Document Title:

Green Roof Team

Solar PV Feasibility Report

Green Roof Team Limited Partnership
Southern Illinois University Carbondale

Last Updated: 05/11/2021

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Acknowledgements

The Green Roof Team appreciates the support of stakeholders across campus towards our mission of transforming the SIU Green Roof into a multidisciplinary innovation hub. Most importantly, recognizing the SIU Advanced Coal and Energy Research Center for their sponsorship of the Green Roof Team and support towards the renewable energy initiatives. The SIU Plant & Service Operation, specifically Justin Harrell and Brian Gorecki, for their feedback and progressing our project. The SIU Sustainability Office for offering the Green Fund Grant which partially paid for the project. The SIU Foundation for launching the SalukiFunder and SIU Day of Giving Campaigns for fundraising towards the project. Dr. John Groninger, associate Dean of the College of Agriculture, for his support towards the Green Roof Project which enabled the renewable energy initiatives to grow and develop. And the SIU Research Park for offering the University Innovation Fellows program and handling the accounting for the project whom of which made all Green Roof activities possible.

Executive Summary

The Green Roof Team formed during the 2019-2020 academic year for the purpose of accomplishing the Green Roof Project. The goal was to transform the SIU Green Roof, an existing green space, into a multidisciplinary innovation hub for academic research across campus. One solution for encouraging researchers to know and become inspired to use the SIU Green Roof was by showcasing opportunities. As a result, the Green Roof Team pursued different projects including an autonomous irrigation system, micro wind turbine, and photovoltaic system.

The Green Roof Team under the University Innovation Fellows program secured stakeholder support across campus towards the Green Roof Project. One important aspect of the project explored renewable energy initiatives from wind and solar energy. SIU Carbondale is a well-known university for its research in clean coal and operating a coal-fired power plant on campus which produces steam, which is used to heat campus buildings, produce chilled water for cooling, and to generate electricity. As a result, the team is bringing a new resource with the intent of expanding and sustaining for future years, student engagement hands-on with renewable energy.

The Green Roof Team's Renewable Energy Initiative is encompassed in a two year plan before sustaining for future renewable energy related opportunities for undergraduates:

2020-2021 Install a temporary wind turbine on the SIU Agriculture Building.

2021-2022 Acquire the finances for wind-solar hybrid system and grid-tied photovoltaic systems while training future renewable energy students on campus.

2021-2022 Provide documentation, support, and finances for future renewable energy projects for a new Registered Student Organization focused on the implementation of renewable energy on-campus.

The Renewable Energy Initiative is focused on providing Salukis with the hands-on training and certification of the implementation of renewable energy, or consultation.

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Solar Feasibility Study

This project is a subproject of the Green Roof Project focused on the implementation of photovoltaic systems for inspiring students and faculty to utilize the SIU Green Roof for their own research projects and promoting clean energy projects on campus. The chosen site is Roof Area D of the Agriculture Building shown in Figure 1 Project Site - Roof Area D. More images can be found in Appendix A: Roof Area D Images.

The site was chosen for the proximity to the SIU Green Roof as described previously as well as recommended by SIU Plant & Service Operations due to the roof warranty's expiration in 2029 is more suitable in comparison to the roof between Roof Area D and the SIU Green Roof, Roof Area C, which expired in 2009 and will be reroofed prior to Roof Area D.

According to the original construction drawings, Roof Area D has a roof slope ratio of 1/11 or approximately a 5 degree slope.

Figure 1 Project Site - Roof Area D

Sun Path Diagram

A sun path diagram shows how the sun will impact a specific site and building throughout the year. We can read the solar azimuth and altitude from Figure 2 Sun Path Diagram by PSO.

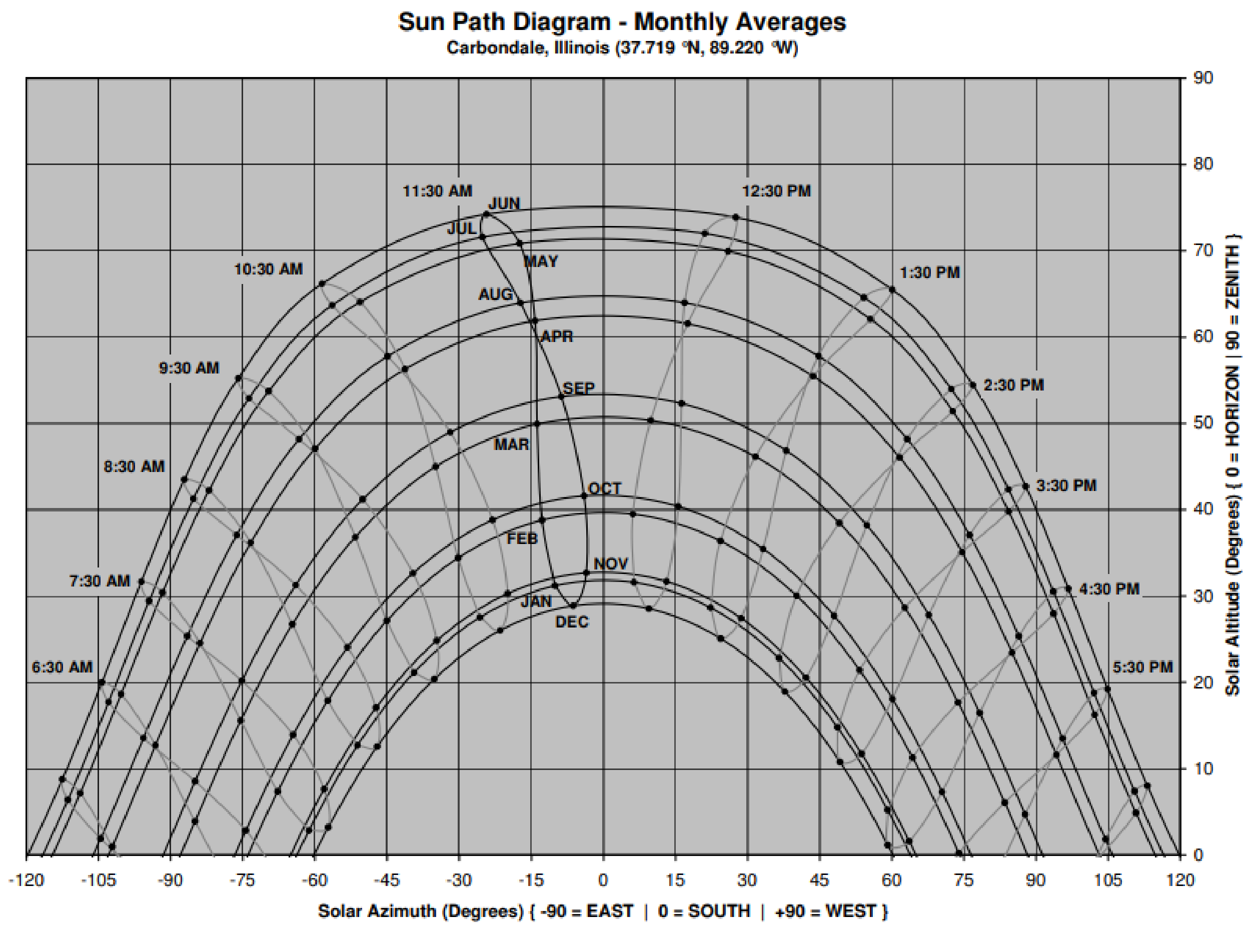


Figure 2 Sun Path Diagram by PSO

PVWatts Calculator by NREL

PVWatts is an online program by the National Renewable Energy Laboratory (NREL) for estimating the energy production and cost of energy for a grid-connected photovoltaic system.

RESULTS

105,051 kWh/Year*

System output may range from 100,681 to 110,461 kWh per year near this location.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	3.14	6,159	558
February	3.94	7,021	636
March	4.70	8,702	788
April	5.55	9,765	885
May	6.09	10,840	982
June	6.65	10,993	996
July	6.56	11,074	1,003
August	6.31	10,505	952
September	5.73	9,426	854
October	4.79	8,728	791
November	3.57	6,571	595
December	2.70	5,268	477
Annual	**4.98**	**105,052**	**$ 9,517**

Location and Station Identification

Requested Location	62901, USA
Weather Data Source	Lat, Lon: 37.73, -89.22 0.4 mi
Latitude	37.73° N
Longitude	89.22° W

PV System Specifications *(Residential)*

DC System Size	75.8 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

Figure 3 PV Watts Feasibility Study Results

PVGIS by European Commission

PVGIS is a web application to understand the solar radiation for a specific location and determine the photovoltaic system's energy production.

PVGIS-5 estimates of solar electricity generation:

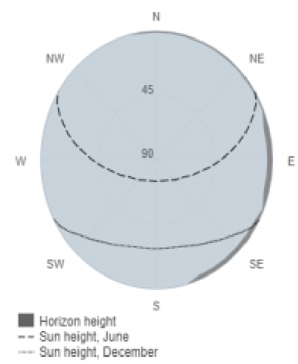
Provided inputs:

Latitude/Longitude:	37.713, -89.222
Horizon:	Calculated
Database used:	PVGIS-NSRDB
PV technology:	Crystalline silicon
PV installed:	1 kWp
System loss:	14 %

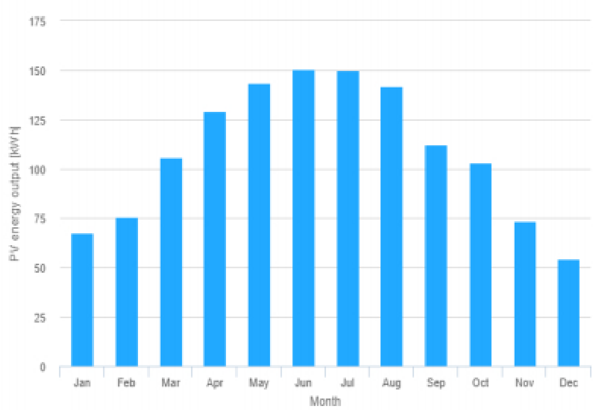
Simulation outputs

Slope angle:	10 °
Azimuth angle:	0 °
Yearly PV energy production:	1306.85 kWh
Yearly in-plane irradiation:	1685.39 kWh/m²
Year-to-year variability:	37.67 kWh
Changes in output due to:	
Angle of incidence:	-3.24 %
Spectral effects:	NaN %
Temperature and low irradiance:	-6.82 %
Total loss:	-22.46 %

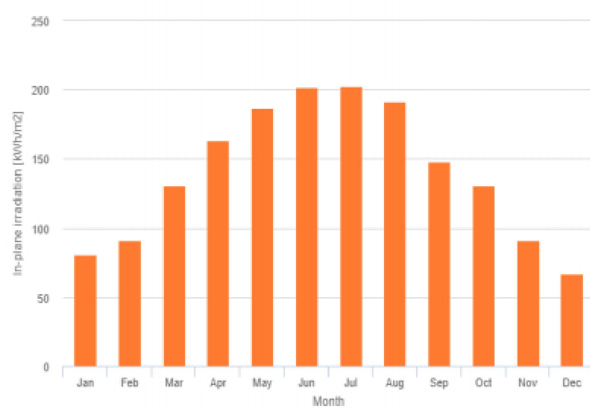
Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:



Monthly in-plane irradiation for fixed-angle:



Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	67.5	80.7	6.2
February	75.9	91.0	7.4
March	105.6	130.7	12.4
April	129.1	163.6	8.7
May	143.3	186.8	12.2
June	150.7	201.8	8.9
July	149.8	202.6	8.1
August	141.8	191.8	7.9
September	112.4	148.3	16.4
October	102.9	130.5	11.9
November	73.3	90.8	8.2
December	54.6	66.8	6.0

E_m: Average monthly electricity production from the given system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Figure 4 PVGIS Feasibility Study Results

ArcGIS by ESRI

Using the Area Solar Radiation tool in ArcMap, we found the areas on West campus with the greatest potential for future solar panel projects based on 2020 solar radiation data. The Area Solar Radiation tool calculates the incoming solar radiation from a raster surface in Wh/m^2 and accounts for atmospheric effects, site latitude and elevation, steepness (slope) and compass direction (aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding topography (ESRI). The results of the solar radiation analysis indicate that the Agriculture Building is suitable for the current solar project as it has a high level of incoming solar radiation, and the buildings most appropriate to expand solar panels to include the Student Services Building, Parkinson, Anthony, Allyn, and Shryock on old West Campus, and the Life Science Buildings.

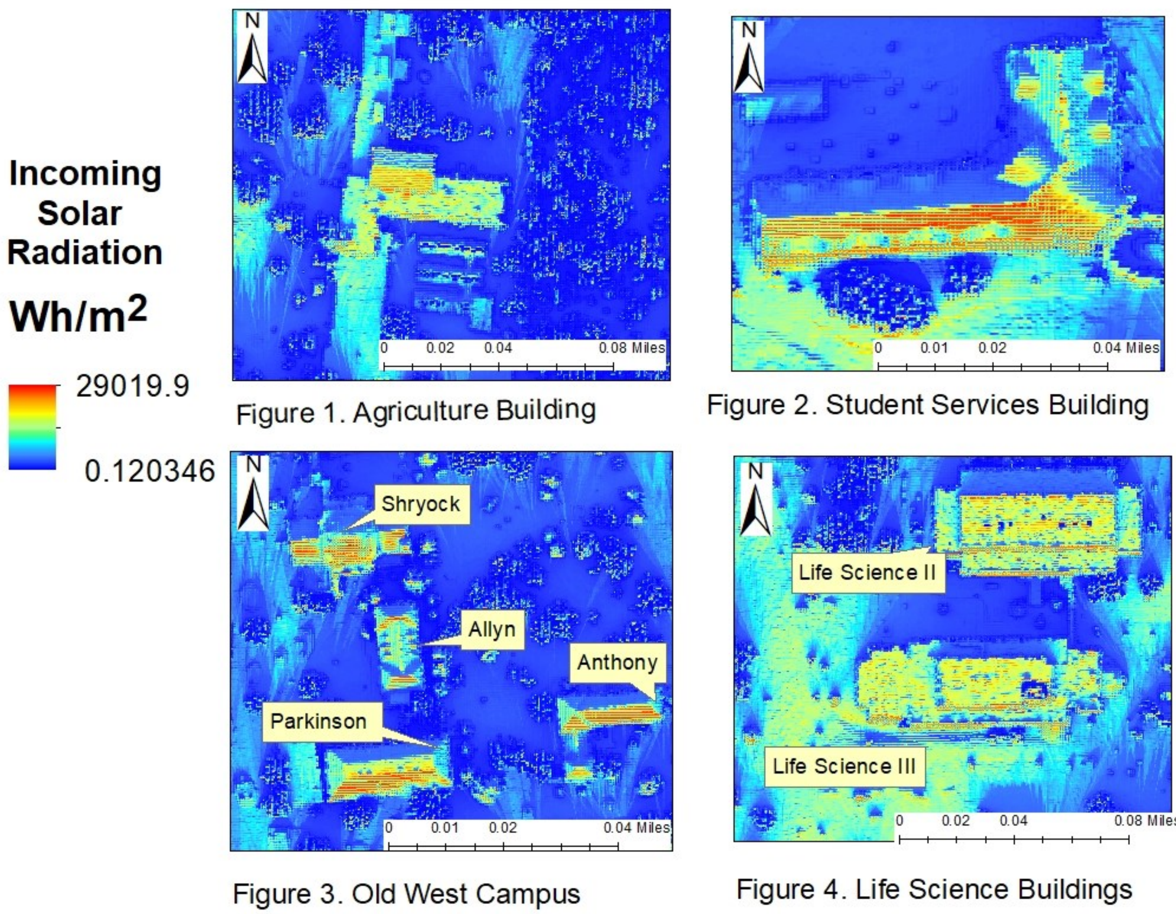


Figure 5 GIS Feasibility Study Results

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HelioScope: Advanced Solar Design Software

HelioScope is a web-based photovoltaic system design software where we designed and simulated the system's efficiency. Figure 6-Figure 8 below show the results for a designed 10kW system on the SIU Agriculture Building's Roof Area D. Results for a 3kW and 5kW system can be found in Appendix C: Feasibility Study - HelioScope. Additionally, the manufacture's specifications for the items used can be found in Appendix D: Manufacturer's Specification.

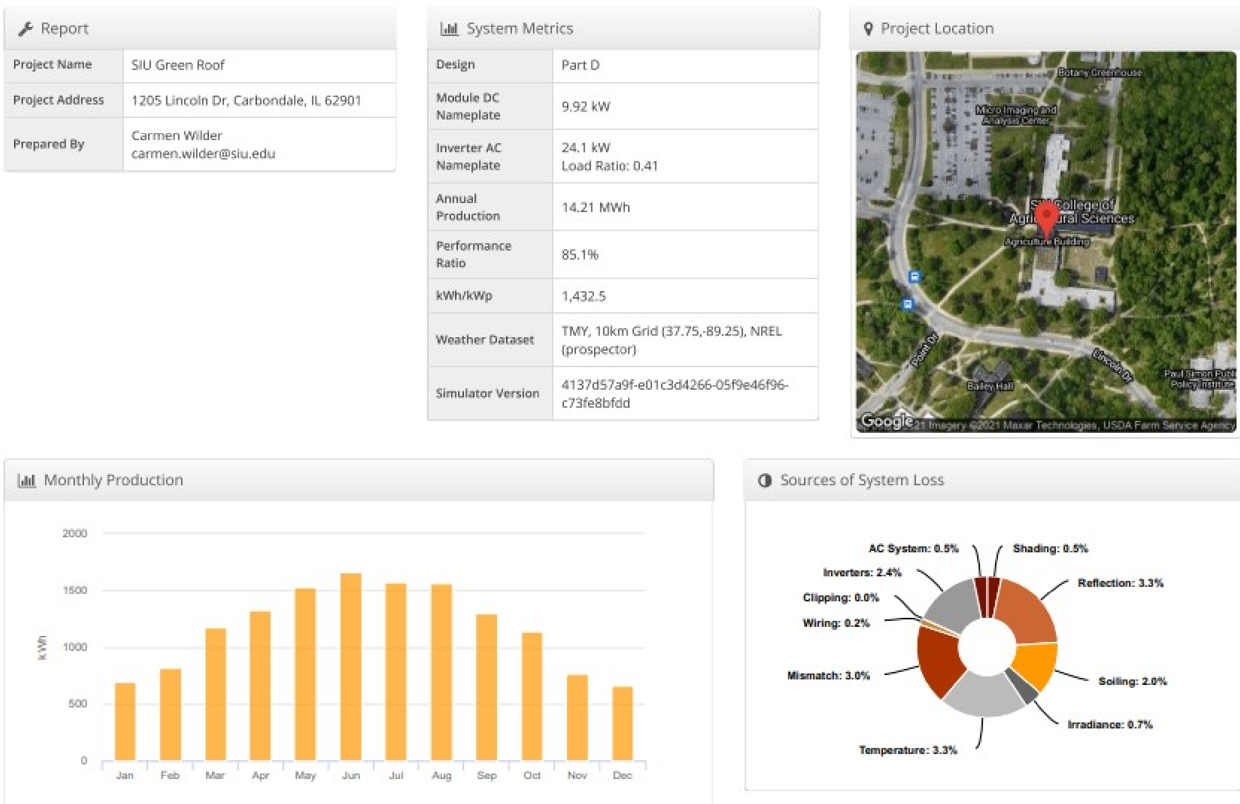


Figure 6 Helioscope Overview Results

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,565.1	
	POA Irradiance	1,683.1	7.5%
	Shaded Irradiance	1,674.5	-0.5%
	Irradiance after Reflection	1,618.9	-3.3%
	Irradiance after Soiling	1,586.5	-2.0%
	Total Collector Irradiance	**1,586.5**	**0.0%**
Energy (kWh)	Nameplate	15,748.5	
	Output at Irradiance Levels	15,640.7	-0.7%
	Output at Cell Temperature Derate	15,127.8	-3.3%
	Output After Mismatch	14,673.6	-3.0%
	Optimal DC Output	14,638.7	-0.2%
	Constrained DC Output	14,638.7	0.0%
	Inverter Output	14,281.4	-2.4%
	Energy to Grid	**14,210.0**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		16.8 °C
	Avg. Operating Cell Temp		24.6 °C
Simulation Metrics			
	Operating Hours		4665
	Solved Hours		4665

Condition Set

Description	Condition Set 1
Weather Dataset	TMY, 10km Grid (37.75,-89.25), NREL (prospector)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model

Temperature Model Parameters

Rack Type	a	b	Temperature Delta
Fixed Tilt	-3.56	-0.075	3°C
Flush Mount	-2.81	-0.0455	0°C

Soiling (%)

J	F	M	A	M	J	J	A	S	O	N	D
2	2	2	2	2	2	2	2	2	2	2	2

Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%

Module Characterizations

Module	Uploaded By	Characterization
TSM-PD14 320 (May16) (Trina Solar)	Folsom Labs	Spec Sheet Characterization, PAN

Component Characterizations

Device	Uploaded By	Characterization
Sunny Tripower 24000TL-US (SMA)	Folsom Labs	Modified CEC

Components

Component	Name	Count
Inverters	Sunny Tripower 24000TL-US (SMA)	1 (24.1 kW)
Strings	10 AWG (Copper)	2 (83.5 ft)
Module	Trina Solar, TSM-PD14 320 (May16) (320W)	31 (9.92 kW)

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	-	5-19	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	10°	180°	1.5 ft	1x1	31	31	9.92 kW

Shading by Field Segment

Description	Tilt	Azimuth	Modules	Nameplate	Shaded Irradiance	AC Energy	TOF[2]	Solar Access	Avg TSRF [2]
Field Segment 1	10.0°	180.0°	31	9.92 kWp	1,674.5kWh/m²	14.2 MWh[1]	93.4%	99.5%	92.9%
Totals, weighted by kWp			**31**	**9.92 kWp**	**1,674.5kWh/m²**	**14.2 MWh**	**93.4%**	**99.5%**	**92.9%**

[1] approximate, varies based on inverter performance
[2] based on location Optimal POA Irradiance of 1,802.2kWh/m² at 33.8° tilt and 183.0° azimuth

Solar Access by Month

Description	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Field Segment 1	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%	99%
Solar Access, weighted by kWp	98.9%	99.5%	99.6%	99.6%	99.6%	99.6%	99.6%	99.6%	99.6%	99.6%	99.2%	98.6%
AC Power (kWh)	694.5	822.1	1,177.6	1,327.2	1,530.3	1,665.1	1,576.9	1,561.5	1,296.1	1,138.9	760.8	659.1

Figure 7 Helioscope Feasibility Study Results

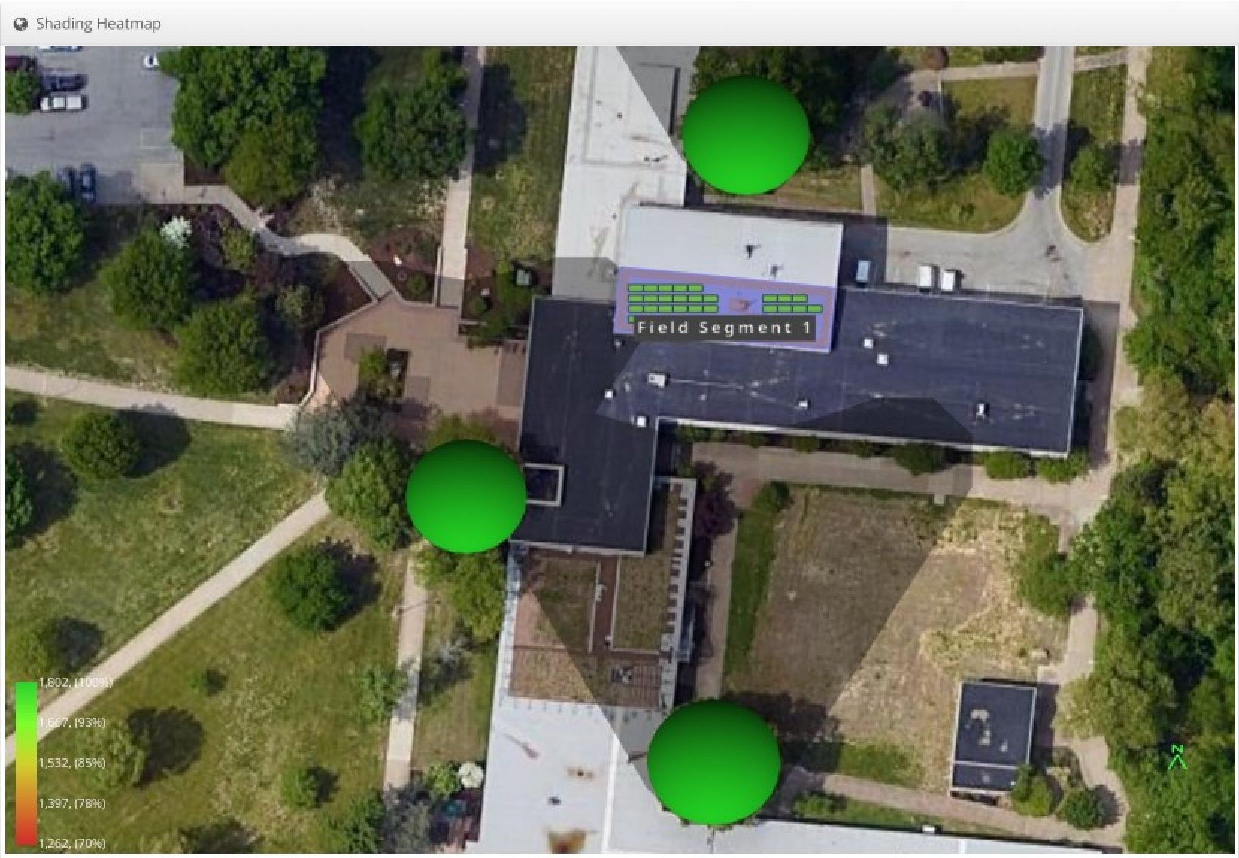
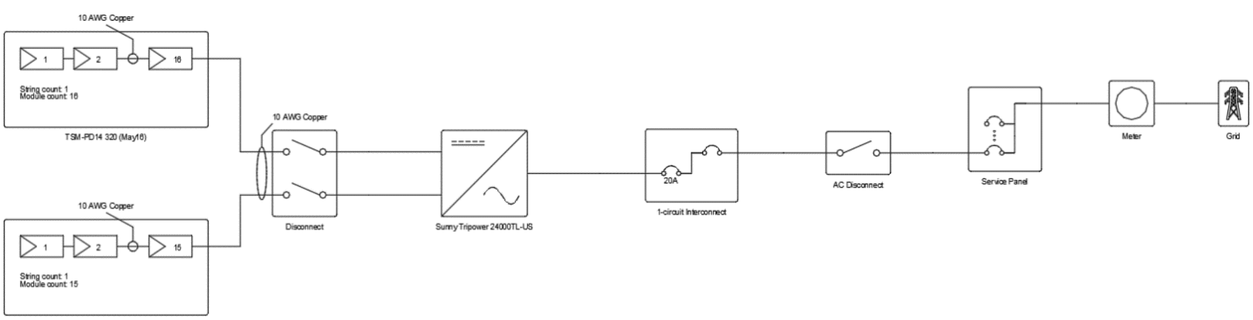


Figure 8 Helioscope Shading Heatmap



Module Specifications	
31x Trina Solar TSM-PD14 320 (May16)	
STC Rating	320 W
Vmp	37.1 V
Imp	8.63 A
Voc	45.8 V
Isc	9.1 A

Inverter Specifications	
1x SMA SunnyTripower 24000TL-US	
Max AC Power Rating	24.06 kW
Max Input Voltage	1,000 V

Wire Schedule		
Tier	Wire	Length
String	2x 10 AWG	83ft

Figure 9 Helioscope AutoCAD Electrical Diagram

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For comparing the results with the results of the following section found with ArcGIS, we divide the annual energy measured in kWh by the below for the final units measured in Wh/m^2.

$$AC\ Energy * \frac{\frac{100W}{kW}}{Area} = \ 22000\ Wh/m\text{^}2$$

$$Area = modules * length * width =$$
$$31\ modules * (1.961\ meter * 0.993\ meter) = 60.37m\text{^}2$$

Below is the specification for the PV modules used in the Helioscope simulation:

1.961	Height (meter)
0.993	Width (meter)
31.000	#Panels
1.947	Module Area (square meter)
60.370	System Area (square meter)

Figure 10 Helioscope System Area Calculation

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Grid-Tied PV System – Preliminary Design

A standard grid-tied system is shown in Figure 11 Grid-tied Wire Diagram. Grid-tied system follow specific building codes and guidelines set forth by professional bodies to maintain safety and a high level of quality. For the wiring, a conduit will be used appropriately for any connections made as well as protection for the wire.

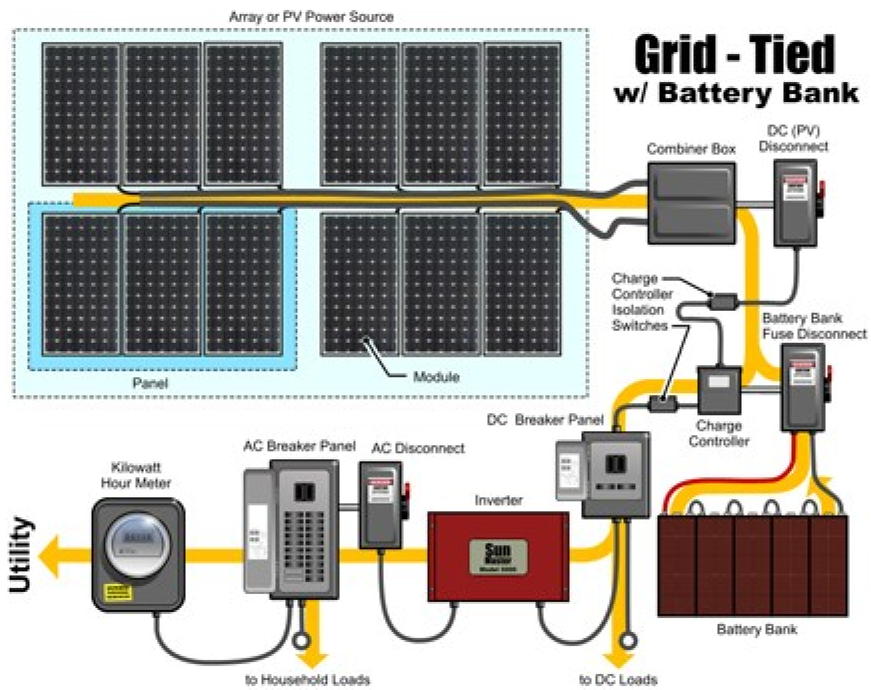


Figure 11 Grid-tied Wire Diagram

Safety Concerns

For safety in relations to photovoltaics, we referred the National Electric Code, Article 690 with the following. Installation will be performed by qualified personnel referred in Article 100. The electrical circuit will have a max voltage determined based on the ratings of conductors, cables, disconnects, overcurrent devices and other equipment; DC-DC converter source and output circuits such as a single DC-DC converter where the max voltage is the max rated voltage output of DC-DC convert. The maximum current is determined based on the circuit's current. Overcurrent protection is integrated within the charge controller which will be placed in the same polarity for all circuits within the system.

The disconnection location will be accessible with less than six switches within the circuit breaker and properly labeled with warning of shock hazard. The system's label will contain the voltage, current, power, AC frequency, and overcurrent information.

The charge controller will have the system's circuit match the voltage ratings and current requirements of the interconnected battery cells and the maximum charging current multiplied by one hour is less than three percent of the rated battery capacity expressed in ampere-hours.

Solar PV at SIU Carbondale

In 2004, SIU installed a 28kW photovoltaic system by the SIU Plant & Service Operations building. The system has produced over 91,000kWh of electricity and has been used for educational and research opportunities.

Figure 12 PSO's Photovoltaic System (SIU Sustainability Office, 2021)

Other photovoltaic systems on campus includes the solar charging picnic tables with an umbrella, four seats, a 110-volt charger, and a display box with two USB ports. As well as solar powered trash compactor.

Figure 13 SIU Solar Charging Picnic Table (SIU Sustainability Office, 2021)

Additional Solar Energy Sustainability Projects

While a 3-5kW, at a minimum, grid-tied photovoltaic system is the Green Roof Team's primary project, we recommend several additional projects for any additional funds available shall be used towards. The projects listed in this section are ordered in a non-specific order and all related to the improvement of campus sustainability.

Other Rooftop Solar Installations

Once we reach the maximum number of panels on the SIU Agriculture Building's Roof Area D, we will use any remaining funds, within reason, to install additional solar systems on recommended buildings based on the GIS Feasibility Study found in Appendix B: Feasibility Study – ArcGIS Maps.

Campus Energy Dashboard

A campus energy dashboard measures the energy use of overall buildings and digitally stores/allows the public to view the energy use for a selected timeframe.

Solar Tree

A solar tree is a product designed for aesthetics while converting the sunlight into usable electrical energy. Similar to the solar charging picnic tables seen on campus, a solar tree is a structure for showcasing our support and dedication to improving our campus's sustainability.

Recommendations

The Green Roof Team at Southern Illinois University Carbondale recommends installing, at minimum, a 3-5 kW photovoltaic system on Roof Area D of the SIU Agriculture Building in Spring 2022. The importance of the site is the proximity of the SIU Green Roof where this system will serve as an inspiration for students to use the SIU Green Roof for their own research projects as well as developing renewable energy related projects.

Once a 3-5 kW photovoltaic system obtains project success, where the project obtains design and installation approval, the next opportunities include increasing the size of the system based on the roof size and available budget. Once the system is maximized, a new feasibility study for more rooftop systems and ground mounted solar trees will be explored until budget depletion for the goal of providing student opportunities in the clean energy field.

Next Steps: Design and Cost Considerations

The decision to install a photovoltaic system on the Agriculture Building is multifaceted. If this initiative moves forward, the next step required is to conduct an engineering study, which is necessary for establishing an actual project design. The essence of the engineering study is to design the actual solar installation, evaluate and estimate the power generation, and determine the cost and benefits of the installation for the life span of the project. Results of an engineering study should include design scope and financial cost derivations including, but not limited to:

- Solar PV module cost (approximately $5.00 per DC Watt)
- Engineering design, includes electrical, architectural, and structural analysis
- Mounting equipment
- Electrical equipment, includes inverters, isolation transformers, lightning protection, conduits, cables, grounding wires
- Material delivery and storage
- Labor wages
- Construction drawings and reproduction
- Permit fees
- Ameren Transmission Fee
- Maintenance training manuals
- Maintenance, casualty insurance, and warranties
- Spare parts and components
- Testing and commissioning
- Overhead and profit
- Construction bond and liability insurance
- Mobilization cost, site office, and utility expenses
- Federal taxes and state sales taxes
- Insurance/liability considerations

The Green Roof Team will work on the preliminary designs with collaboration of SIU Plant & Service Operations and certified local solar contractors as an educational opportunity.

An estimated budget for photovoltaic systems is $5,000-7,500 per kW installed. This is an average derived from SIU Plant & Service Operations and literature reviewed. The SIU Foundation is assisting with writing various clean energy related grants and assisting the Green Roof Team acquiring corporate sponsorships. Available funds will be managed by the SIU Research Park and cost efficiently for minimizing cost overruns.

References

Milos. *Ballast Calculations for Temporary Structures*. *YouTube*, Milos, 15 Mar. 2017, youtu.be/n1QhYFn4hI8.

SIU Sustainability Office. *Campus Solar*. SIU Carbondale, 27 Jan. 2021, https://sustainability.siu.edu/green-fee/green-fund-projects/campus-solar.php

ArcGIS Resources

ESRI. *An Overview of the Solar Radiation tools.* https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/an-overview-of-the-solar-radiation-tools.htm

ESRI. *Understanding Solar Radiation Analysis.* https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/understanding-solar-radiation-analysis.htm

Appendices

Appendix A: Roof Area D Images

Figure 14 Roof Area D Image

Figure 15 Roof Area D Image

Appendix B: Feasibility Study – ArcGIS Maps

Below are the results of a Solar Radiation Analysis from ArcGIS on SIU Carbondale's campus.

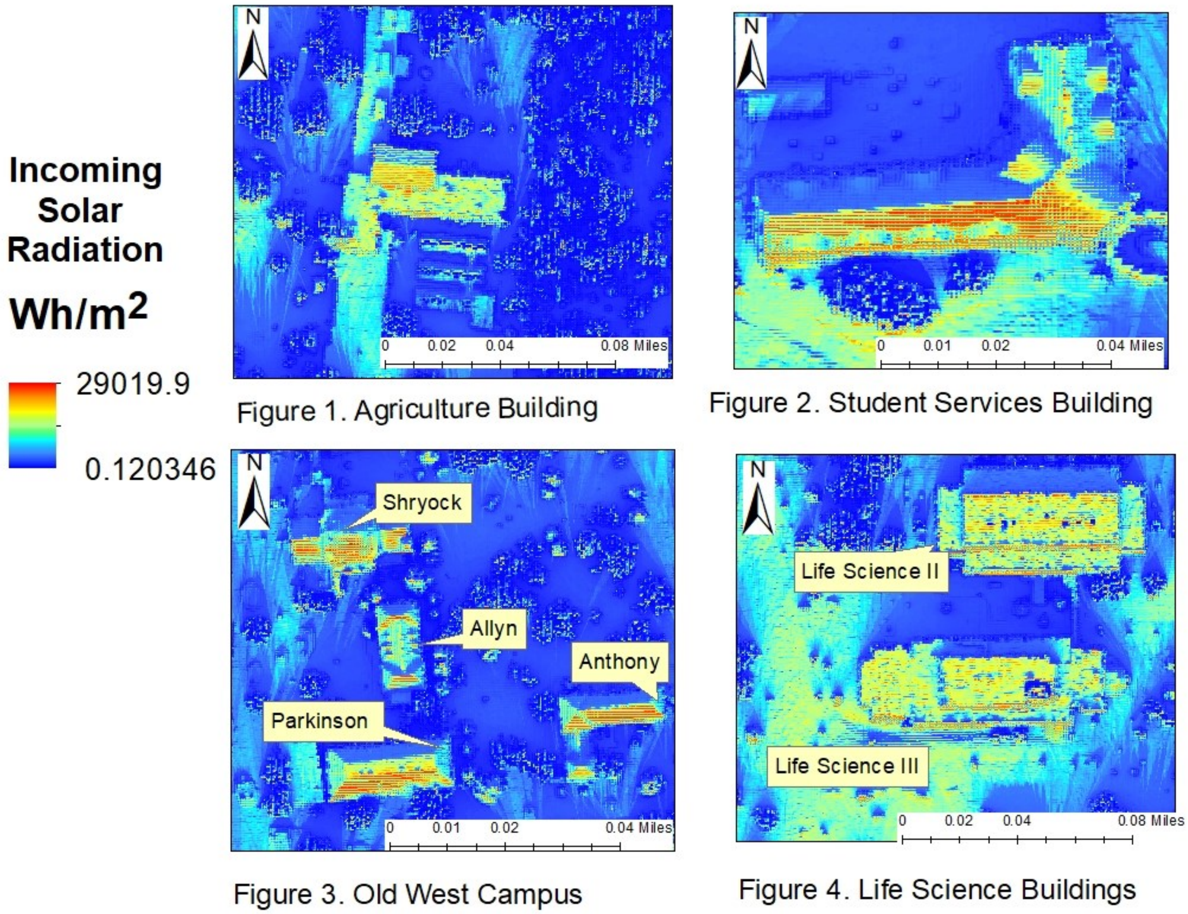
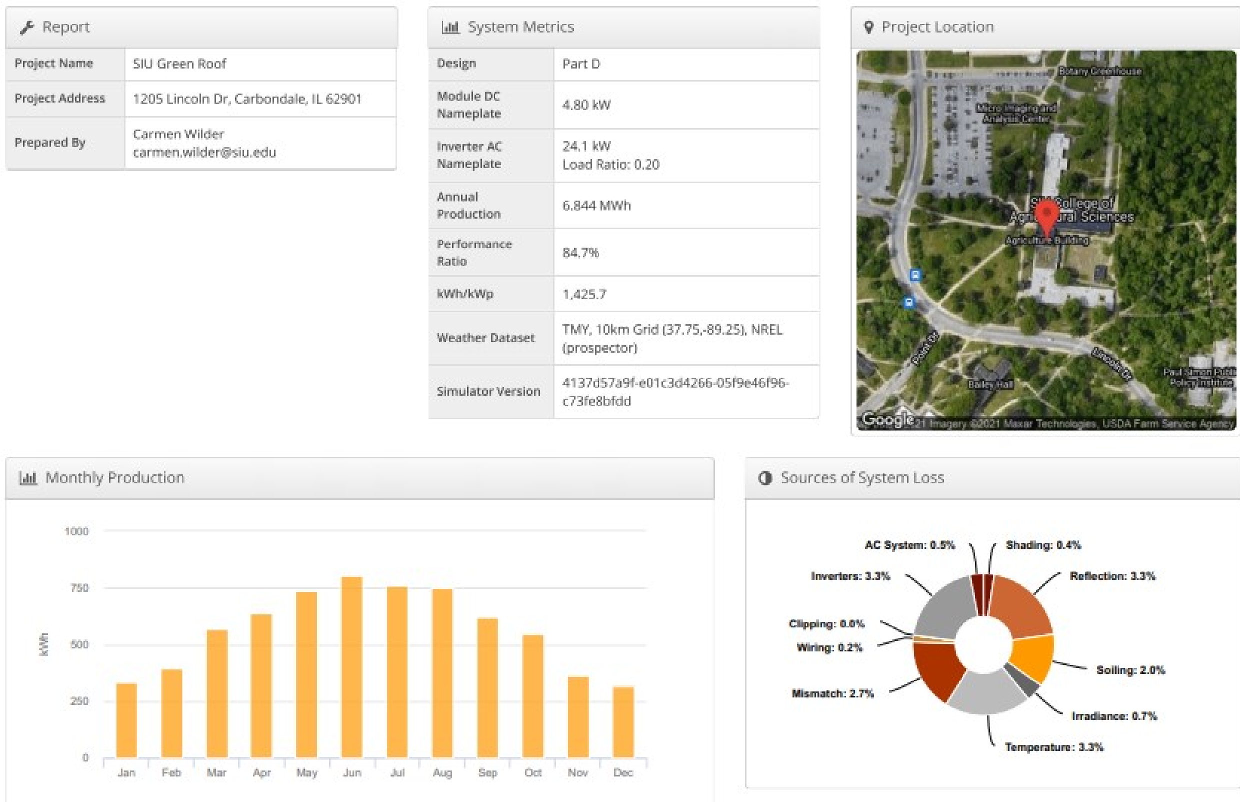


Figure 16 GIS Feasibility Study Results

Appendix C: Feasibility Study - HelioScope

Below are the results of a 5kW system installed on Roof Area D.



Report	
Project Name	SIU Green Roof
Project Address	1205 Lincoln Dr, Carbondale, IL 62901
Prepared By	Carmen Wilder carmen.wilder@siu.edu

System Metrics	
Design	Part D
Module DC Nameplate	4.80 kW
Inverter AC Nameplate	24.1 kW Load Ratio: 0.20
Annual Production	6.844 MWh
Performance Ratio	84.7%
kWh/kWp	1,425.7
Weather Dataset	TMY, 10km Grid (37.75,-89.25), NREL (prospector)
Simulator Version	4137d57a9f-e01c3d4266-05f9e46f96-c73fe8bfdd

Figure 17 Helioscope Overview Results

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,565.1	
	POA Irradiance	1,683.1	7.5%
	Shaded Irradiance	1,676.3	-0.4%
	Irradiance after Reflection	1,620.6	-3.3%
	Irradiance after Soiling	1,588.2	-2.0%
	Total Collector Irradiance	**1,588.3**	**0.0%**
Energy (kWh)	Nameplate	7,627.7	
	Output at Irradiance Levels	7,575.6	-0.7%
	Output at Cell Temperature Derate	7,327.3	-3.3%
	Output After Mismatch	7,127.1	-2.7%
	Optimal DC Output	7,109.4	-0.2%
	Constrained DC Output	7,109.4	0.0%
	Inverter Output	6,877.9	-3.3%
	Energy to Grid	**6,843.5**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		16.8 °C
	Avg. Operating Cell Temp		24.6 °C
Simulation Metrics			
	Operating Hours		4665
	Solved Hours		4665

Condition Set

Description	Condition Set 1
Weather Dataset	TMY, 10km Grid (37.75,-89.25), NREL (prospector)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model

Temperature Model Parameters

Rack Type	a	b	Temperature Delta
Fixed Tilt	-3.56	-0.075	3°C
Flush Mount	-2.81	-0.0455	0°C

Soiling (%)

J	F	M	A	M	J	J	A	S	O	N	D
2	2	2	2	2	2	2	2	2	2	2	2

Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%

Module Characterizations

Module	Uploaded By	Characterization
TSM-PD14 320 (May16) (Trina Solar)	Folsom Labs	Spec Sheet Characterization, PAN

Component Characterizations

Device	Uploaded By	Characterization
Sunny Tripower 24000TL-US (SMA)	Folsom Labs	Modified CEC

Components

Component	Name	Count
Inverters	Sunny Tripower 24000TL-US (SMA)	1 (24.1 kW)
Module	Trina Solar, TSM-PD14 320 (May16) (320W)	15 (4.80 kW)

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	-	5-19	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	10°	180°	1.5 ft	1x1	15	15	4.80 kW

Shading by Field Segment

Description	Tilt	Azimuth	Modules	Nameplate	Shaded Irradiance	AC Energy	TOF[2]	Solar Access	Avg TSRF [2]
Field Segment 1	10.0°	180.0°	15	4.80 kWp	1,676.3kWh/m²	6.84 MWh[1]	93.4%	99.6%	93.0%
Totals, weighted by kWp			**15**	**4.80 kWp**	**1,676.3kWh/m²**	**6.84 MWh**	**93.4%**	**99.6%**	**93.0%**

[1] approximate, varies based on inverter performance
[2] based on location Optimal POA Irradiance of 1,802.2kWh/m² at 33.8° tilt and 183.0° azimuth

Solar Access by Month

Description	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Field Segment 1	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%	99%
Solar Access, weighted by kWp	99.2%	99.6%	99.7%	99.7%	99.6%	99.7%	99.7%	99.7%	99.7%	99.7%	99.4%	99.0%
AC Power (kWh)	334.5	395.8	567.9	639.9	737.4	802.3	760.0	750.8	623.4	548.2	365.7	317.6

Figure 18 Helioscope Feasibility Study Results

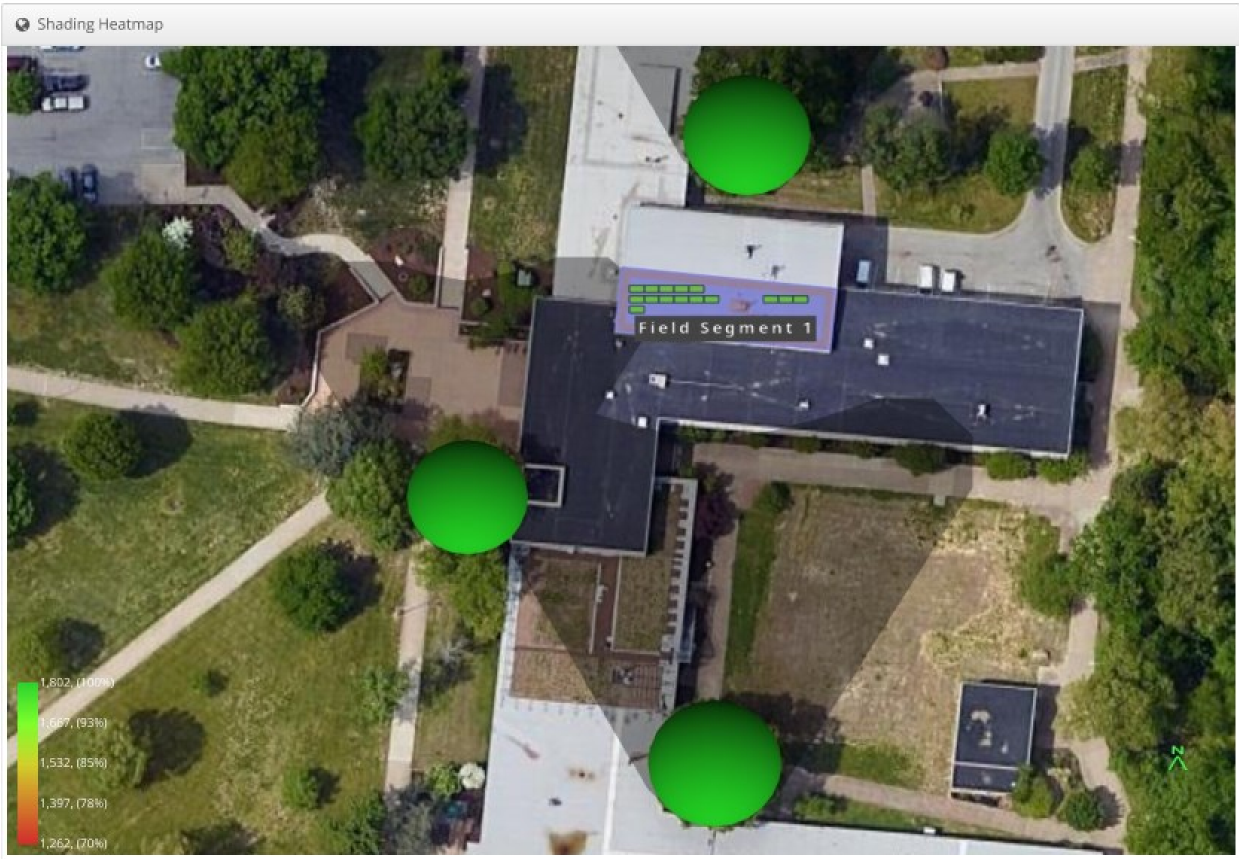
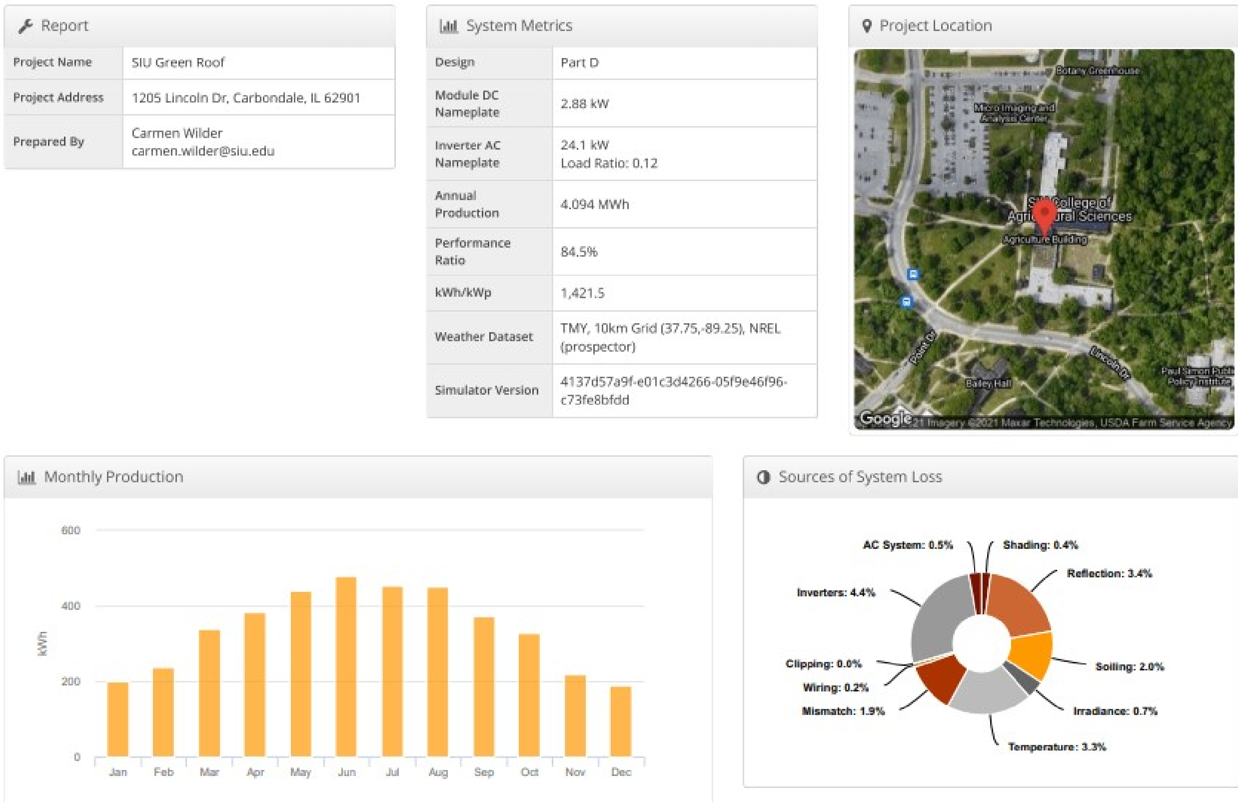


Figure 19 Helioscope Shading Heatmap

Below are the results of a 3kW system installed on Roof Area D.



Project Name	SIU Green Roof
Project Address	1205 Lincoln Dr, Carbondale, IL 62901
Prepared By	Carmen Wilder carmen.wilder@siu.edu

System Metrics

Design	Part D
Module DC Nameplate	2.88 kW
Inverter AC Nameplate	24.1 kW Load Ratio: 0.12
Annual Production	4.094 MWh
Performance Ratio	84.5%
kWh/kWp	1,421.5
Weather Dataset	TMY, 10km Grid (37.75,-89.25), NREL (prospector)
Simulator Version	4137d57a9f-e01c3d4266-05f9e46f96-c73fe8bfdd

Figure 20 Helioscope Overview Results

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,565.1	
	POA Irradiance	1,683.1	7.5%
	Shaded Irradiance	1,677.1	-0.4%
	Irradiance after Reflection	1,620.7	-3.4%
	Irradiance after Soiling	1,588.3	-2.0%
	Total Collector Irradiance	**1,588.5**	**0.0%**
Energy (kWh)	Nameplate	4,577.3	
	Output at Irradiance Levels	4,546.1	-0.7%
	Output at Cell Temperature Derate	4,397.1	-3.3%
	Output After Mismatch	4,311.7	-1.9%
	Optimal DC Output	4,304.8	-0.2%
	Constrained DC Output	4,304.8	0.0%
	Inverter Output	4,114.5	-4.4%
	Energy to Grid	**4,093.9**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		16.8 °C
	Avg. Operating Cell Temp		24.6 °C
Simulation Metrics			
	Operating Hours		4665
	Solved Hours		4665

Condition Set

Description	Condition Set 1
Weather Dataset	TMY, 10km Grid (37.75,-89.25), NREL (prospector)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model
Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%

Temperature Model Parameters

Rack Type	a	b	Temperature Delta
Fixed Tilt	-3.56	-0.075	3°C
Flush Mount	-2.81	-0.0455	0°C

Soiling (%)

J	F	M	A	M	J	J	A	S	O	N	D
2	2	2	2	2	2	2	2	2	2	2	2

Module Characterizations

Module	Uploaded By	Characterization
TSM-PD14 320 (May16) (Trina Solar)	Folsom Labs	Spec Sheet Characterization, PAN

Component Characterizations

Device	Uploaded By	Characterization
Sunny Tripower 24000TL-US (SMA)	Folsom Labs	Modified CEC

Components

Component	Name	Count
Inverters	Sunny Tripower 24000TL-US (SMA)	1 (24.1 kW)
Module	Trina Solar, TSM-PD14 320 (May16) (320W)	9 (2.88 kW)

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	-	5-19	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	10°	180°	1.5 ft	1x1	9	9	2.88 kW

Shading by Field Segment

Description	Tilt	Azimuth	Modules	Nameplate	Shaded Irradiance	AC Energy	TOF[2]	Solar Access	Avg TSRF [2]
Field Segment 1	10.0°	180.0°	9	2.88 kWp	1,677.1kWh/m²	4.09 MWh[1]	93.4%	99.6%	93.1%
Totals, weighted by kWp			**9**	**2.88 kWp**	**1,677.1kWh/m²**	**4.09 MWh**	**93.4%**	**99.6%**	**93.1%**

[1] approximate, varies based on inverter performance
[2] based on location Optimal POA Irradiance of 1,802.2kWh/m² at 33.8° tilt and 183.0° azimuth

Solar Access by Month

Description	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Field Segment 1	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%	99%
Solar Access, weighted by kWp	**99.2%**	**99.6%**	**99.7%**	**99.7%**	**99.7%**	**99.7%**	**99.7%**	**99.7%**	**99.8%**	**99.7%**	**99.4%**	**98.9%**
AC Power (kWh)	**199.9**	**237.0**	**339.4**	**382.8**	**441.1**	**479.7**	**454.4**	**449.8**	**373.2**	**327.9**	**218.9**	**189.7**

Figure 21 Helioscope Feasibility Study Results

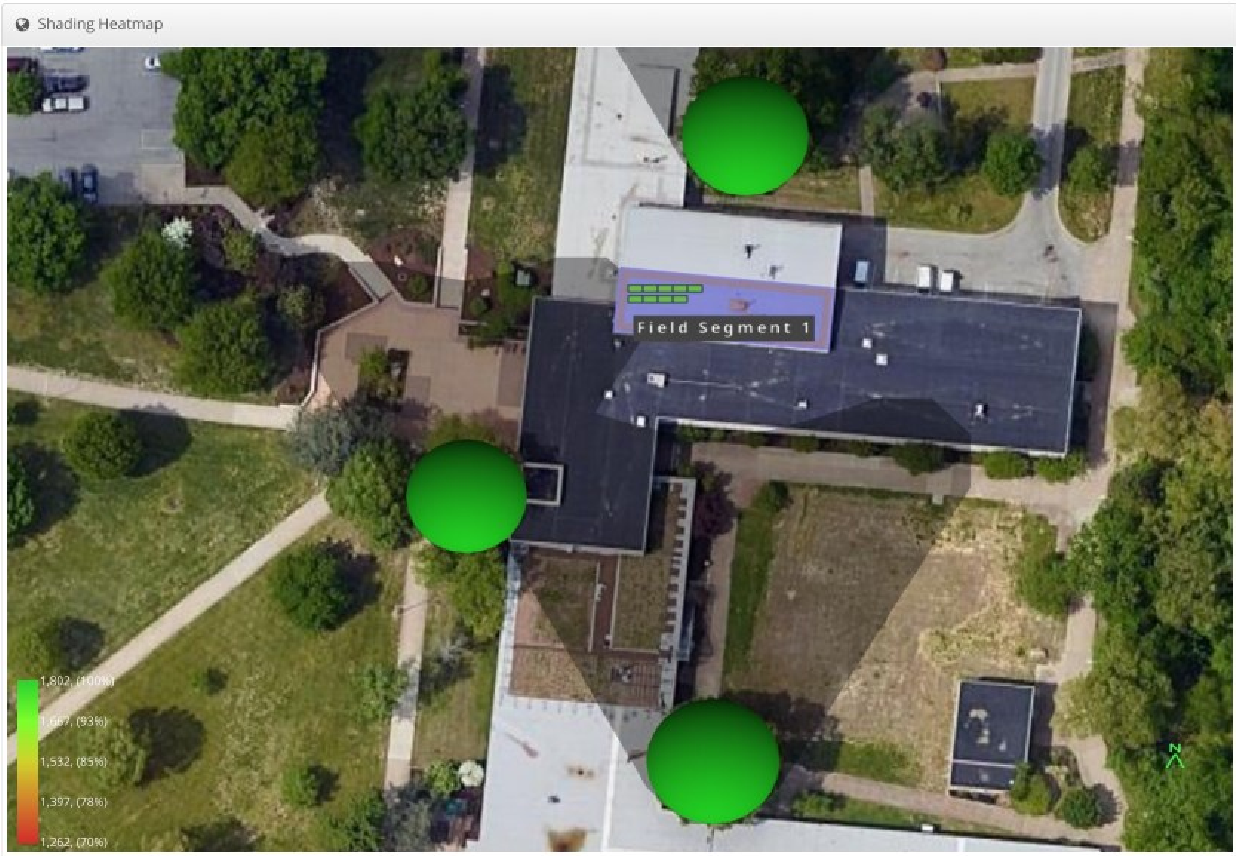


Figure 22 Helioscope Shading Heatmap

Appendix D: Manufacturer's Specification

Below are the manufacture's specifications for the equipment used in the Helioscope simulation.

SUNNY TRIPOWER 12000TL-US / 15000TL-US / 20000TL-US / 24000TL-US / 30000TL-US

Design flexibility
- 1000 V DC or 600 V DC
- Two independent DC inputs
- 15° to 90° mounting angle range
- Detachable DC Connection Unit

System efficiency
- 98.0% CEC, 98.6% Peak
- 1000 V DC increases system efficiency
- OptiTrac Global Peak MPPT

Enhanced safety
- Integrated DC AFCI
- Floating system with all-pole sensitive ground fault protection
- Reverse polarity indicator in combination with Connection Unit

Future-proof
- Complete grid management feature set
- Integrated Speedwire, WebConnect, ModBus interface
- Bi-directional Ethernet communications
- Utility-interactive controls for active and reactive power

SUNNY TRIPOWER 12000TL-US / 15000TL-US / 20000TL-US / 24000TL-US / 30000TL-US

The ultimate solution for decentralized PV plants, now up to 30 kilowatts

The world's best-selling three-phase PV inverter, the SMA Sunny Tripower TL-US, is raising the bar for decentralized commercial PV systems. This three-phase, transformerless inverter is UL listed for up to 1000 V DC maximum system voltage and has a peak efficiency above 98 percent, while OptiTrac Global Peak minimizes the effects of shade for maximum energy production. The Sunny Tripower delivers a future-proof solution with full grid management functionality, cutting edge communications and advanced monitoring. The Sunny Tripower is also equipped with all-pole ground fault protection and integrated AFCI for a safe, reliable solution. It offers unmatched flexibility with a wide input voltage range and two independent MPP trackers. Suitable for both 600 V DC and 1,000 V DC applications, the Sunny Tripower allows for flexible design and a lower levelized cost of energy.

www.SMA-America.com

Figure 23 Inverter Specifications

Green Roof
1205 Lincoln Dr
Carbondale, IL 62901
greenroof@siu.edu

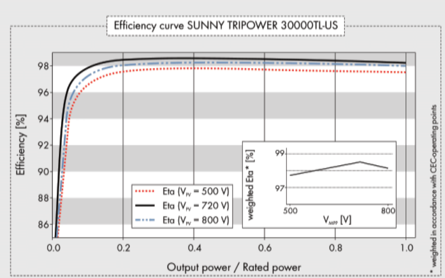
Technical data	Sunny Tripower 12000TL-US	Sunny Tripower 15000TL-US	Sunny Tripower 20000TL-US	Sunny Tripower 24000TL-US	Sunny Tripower 30000TL-US
Input (DC)					
Max. array power	18000 Wp STC	22500 Wp STC	30000 Wp STC	36000 Wp STC	45000 Wp STC
Max. DC voltage	*1000 V				1000 V
Rated MPPT voltage range	300 V...800 V	300 V...800 V	380 V...800 V	450 V...800 V	500 V...800 V
MPPT operating voltage range	150 V...1000 V				
Min. DC voltage / start voltage	150 V / 188 V				
Number of MPP tracker inputs	2				
Max. operating input current / per MPP tracker	66 A / 33 A				
Max. short circuit current per MPPT / string input	53 A / 53 A				
Output (AC)					
AC nominal power	12000 W	15000 W	20000 W	24000 W	30000 W
Max. AC apparent power	12000 VA	15000 VA	20000 VA	24000 VA	30000 VA
Output phases / line connections	3 / 3-N-PE				3 / 3-N-PE, 3-PE
Nominal AC voltage	480 / 277 V WYE				480 / 277 V WYE, 480 V Delta
AC voltage range	244 V...305 V				
Rated AC grid frequency	60 Hz				
AC grid frequency / range	50 Hz, 60 Hz / -6 Hz...+5 Hz				
Max. output current	14.4 A	18 A	24 A	29 A	36.2 A
Power factor at rated power / adjustable displacement	1 / 0.0 leading...0.0 lagging				
Harmonics	< 3%				
Efficiency					
Max. efficiency / CEC efficiency	98.2% / 97.5%	98.2% / 97.5%	98.5% / 97.5%	98.5% / 98.0%	98.6% / 98.0%
Protection devices					
DC reverse polarity protection	●				
Ground fault monitoring / grid monitoring	●				
All-pole sensitive residual current monitoring unit	●				
DC AFCI compliant to UL 1699B	●				
AC short circuit protection	●				
Protection class / overvoltage category	I / IV				
General data					
Dimensions (W / H / D) in mm (in)	665 / 650 / 265 (26.2 / 25.6 / 10.4)				
Packing dimensions (W / H / D) in mm (in)	780 / 790 / 380 (30.7 / 31.1 / 15.0)				
Weight	55 kg (121 lbs)				
Packing weight	61 kg (134.5 lbs)				
Operating temperature range	-25°C...+60°C				
Noise emission (typical) / internal consumption at night	51 dB(A) / 1 W				
Topology	Transformerless				
Cooling concept / electronics protection rating	OptiCool / NEMA 3R				
Features					
Display / LED indicators (Status / Fault / Communication)	– / ●				
Interface: RS485 / Speedwire, WebConnect	○/●				
Data interface: SMA Modbus / SunSpec ModBus	●/●				
Mounting angle range	15°...90°				
Warranty: 10 / 15 / 20 years	●/○/○				
Certifications and approvals	UL 1741, UL 1741SA, CA Rule 21, UL 1998, UL 1699B, IEEE 1547, FCC Part 15 (Class A & B), CAN/CSA C22.2 107.1-1				
NOTE: US inverters ship with gray lids. Data at nominal conditions, August 2017. *Suitable for 600 V DC max. systems					
● Standard features ○ Optional features – Not available					
Type designation	STP 12000TL-US-10	STP 15000TL-US-10	STP 20000TL-US-10	STP 24000TL-US-10	STP 30000TL-US-10

Accessories

RS485 interface
DM-485CB-US-10

Connection Unit
CU 1000-US-11

SMA Cluster Controller
CLCON-10



Below are the manufacture's specifications for the equipment used in the Helioscope simulation.

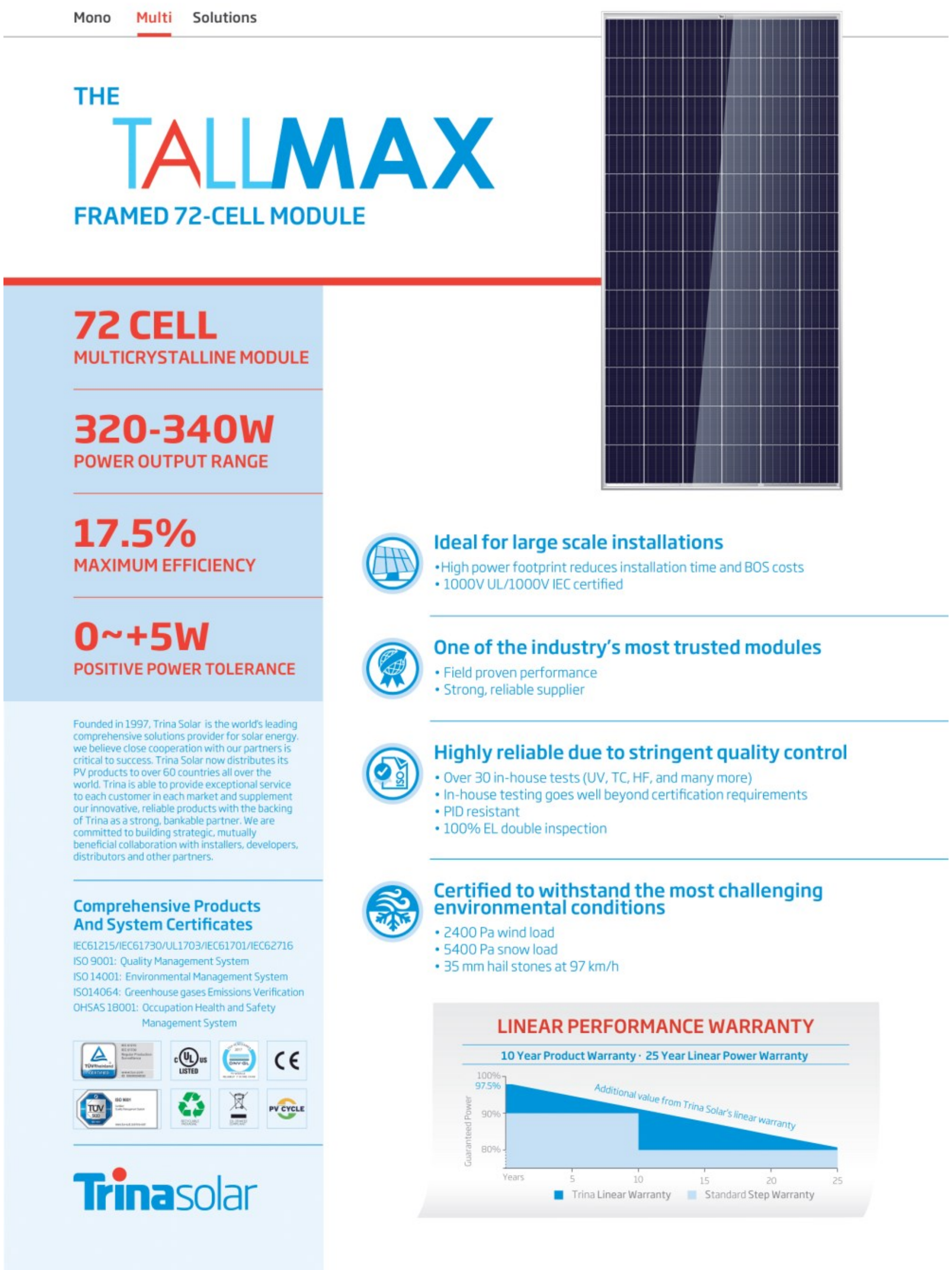


Figure 24 PV Module Specifications

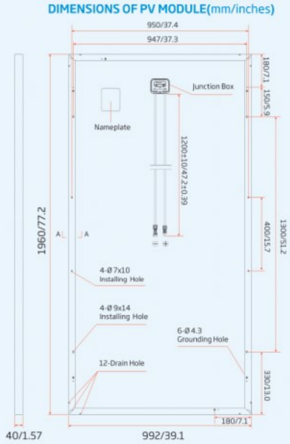
Green Roof
1205 Lincoln Dr
Carbondale, IL 62901
greenroof@siu.edu

TALLMAX

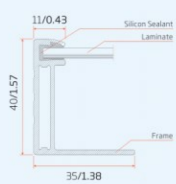
FRAMED 72-CELL MODULE

PRODUCTS	POWER RANGE
TSM-PD14	320-340W

DIMENSIONS OF PV MODULE(mm/inches)

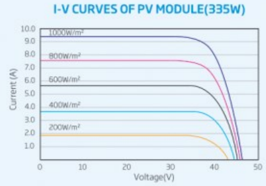


Back View

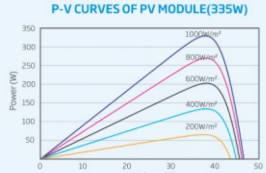


(A-A)

I-V CURVES OF PV MODULE(335W)



P-V CURVES OF PV MODULE(335W)



ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	320	325	330	335	340
Power Output Tolerance-P_{MAX} (W)	0 ~ +5				
Maximum Power Voltage-V_{MPP} (V)	37.1	37.2	37.4	37.6	37.8
Maximum Power Current-I_{MPP} (A)	8.63	8.73	8.83	8.91	8.99
Open Circuit Voltage-V_{OC} (V)	45.5	45.6	45.8	46.0	46.2
Short Circuit Current-I_{SC} (A)	9.15	9.19	9.28	9.35	9.42
Module Efficiency η_m (%)	16.5	16.7	17.0	17.2	17.5

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5.
*Measuring tolerance: ±3%.

ELECTRICAL DATA (NOCT)

Maximum Power-P_{MAX} (Wp)	237	241	245	249	252
Maximum Power Voltage-V_{MPP} (V)	34.3	34.4	34.6	34.8	35.0
Maximum Power Current-I_{MPP} (A)	6.92	7.00	7.08	7.14	7.21
Open Circuit Voltage-V_{OC} (V)	42.1	42.2	42.4	42.6	42.8
Short Circuit Current-I_{SC} (A)	7.39	7.42	7.49	7.55	7.60

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

MECHANICAL DATA

Solar Cells	Multicrystalline 156 × 156 mm (6 inches), 4BBMulticrystalline
Cell Orientation	156.75 × 156.75 mm (6 inches), 72 cells (6 × 12)
Module Dimensions	1960 × 992 × 40 mm (77.2 × 39.1 × 1.57 inches)
Weight	22.5 kg (49.6 lb)
Glass	3.2 mm (0.13 inches), High Transmission, AR Coated Tempered Glass
Backsheet	White
Frame	Silver Anodized Aluminium Alloy
J-Box	IP 67 or IP 68 rated
Cables	Photovoltaic Technology Cable 4.0mm² (0.006 inches²), 1200 mm (47.2 inches)
Connector	Trina TS4
Fire Type	Type1 or Type 2

TEMPERATURE RATINGS

NOCT (Nominal Operating Cell Temperature)	44°C (±2°C)
Temperature Coefficient of P_{MAX}	- 0.41%/°C
Temperature Coefficient of V_{OC}	- 0.32%/°C
Temperature Coefficient of I_{SC}	0.05%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC (IEC)
	1000V DC (UL)
Max Series Fuse Rating	15A

(DO NOT connect Fuse in Combiner Box with two or more strings in parallel connection)

WARRANTY

10 year Product Workmanship Warranty

25 year Linear Power Warranty

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 27 pieces

Modules per 40' container: 648 pieces

Trinasolar

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Version number: TSM_EN_2018_B
www.trinasolar.com