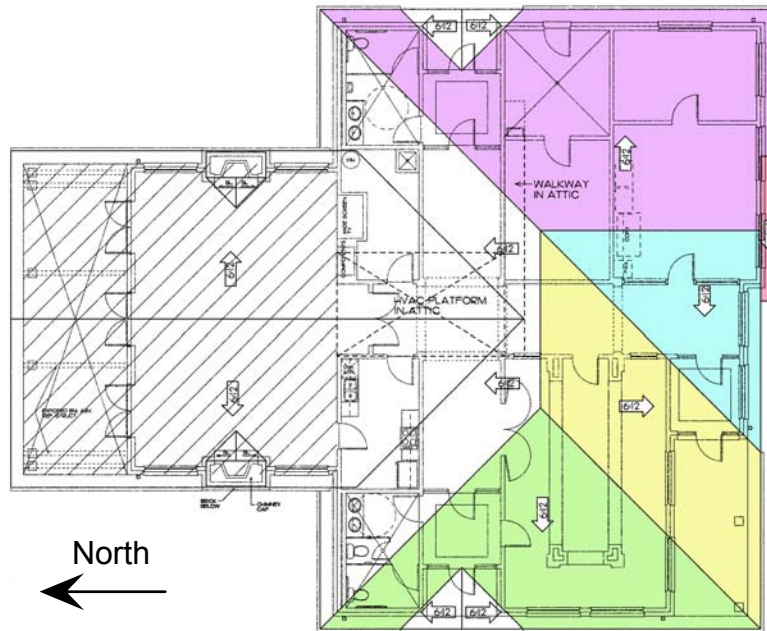
Unfortunately, the grant was obtained too late in the construction process to contract for the installation of the singles prior to the conventional roof installation. This necessitated the removal of the newly installed asphalt shingles.

Four roof sections were utilized to obtain enough surface area to meet the project's specified 10kW minimum capacity. It was a difficult installation, with multiple, non-rectangular shingle arrays. These sections face south, east, and west. Therefore, not all sections will produce their peak output concurrently. The 10kW total installed PV capacity provides for a 7-9 kW equivalent of south facing shingles. For maximum energy output, PV needs to be installed facing due south at an inclination approximately equal to the latitude. A more shallow installation would favor summer energy production while a more vertical inclination favors the low winter sun.

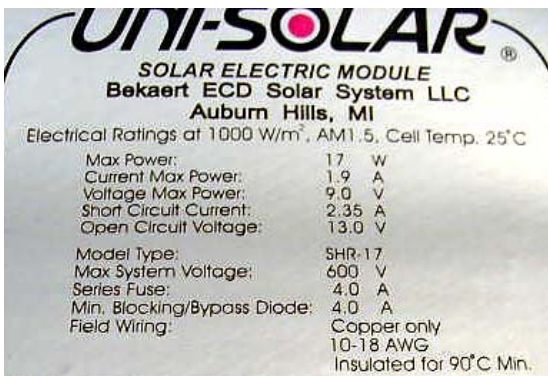
However, this configuration provides an excellent research opportunity to study the output of non-south facing PV. We will be able to document the “de-rating” of a westerly or easterly array.

Roof Layout

The four roof surfaces to receive PV shingles are illustrated below. The violet faces east, the yellow faces south, and both of the blue and green face west.



Uni-Solar PV Material Performance



Single PV module label showing that under full sun (1,000 W / m² and 25°C)

Max Power:	17 W
Current at Max Power:	1.9 A
Voltage at Max Power:	9.0 V
Short Circuit Current:	2.35 A
Open Circuit Voltage:	13.0

During initial 8-10 weeks of operation, the module has higher electrical output than rated output. The output power may be higher by 15%, the operating voltage may be higher by 11% and operating current may be higher by 4%.

Also, there is an 8-10 week initial period where the output is higher than the above rating. This must be accounted for in the system design.

Weather Review

The higher voltages seen during the first 8-10 weeks of exposure to sunlight needs to be accounted for by the electrical system design. Care must be taken to not install a string of shingles with an initial “break-in” voltage above the rating of the selected inverter.

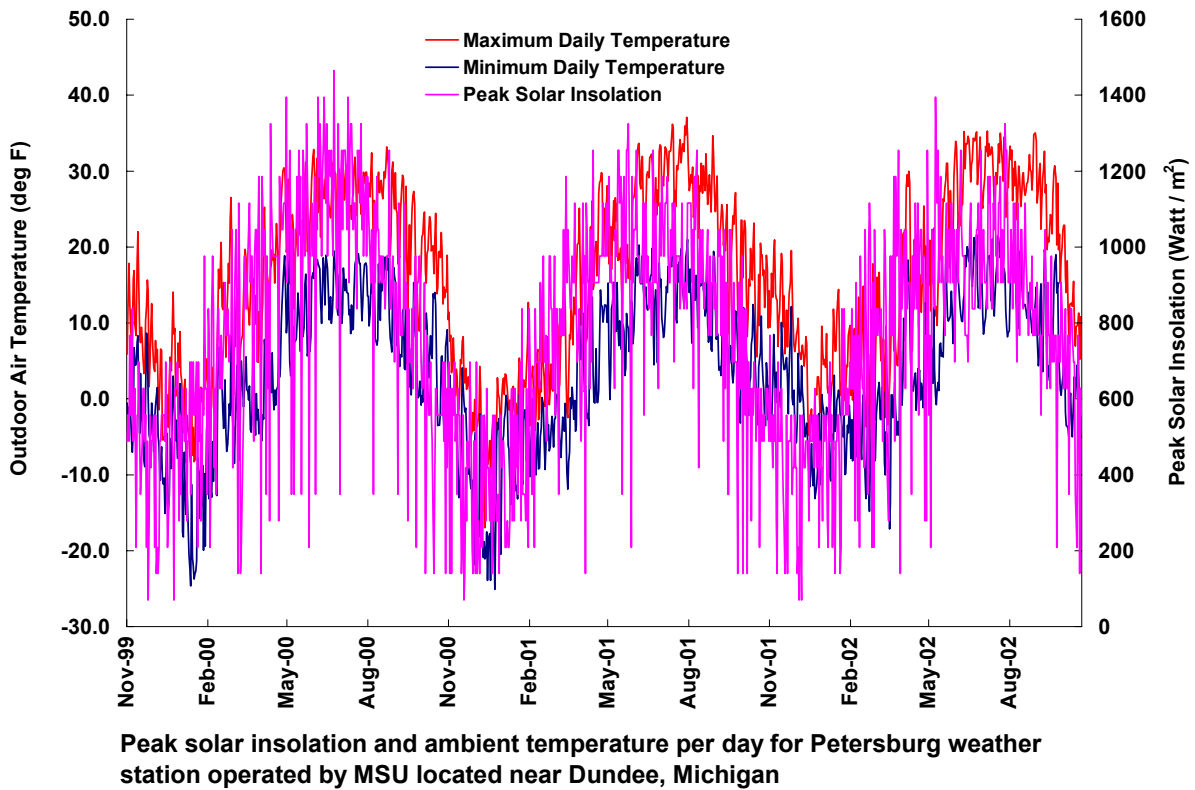
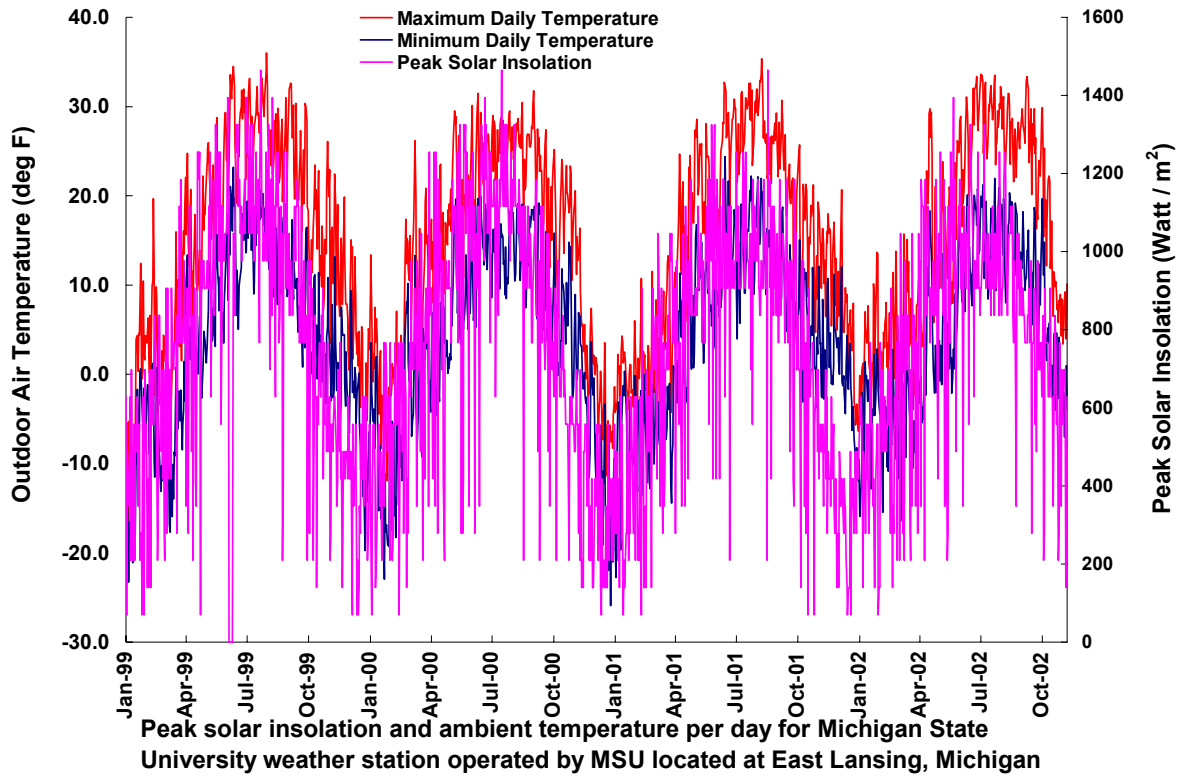
A proper design procedure would be to calculate the worst case scenario producing the highest possible output voltage (corresponding to the highest solar radiation and coldest ambient temperature) and select the number of shingles to match the highest allowable inverter voltage. The “worst case scenario” rating was taken as 1,250 W/m² at -10 °C ambient. If you use this rating during the 8-10 week break in period, you will find that your shingle count per inverter and per DC series string is reduced from a design based on nominal voltage and power levels.

However, to maximize the use of each inverter, it is desirable to load up each inverter as much as practical, but within the limits of the worst case scenario. Therefore, a weather review was undertaken to ascertain the frequency and likelihood of these worst case conditions. The Michigan Automated Weather Network operated by the Michigan State University Extension service (<http://www.agweather.geo.msu.edu/mawn/>) has online data for multiple weather stations across Michigan. Two SE Michigan stations were used to obtain solar radiation flux and temperature data. Although the two closest stations were not in Oakland County, they gave a fairly close approximation of conditions here at Oakland University.

At both locations, from 1999 through 2002, there were no days which concurrently had a -10 °C ambient and 1,250 W/m² solar flux. The temperature used for this calculation was the average of the daily minimum and maximum. A check for conditions in the range of 0 °C and 1,000 W/m² solar flux occurred 8 and 9 times at Petersburg and Lansing, respectively. Below is an illustration of each of the two sites weather conditions.

Therefore, after consultation with SMA technical support in California, the final design allowed for up to 152 shingles on one inverter for a maximum power of 3,476 Watts on the large west roof surface. This exceeds the 2,500 W rating of the 2500U inverter, but should not be seen very often, if ever. In addition, the inverters are located in a temperature controlled telecommunications room where excessive heat sink temperatures should not be a problem under full load conditions.

The highest voltage allowed by the design was for the east and west roof inverters with 40 shingles per string. With 40 shingles, an open circuit voltage of 592VDC will be seen at -10 °C and 1,250 W/m². The design analysis table for three strings of 40 shingles each is shown below, on page 14.



Shingle Counts

Below is a design table for the large west roof inverter connected to 120 shingles, the largest connected load for the entire system. Three strings of 40 shingles wired in series are connected in parallel to the inverter DC input. During the initial 8-10 week break-in period, the voltages and wattages will surpass the inverter rating. Therefore, the shingles were be installed on the roof in late March of 2003, and the electrical connections were not made until the early June.

Uni-Solar SHR-17 String Sizing Table

Inverter:	Sunny Boy 2500U				
Shingles per String:	40	Number of Parallel Strings:	3	Total:	120

Parameter	Units	Conditions	Single Module	Single String	Total For All Strings	Min Limit	Max Limit	Within Limits?
V peak	V DC	+25 °C, 1000 W/m ²	9.00	360		234	550	OK
V peak	V DC	+75 °C, 1000 W/m ²	7.60	304		234	550	OK
V open circuit	V DC	+25 °C, 1000 W/m ²	13.00	520		234	550	OK
V open circuit	V DC	-10 °C, 1250 W/m ²	14.80	592		0	600	OK
I peak	A DC	+25 °C, 1000 W/m ²	1.90		5.7	0	13	OK
I short circuit	A DC	+25 °C, 1000 W/m ²	2.35		7.1	0	13	OK
I short circuit	A DC	+75 °C, 1250 W/m ²	3.10		9.3	0	13	OK
P peak	W DC	+25 °C, 1000 W/m ²	17.10		2,052	0	2710	OK
P peak	W DC	+75 °C, 1000 W/m ²	15.17		1,821	0	2710	OK
P peak	W DC	-10 °C, 1250 W/m ²	22.87		2,744	0	2710	Exceeds Max Power

8-10 Week Break In Period

V peak	V DC	-10 °C, 1000 W/m ²	11.09	443		0	600	OK
V open circuit	V DC	-10 °C, 1000 W/m ²	16.34	654		0	600	Exceeds Max Voltage
V open circuit	V DC	-10 °C, 1250 W/m ²	16.43	657		0	600	Exceeds Max Voltage
I short circuit	A DC	+75 °C, 1000 W/m ²	0.22	8.8		0	13	OK
I short circuit	A DC	+75 °C, 1250 W/m ²	0.27	11.0		0	13	OK
P peak	W DC	+25 °C, 1000 W/m ²	19.74		2,369	0	2710	OK
P peak	W DC	+75 °C, 1000 W/m ²	17.51		2,102	0	2710	OK
P peak	W DC	-10 °C, 1000 W/m ²	21.11		2,534	0	2710	OK
P peak	W DC	-10 °C, 1250 W/m ²	26.39		3,167	0	2710	Exceeds Max Power

+25 °C,
1000 W/m² = Standard Test Conditions

The following table shows the shingle counts and connected power, per roof surface. A total of 586 shingles were used to provide approximately 10 kW total capacity with five inverters. The east roof surface was too large for one inverter, so two were utilized. The same SMA 2500U model was used for consistency and ease of maintenance for all four roof sections.

Shingle Counts and Power per Roof Surface

Roof Face	Color Code	Shingles per String	Number of Strings per Inverter	Number of Inverters	Number of SHR-17	Total Roof Face Nominal Wattage	Individual Inverter Nominal Wattage
West	Green	38	4	1	152	2,584	2,584
West	Blue	40	2	1	80	1,360	1,360
South	Yellow	38	3	1	114	1,938	1,938
East	Violet	40	3	2	240	4,080	2,040
TOTALS				5	586	9,962	

Shingle Counts, Voltage, and Amperage per Roof Surface

Roof Face	Color Code	Shingles per String	Nominal String Operating Voltage	Total String Open Circuit Voltage at -10°C 1,250 W/m ²	Combined String Short Circuit Amperage at 75°C 1,250 W/m ²	Single Inverter Wattage at -10°C 1,250 W/m ³
West	Green	38	342	559	12.4	3,476
West	Blue	40	360	588	6.2	1,830
South	Yellow	38	342	559	9.3	2,607
East	Violet	40	360	588	9.3	2,744

Shingle Counts and Roof Area per Roof Surface

Roof Face	Color Code	Estimated Number of SHR-17	Solar Shingle Area in sq feet	Total Roof Area in sq feet	Percent Power Area	Approx. Asphalt Shingle Area in sq feet
West	Green	152	456	679	67.24%	223
West	Blue	80	240	367	65.4%	127
South	Yellow	114	342	787	43.5%	445
East	Violet	240	720	1,088	66.2%	368
TOTALS		582	1,746	2,921	60.5%	1,175

3 ft²/shingle

Final Roof Layout

As illustrated in the directly table above, 60% of the combined four roof surfaces receive the solar shingles. The remainder received a color matched asphalt shingle. The selected asphalt shingle was the Elk Premium Plus - Sablewood. The entire remaining roof was re-shingled with the Elk Sablewood for color matching. In addition, three PVC

roof vents and two exhaust fan hoods were relocated away from the solar shingled roof surfaces.

The below illustrations detail the shingle layout via AutoCAD drawings of each roof surface. Each string for each inverter is color coded to differentiate the group of series wired shingles. Only the east roof required two inverters. The south and both west roof sections used one inverter each, with 2, 3 or 4 strings per inverter.

The contractor made a field modification to the large west roof (green). The layout was mirrored to allow a straight edge along the southwest corner ridgeline. This provided a much more aesthetically appealing look from the road.

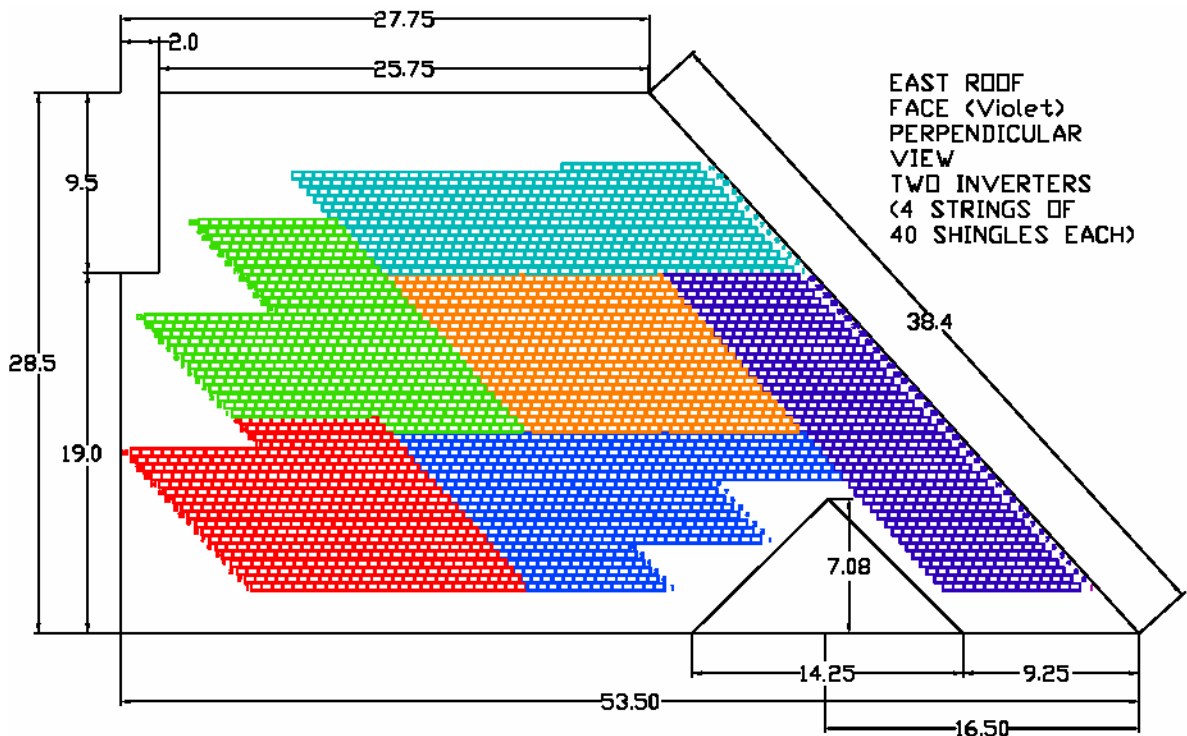
Since a functioning shingle cannot be cut (it is an electrical device), approximately 30 dummy shingles were purchased for cut and fill-in to make our roof layout more visually appealing. These dummies are merely normal shingles which failed to meet the manufacturer's specifications. Their cost was 2/3 of a fully functional shingle module.

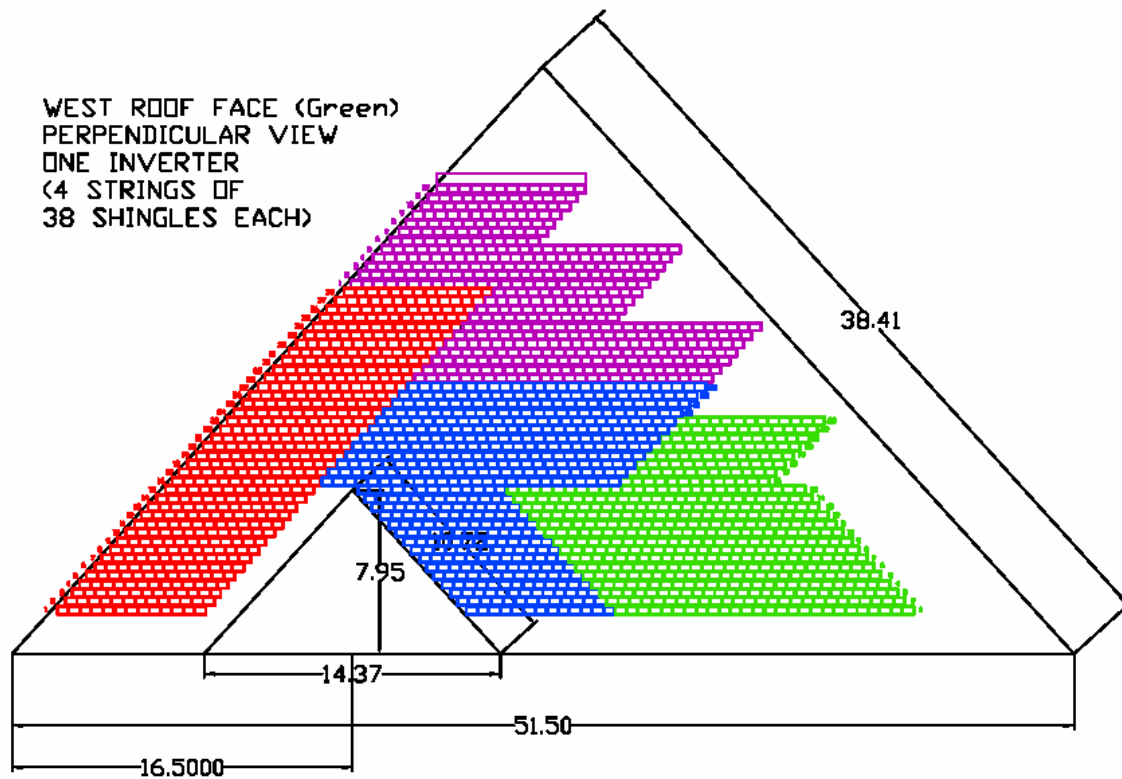
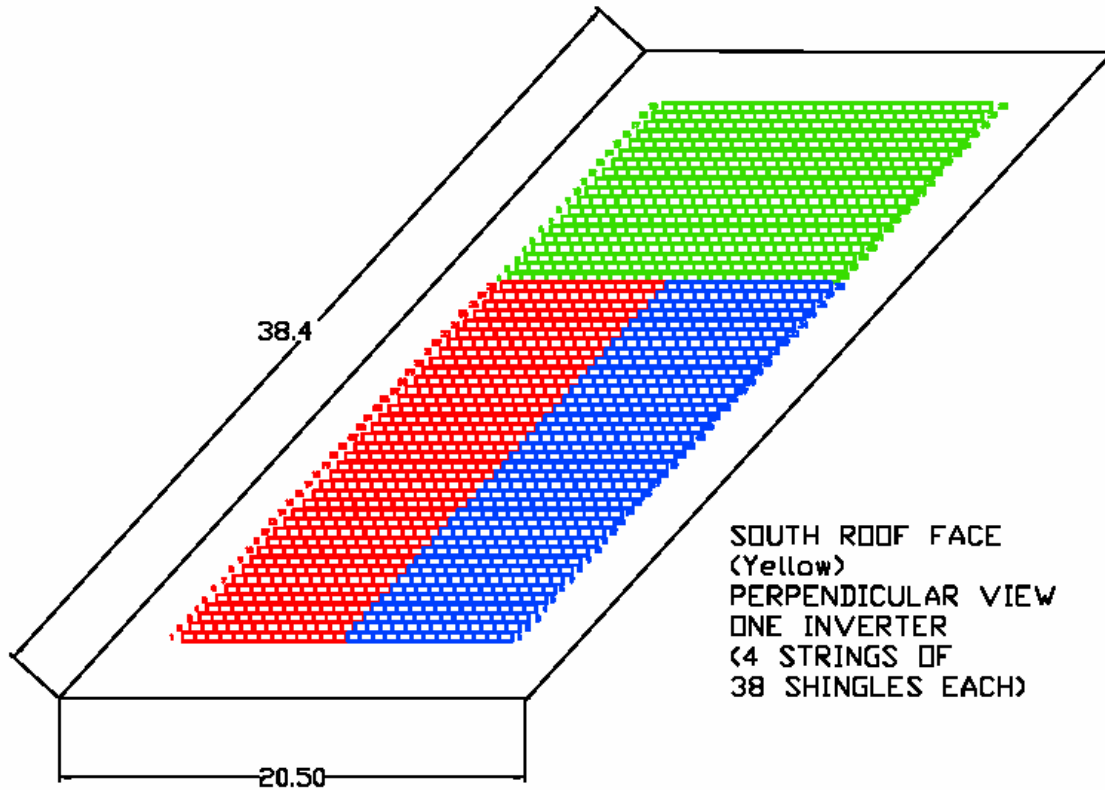
COLOR CODE

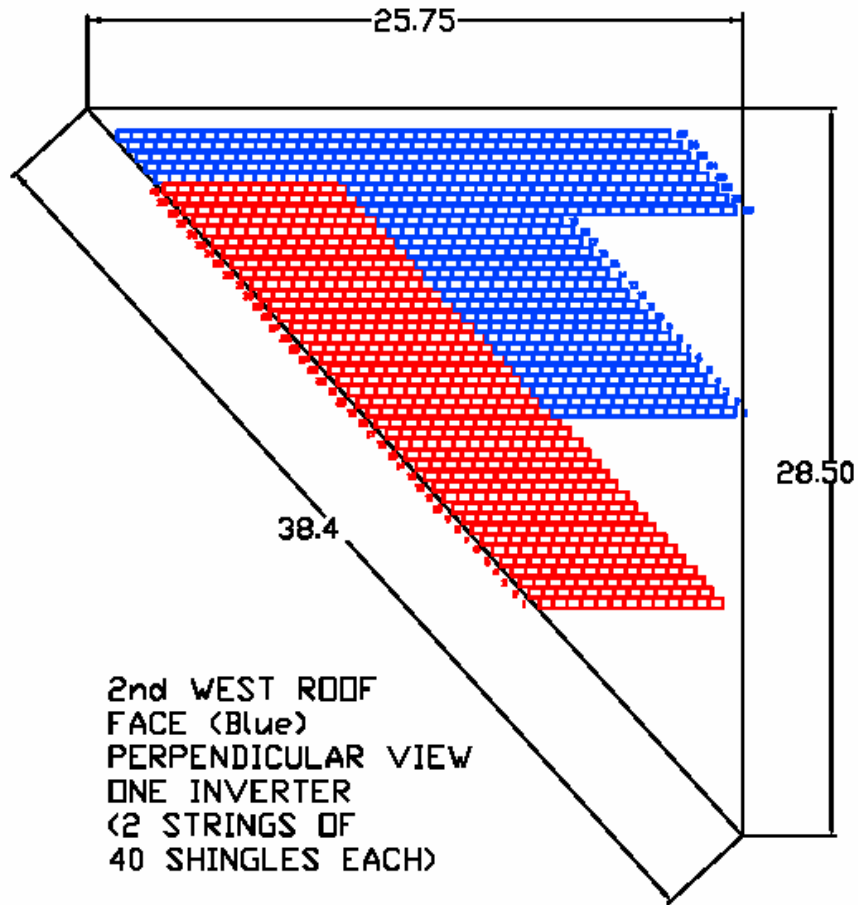
- INVERTER #1 STRING #1
- INVERTER #1 STRING #2
- INVERTER #1 STRING #3
- INVERTER #1 STRING #4

- | | |
|--|-----------------------|
| | INVERTER #2 STRING #1 |
| | INVERTER #2 STRING #2 |
| | INVERTER #2 STRING #3 |

2ND INVERTER ON EAST ROOF ONLY



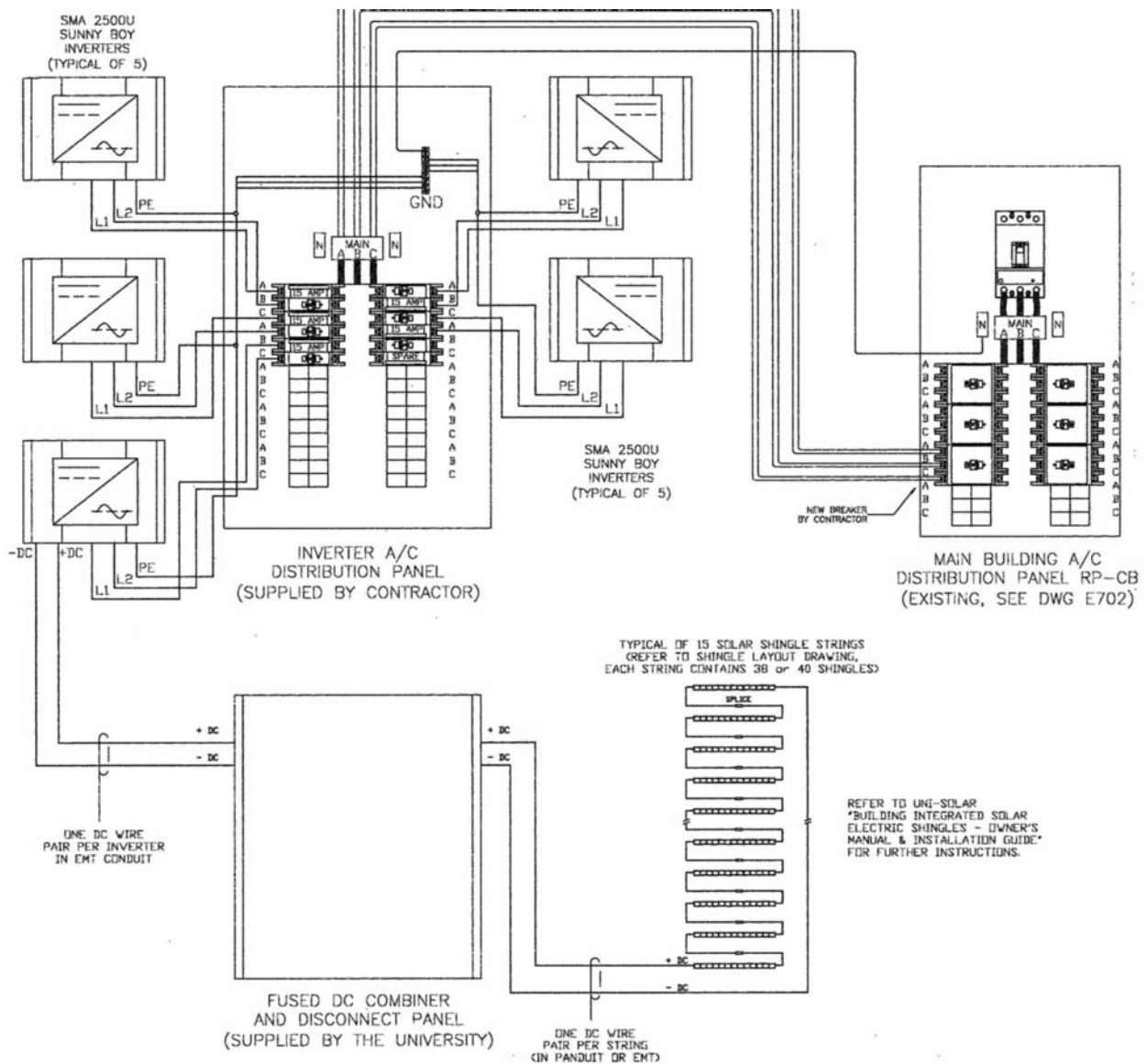




Electrical Design

The schematic below was provided to the contractors at project bid time. The existing three phase 208V main building electrical panel is shown on the right. A new three circuit pole breaker was added to feed a inverter new sub-panel. Each inverter is fed by a two pole 208V breaker from the new sub-panel. All grid synchronization, error checking, and fault protection is accomplished within the inverter. No additional protective devices are required.

A total of 15 series connected shingle strings are wired to a combiner-fuse box located up on the mezzanine level. Each inverter's strings, either 2, 3, or 4, are fused with a 600VDC rated midget fuse and then jumpered together to provide five DC circuits to the inverters located on the first floor. A local DC disconnect is provided for each inverter for servicing and maintenance.



Electrical Schematic

Installation

The photos below will illustrate the installation progress throughout the spring and summer of 2003.



Over 600 shingles stored in electrical room awaiting installation.

March 25th, 2003



Roofing material delivery truck uses its conveyor boom to assist getting the asphalt and PV shingles onto the roof.

March 26th



Three of the four roof faces are 90% complete by the second day.

March 27th



Southwest valley. Work in progress....

Wind picks up and work is halted.

March 27th



Sunshine & clam returns on Monday.

Shingles are nailed the same as conventional asphalt shingles. Care must be taken in nailing to get the nail head flat & square.

April 1



Finished look on south roof.

April 1



Each shingle has a 12 inch wire pigtail which passes through a 1 inch hole drilled through roof sheathing.

April 1



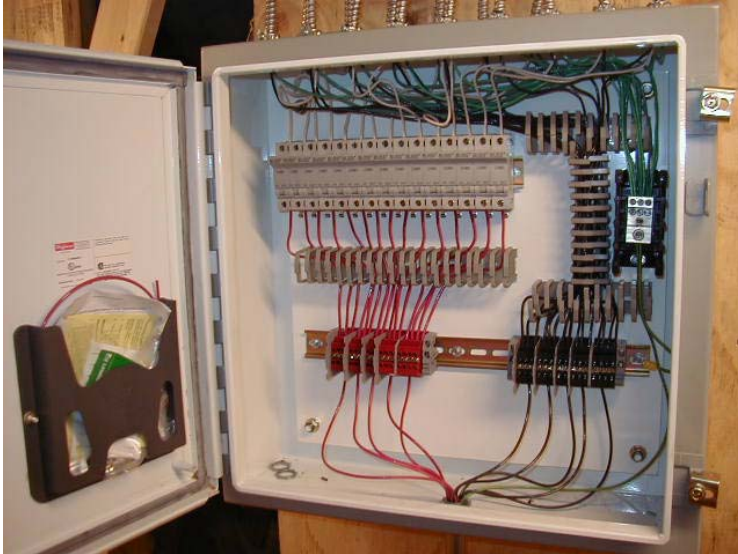
Underneath the roof deck, each row of shingle's wire leads.

April 1



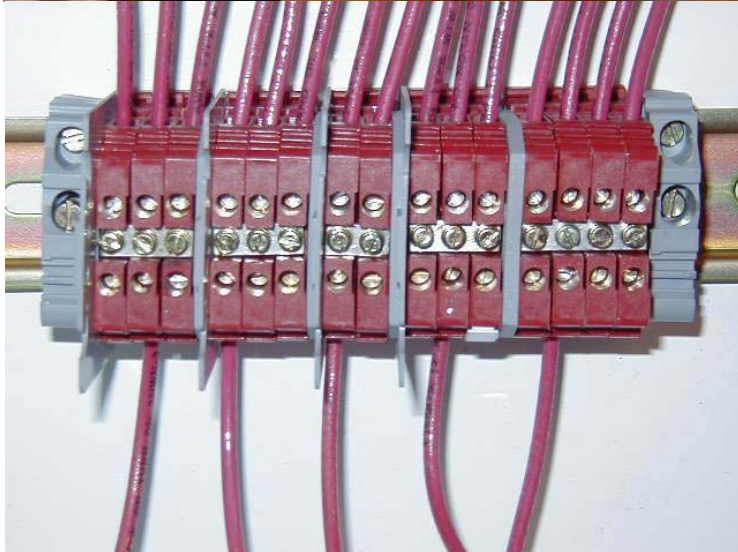
The wires are enclosed in a non-metallic raceway and conduit.

June 2003



The DC fusing and combiner box is mounted on the mezzanine wall.

The 15 strings come in the top where the positive lead is fused with a 600VDC midget fuse. Littlefuse KLDK-3



Each inverter's set of strings is combined by the terminal strip jumper bar located across the top middle of the terminal strips.

The five combined positive leads travel downstairs to the five DC disconnects and five inverters.



Downstairs are the five inverters, each with their own local DC disconnect.



The positive lead of each DC feed is wired through a DC disconnect. It wired through four poles of the switch, in series, to provide for the required rating at 600VDC.

600VDC rated products were very difficult to locate.



Close up view of the SMA Sunny Boy 2500U inverter.

The device is UL listed and rated for a nominal 2,500 Watts.



Interior view of the Sunny Boy inverter. The DC power is converted to 208V AC power.

All grid synchronization and protection is provided by this device.



The AC sub-panel has a two pole breaker for each inverter.

This provides an AC, local disconnect means.



The AC sub-panel is fed by a three pole circuit breaker in the main building feeder panel.

208VAC 3 Φ Y service

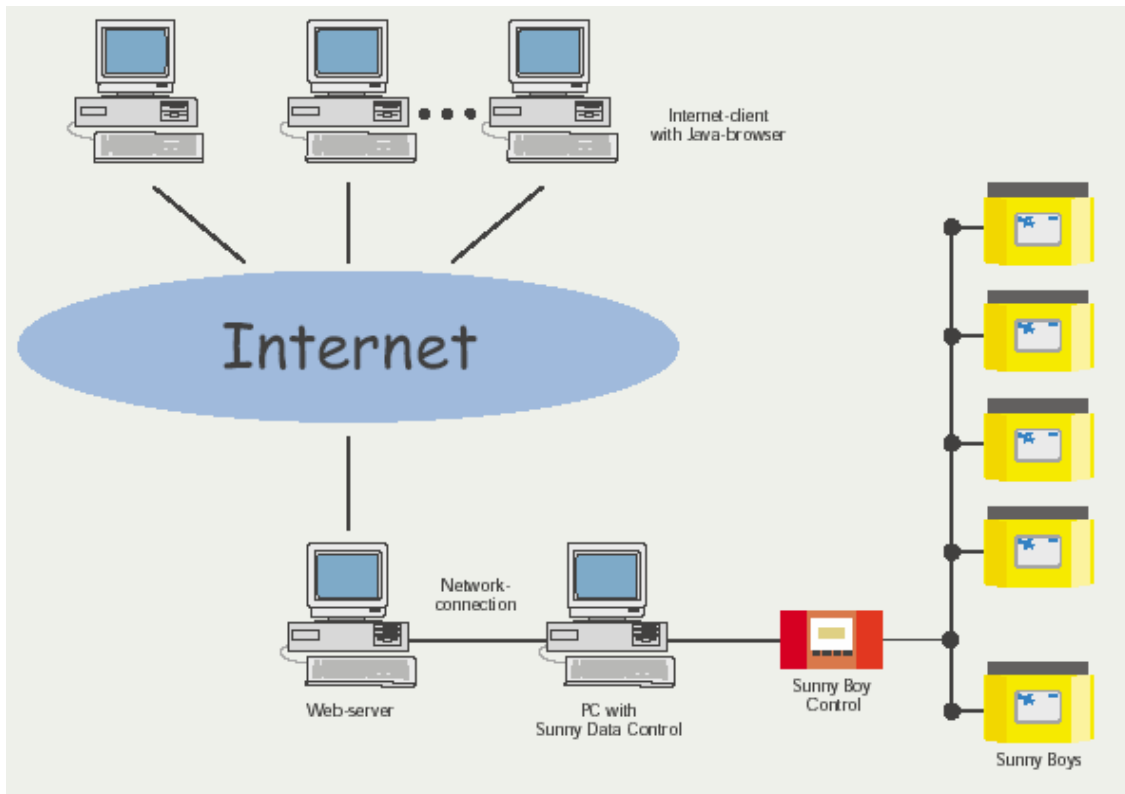
Instrumentation

An SMA Sunny Boy Control Plus module communicates with each of the five inverters. Each inverter's AC and DC power, voltage, current, etc. is monitored and logged by the Control Plus module. In addition, a set of weather sensors were wired to the analog and digital inputs on the Control Plus module. All of this data is then archived and displayed on local computer running the SMA Sunny Data Control software.

Lastly, an internet web server was installed to allow remote HTML interface to the archived data. This will be programmed and commissioned by the OU engineering department in the coming weeks.

Weather Instrumentation Table

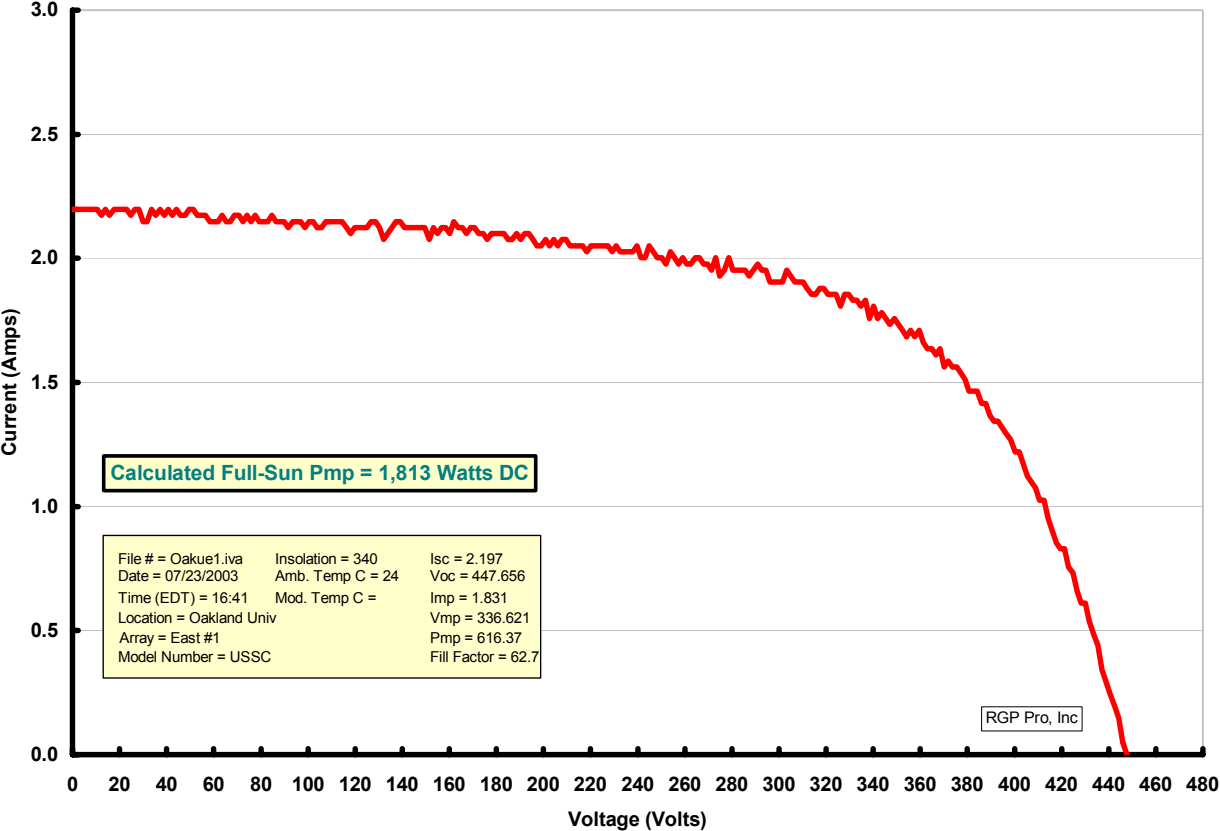
Measured Item	Sensor Type	Qty	Manufacturer	Model
Solar Irradiation	Pyranometer	3	Lycor	220SA
	millivolt adapter	3	Lycor	
Wind Speed and Direction	Anemometer	1	Davis Instruments	#7914
	with mounting mast	1	Davis Instruments	
Ambient Temp	Platinum RTD	1	Pyranomation	R1T185L484-004-T3M012
	with sun sheild	1	Davis Instrm.	#7714
Roof Shingle Temp	Platinum RTD	3	Pyranomation	R1T185L484-004-T3M012
	with 4-20mA transmitter	3	Davis Instruments	
AC Electric Circuits	8 channel power meter	1	Veris Industries	
	Data Acquisition & Communications w/Display	1	SMA	Sunny Control Plus



Communication Schematic

System Performance

A system test was performed by Robert Pratt of RGP, Pro. Mr. Pratt, formerly of Detroit Edison, is one of Michigan’s PV experts. He connected each inverter’s combined shingle strings to a PV testing device which measured the volt-amp response of the array with varying impedance. A sample chart is shown below for the east roof, section #1 under 340 W/m² solar flux.



Voltage – current response of east roof, array #1 under varying impedance

Under the given ambient conditions, the voltage peaks at 447VDC. This would be the open circuit voltage at infinite impedance. The current peaks at about 2.2 amps, corresponding to the short circuit current, or zero impedance.

Similar curves were taken for each of the inverter shingle arrays, and the results are tabulated below. It was a partly cloudy day, so the light level was measured concurrently as each volt-amp curve was recorded. The measured levels were then normalized to standard conditions of 1,000 W/m² and 25°C. The total of these normalized values was 8,558 Watts as compared to the design power of 9,962 at the same standard conditions. Therefore, the measured performance is 86% of the expected design. From past PV project experience, this was regarded to be a very respectable value by Mr. Pratt. This type of analysis will be performed and tracked as

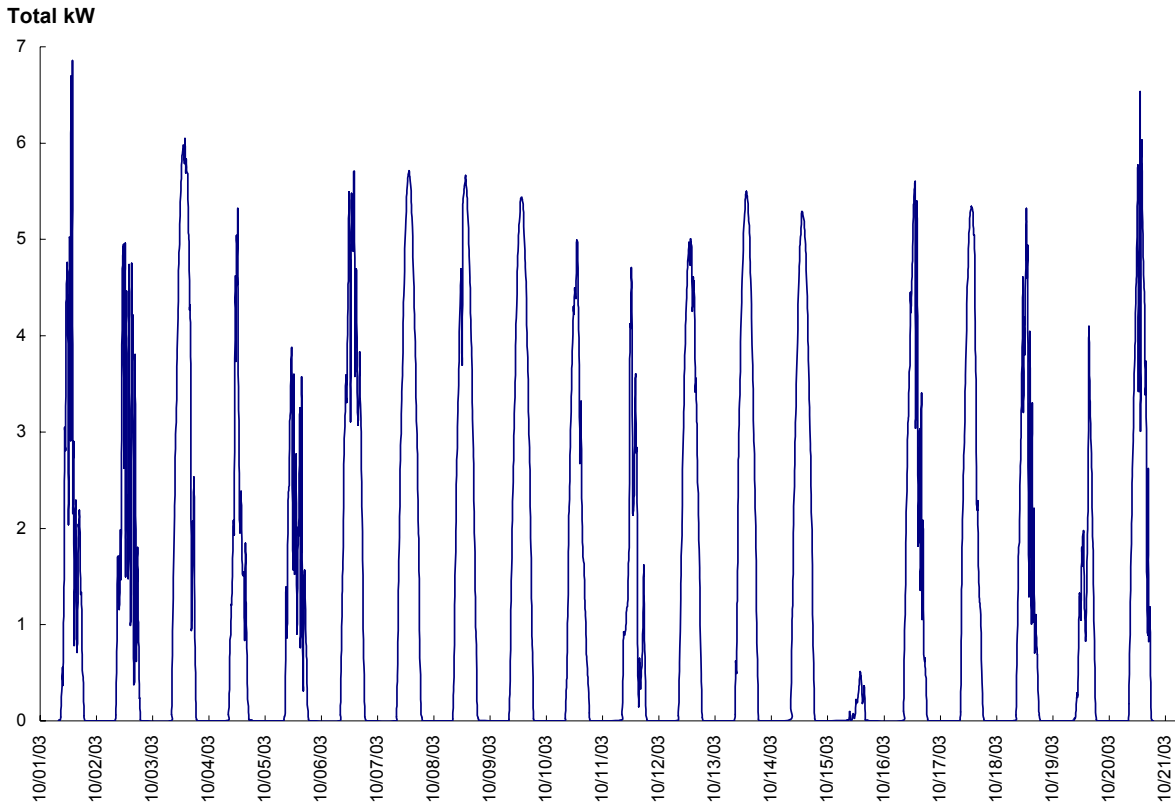
the system ages. Lastly, these are the “ideal” values. Once the system voltage drops and inverter losses are accounted for, estimated peak AC output is about 7.5 kW

Measured and Normalized Array Power

===== Design Calculations =====						
Measured	Measured	Calculated	As-Built	As-Built	As-Built	As-Built
Insolation	Pmp	1 kW/m ²	STC ¹	STC ²	+75°C	-10°C
<u>W/m²</u>	<u>Watts</u>	<u>Watts</u>	<u>Watts</u>	<u>Watts</u>	<u>Watts</u>	<u>Watts</u>
340	616	1,812	2,040	2,052	1,821	2,195
315	509	1,616	2,040	2,052	1,821	2,195
690	1,004	1,455	1,938	1,949	1,730	2,085
580	768	1,324	1,360	1,368	1,214	1,463
690	1,622	<u>2,351</u>	<u>2,584</u>	<u>2,599</u>	<u>2,307</u>	<u>2,780</u>
	Total	8,558	9,962	10,020	8,893	10,718

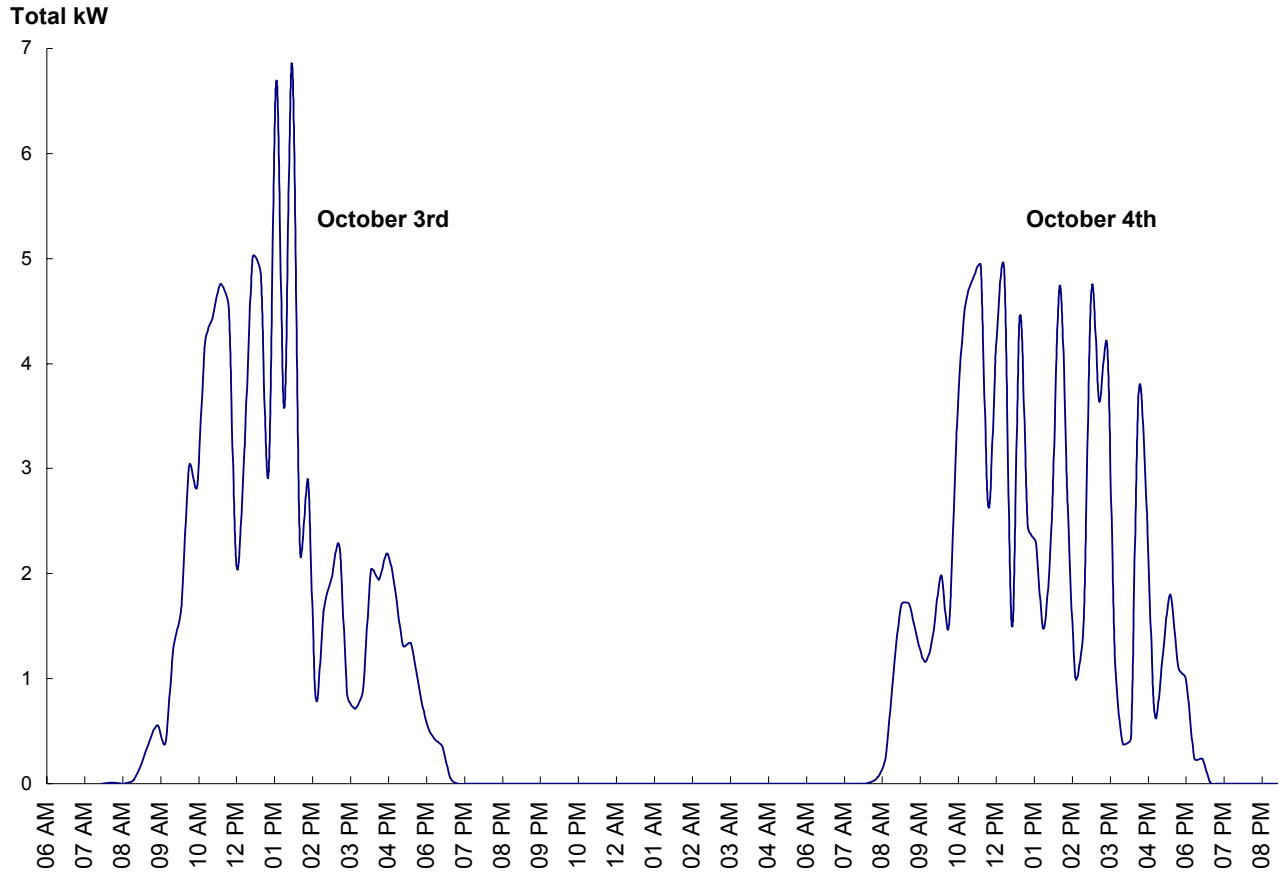
Data recorded 7-23-03 and analyzed by RGP Pro, Inc

Next, the output of the inverters themselves is tracked via the Sunny Data Control Plus module. An illustration of the total system power output throughout the month of October is shown below. The weather instruments were not yet on-line. The peak output almost reached 7 kW, but was most often in the 5kW range.



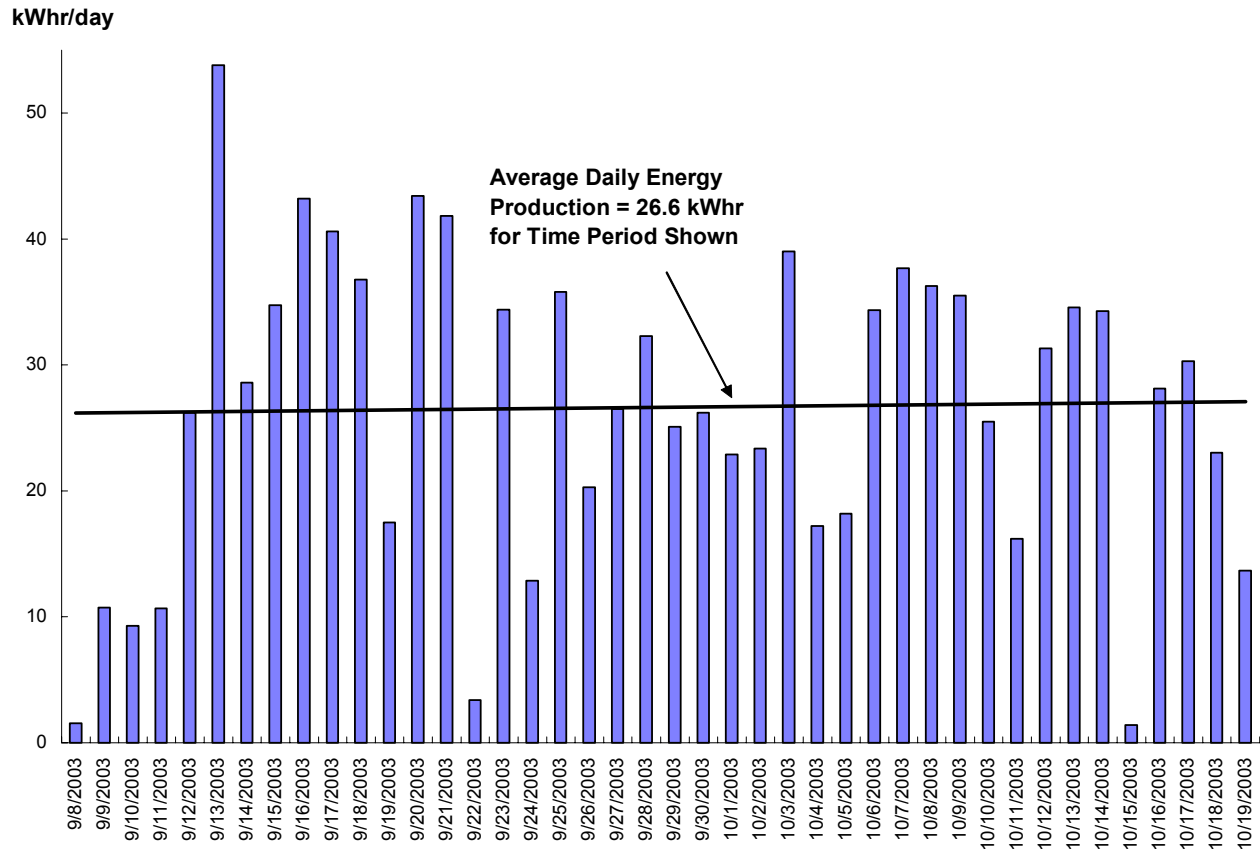
Total PV system power output for October 2003

A more detailed illustration of the daily performance can be seen below for October 3rd and 4th. Varying cloud cover produces a variable system output between zero to seven kilowatts.



Two day power output for total PV system, October 3rd & 4th, 2003

The daily energy production from September 8th through October 16th, 2003 is illustrated on the following figure. Average daily production during this time period was 26.6 kW hours. This would correspond to approximately 10,000 kW hours per year. At a \$0.10 per kilowatt hour electrical rate, this would provide for a \$1,000 per year cost savings.



Daily energy production from September 8th through October 16th, 2003

Conclusion

The system was successfully installed and is performing within expectations. As data accumulates on the system performance and weather conditions, the Oakland University engineering department will assist with further study and analysis.

The public demonstration goals were also achieved. So far to date there have been five articles published in local and city newspapers covering the project. The open house and project web site have generated a fair number of inquiries and requests for more information.

The State of Michigan should continue to pursue additional public demonstration projects. But more importantly, the State should encourage additional solar and renewable energy investment through additional incentives such as direct project support through tax incentives and rebates, net metering, and a minimum state-wide renewable energy portfolio requirement.