ECEP 480 Solar Energy Engineering Rooftop PV Design

Group 01
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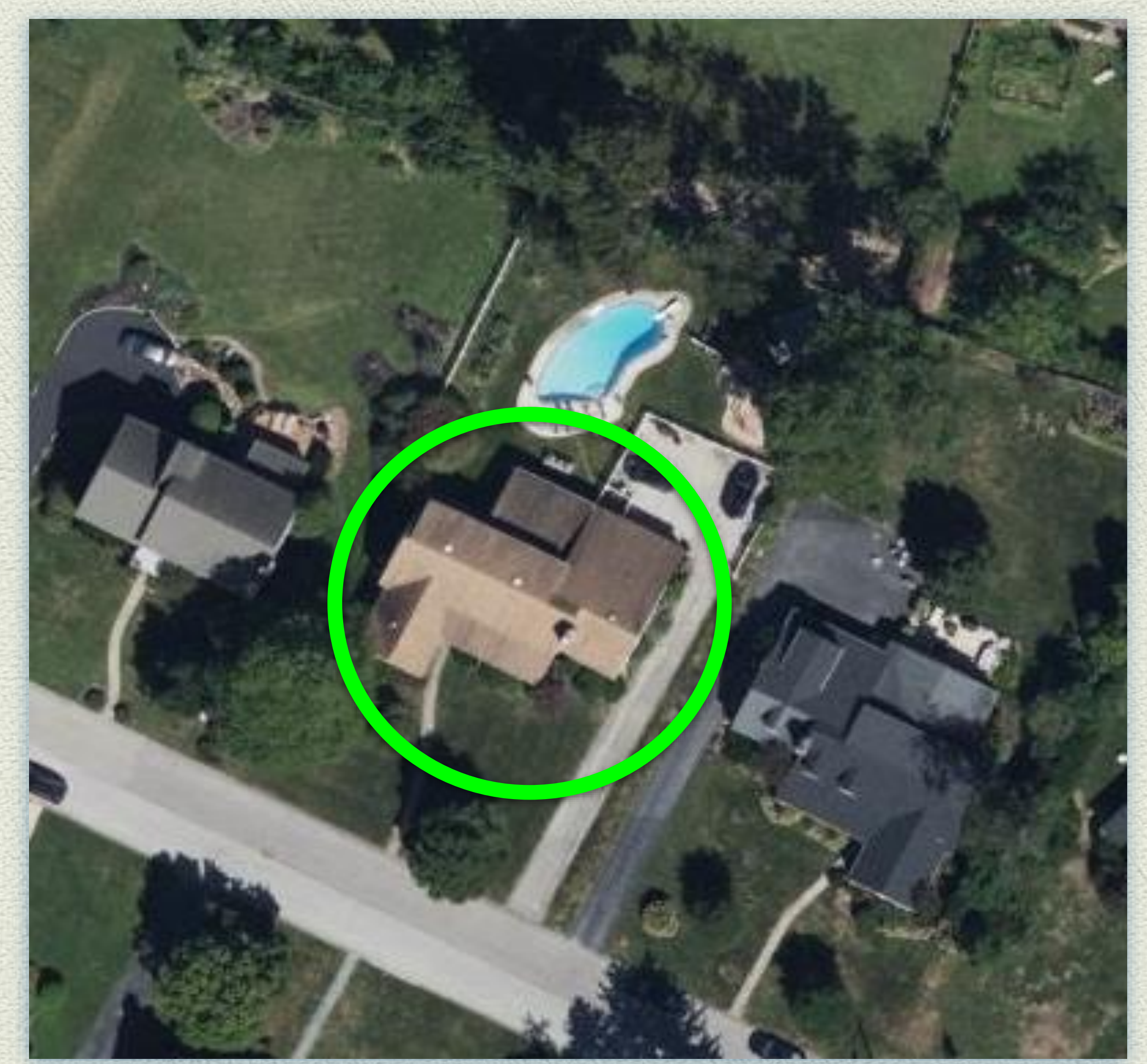
What is a PV system

- PV stands for photovoltaic
- Includes solar panels along with other components
- Electricity from sunlight

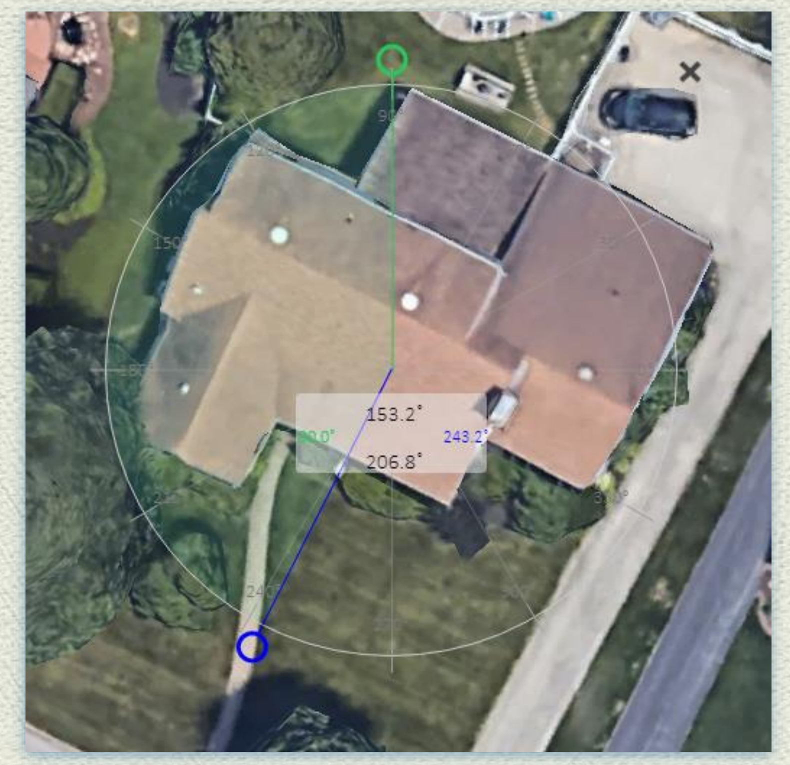
The Project

3009 Robin Lane, Havertown, PA 19083



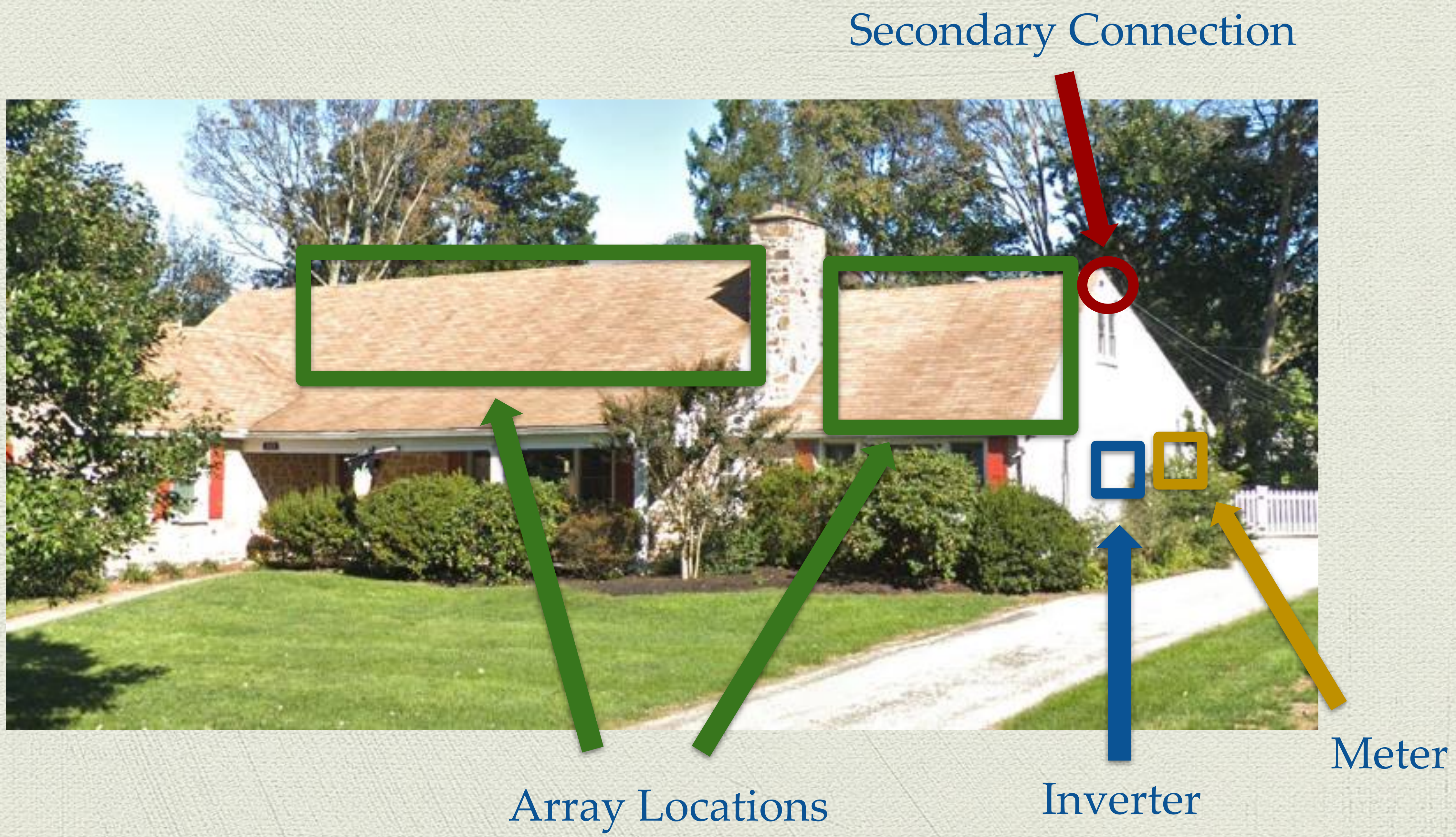
- Longitude: -75.34
- Latitude: 40.01
- Elevation: 111 meters

Installation Overview

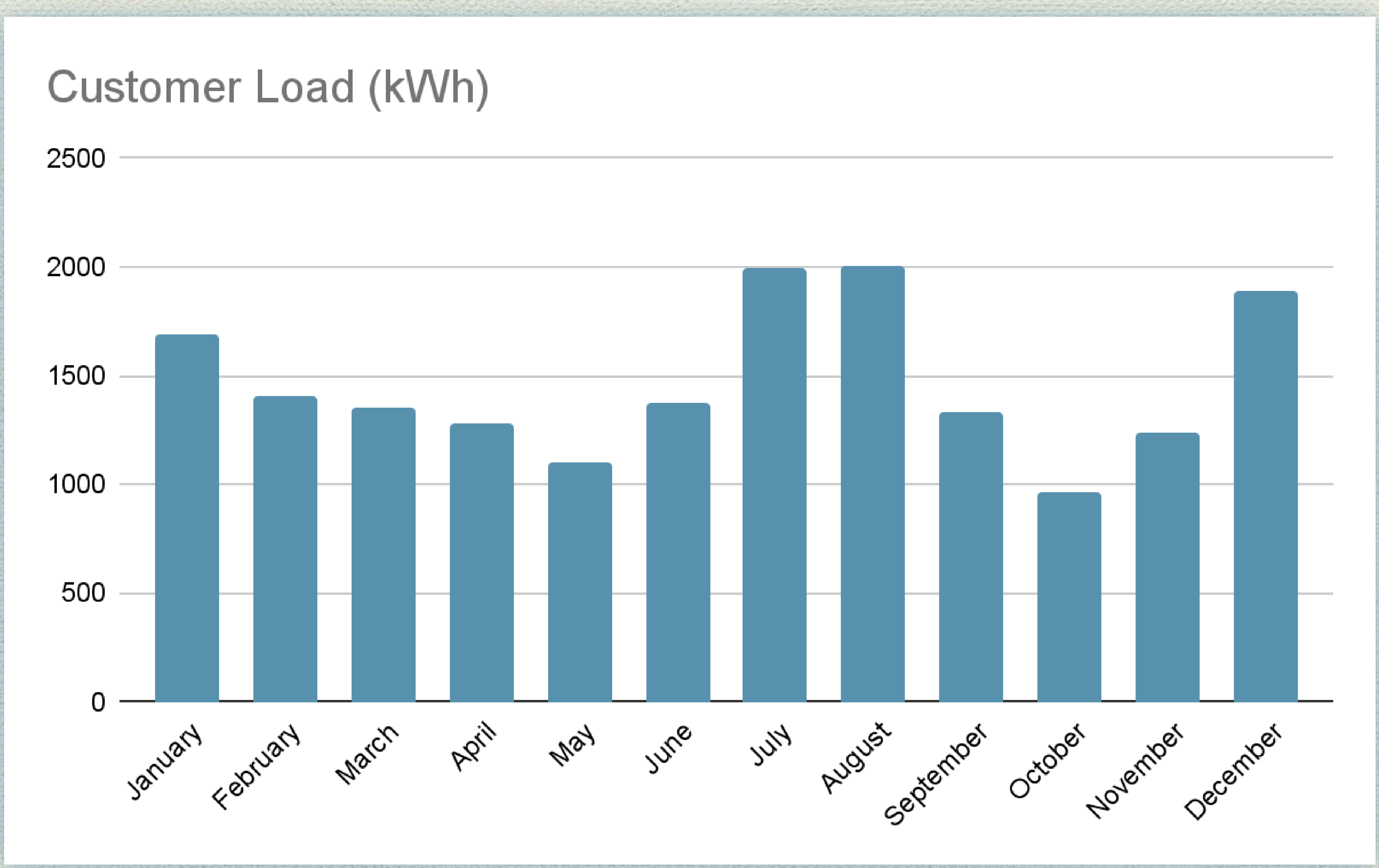


Active Surface	Area (m. sq.)	Azimuth (deg)
1	14.49	116.8
2	26.76	206.8
3	37.4	206.8
4	14.96	206.8

Installation Overview



Customer Load



Total: 17,631 kWh/year

What is SAM?

- Model many types of renewable energy systems
- Produce financial models for projects
- Used by
    - Project managers and engineers
    - Policy analysts
    - Technology developers
    - Researchers

Initial Design

Initial PV energy supply goal : 100%

Estimate initially with 18kW gives 23,608kWh… Too much!

DC System Size (kW):	18
Module Type:	Standard
Array Type:	Fixed (open rack)
System Losses (%):	14.08
Tilt (deg):	26
Azimuth (deg):	206.8

$$\left(\frac{17,631\text{kWh}}{23,608\text{kWh}}\right)\times 18\text{kW} = 13.443\text{kW}$$

After calculating the actual power needed

DC System Size (kW):	13.443
Module Type:	Standard
Array Type:	Fixed (open rack)
System Losses (%):	14.08
Tilt (deg):	26
Azimuth (deg):	206.8

Array size needed: 13.443kWdc

Design Approach and Component Calculations - Initial Design

- Inverter - Fronius USA: Fronius Primo 15.0-1 [240V]
  - 15000W
  - MPPT: 320V < V < 800

- Module - Seraphim Energy Group Inc. SEG-440-BMA-BG
  - 440W (31 of them gives 13640W)
  - $V_{OC\ Max}$ of 55.48V
  - $V_{M\ Min}$ of 39.65
  - Operating Temperatures: -40°C < T < 85°C

- Could not fit allotted 31 modules for 100% of the load
- Inverter was oversized

Design Approach and Component Calculations - Final Design

- Inverter - Fronius USA: Fronius Primo 12.5-1 [240V]
    - 12500W
    - MPPT: 260V < V < 800

- Module - Seraphim Energy Group Inc. SEG-440-BMA-BG
    - 440W (28 of them gives 12320W)
    - $V_{OC\ Max}$ of 55.48V
    - $V_{M\ Min}$ of 39.65
    - Operating Temperatures: -40°C < T < 85°C

Determine String Size

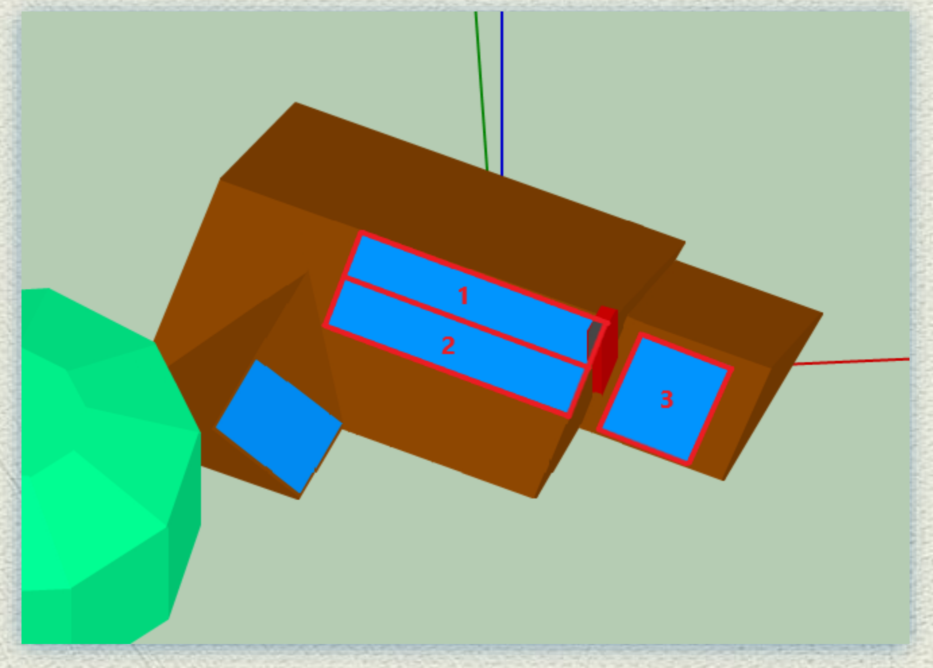
- Step 1: Determine $V_{OC\ Max}$ and $V_{M\ Min}$

$$V_{m(min)} = V\left(25^{\circ}C\right)\left[1+\left(T_{max}-25^{\circ}C\right)\frac{\Delta V_m}{\Delta T}\right] \qquad V_{oc(max)} = V\left(25^{\circ}C\right)\left[1+\left(T_{min}-25^{\circ}C\right)\frac{\Delta V_{oc}}{\Delta T}\right]$$

- Step 2: Determine maximum and minimum number of modules

$$Modules_{min} = \frac{MPPT_{(min)}}{V_{m(min)}} \qquad Modules_{max} = \frac{MPPT_{(max)}}{V_{oc(max)}}$$

- String size
  - 7 < #modules < 14 per string
  - Need 31 modules to satisfy 100% of the load
  - Can only fit 28 modules in our design



Balance of System

Calculations Voltage Drop(%VD)	**String of Modules**	
Open Loop Length	78.6 ft	Total Wiring of System
One Way distance	39.3 ft	Total Wiring of System/2
Isc	11.3 A	Short Circuit Current
Im	10.6 A	Max Rated Current
VM(String)	331.2 V	8 * Vm per module
12 Awg (Ω/kft)	1.93	
%VD	0.485 %	

Balance of System

- The connection between the junction box and inverter is 60ft and must carry the output of 2 strings.
  - 18.2 m length (60 ft)
  - Conduit 2" above roof 100 °F (38 °C) ambient temperature
  - Isc = 11.3 A
  - Im = 10.6 A
  - NEC 690.8(A) NEC 690.8(0.1)
    - 11.3 A x 156% is 17.628 A/string
    - 17.628 A x 2 = 35.256 A total
  - Conduit run temperature correction Table 4.13 – 38 + 22 = 60 °C
  - Ambient temp ampacity correction Table 4.12 – 0.71 for 60 °C
  - Derate based on the conduit fill – factor of 1.0

Table 4.13 Ambient Temperature Correction Factors for Conduit Run across Rooftops

Height of conduit above roof (in.)	0–0.5	0.5–3.5	3.5–12	>12
Add to ambient (°C)	33	22	17	14

$$\frac{(1.25 \times 11.3A)(2)}{(0.71)(1)} = 39.7A$$

Table 4.12 Summary of Ambient Temperature Correction Factors for Wire with 90°C Insulation

Temp (°C)	21–25	26–30	31–35	36–40	41–45
Correction	1.04	1.00	0.96	0.91	0.87
Temp (°C)	46–50	51–55	56–60	61–65	66–70
Correction	0.82	0.76	0.71	0.58	0.41

Balance of System

- The 30 °C ampacity must be no less than 39.7 A, or the higher of the two numbers. From Table 4.2, no less than 10 AWG, with a current of 40 A.

Table 4.2 Properties of Copper Conductors with 90°C Insulation

Size (AWG)	18	16	14	12	$\boxed{10}$	8	6	4
dc (Ω/kft)	7.77	4.89	3.07	1.93	$\boxed{1.21}$	0.764	0.491	0.308
I_{max} (A)	14	18	25	30	$\boxed{40}$	55	75	95
Size	3	2	1	0	00	000	0000	250 kcm
dc (Ω/kft)	0.245	0.194	0.154	0.122	0.0967	0.0766	0.0608	0.0515
I_{max} (A)	110	130	150	170	195	225	260	290

- At 10 AWG,

$$\%\,\mathrm{VD} = \left[\frac{0.2\times(2\ \mathrm{Strings}\times 10.6\mathrm{A})\times 60\mathrm{ft}}{8\ \mathrm{Modules}\ \times 41.4\mathrm{V}}\left(1.21\frac{\Omega}{\mathrm{kft}}\right)\right] = 0.929\,\%$$

- Total %VD = 0.485% + 0.929% = 1.414%

SAM Simulation

Modules	
Seraphim Energy Group Inc. SEG-440-BMA-BG	
Cell material	Mono-c-Si
Module area	1.87 m²
Module capacity	440.08 DC Watts
Quantity	28
Total capacity	12.32 DC kW
Total area	52 m²

Inverters	
Fronius USA: Fronius Primo 12.5-1	
Unit capacity	12.5 AC kW
Input voltage	260 - 800 VDC DC V
Quantity	1
Total capacity	12.5 AC kW
DC to AC Capacity Ratio	0.99
AC losses (%)	1.00

- Max Power: 440Wd
- V_{MP}: 41.4Vdc
- V_{OC}: 49.7Vdc
- I_{SC}: 11.3Adc
- Efficiency: 23.53%

- AC Power: 12500 Wac
- DC Power: 13000Wdc
- AC Voltage: 240Vac
- MPPT: 260V < V < 800V

SAM Simulation

Shading of Array on Main Roof

Subarray 1, String 1 — Shade Loss (%): 0=no shade, 100=fully shaded

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	100	100	100	100	100	100	100	0	0	0	0	0	0	0	0	17.9272	79.9065	100	100	100	100	100	100	100
Feb	100	100	100	100	100	100	100	21.1058	0	0	0	0	0	0	0	0	68.1785	100	100	100	100	100	100	100
Mar	100	100	100	100	100	100	100	47.7859	0	0	0	0	0	0	0	0	12.0882	100	100	100	100	100	100	100
Apr	100	100	100	100	100	100	100	27.3071	1.87219	0	0	0	0	0	0	0	0	8.04703	60.2649	100	100	100	100	100
May	100	100	100	100	100	100	21.7145	21.0974	3.67963	0	0	0	0	0	0	0	0	0.686169	13.5131	100	100	100	100	100
Jun	100	100	100	100	100	100	20.3818	20.3841	5.14998	0.119695	0	0	0	0	0	0	0	0.194212	5.92643	100	100	100	100	100
Jul	100	100	100	100	100	100	5.76923	22.3626	5.76721	0.0830392	0	0	0	0	0	0	0	0.152947	6.04519	100	100	100	100	100
Aug	100	100	100	100	100	100	100	26.4745	3.76018	0	0	0	0	0	0	0	0	0.974098	20.9492	100	100	100	100	100
Sep	100	100	100	100	100	100	100	25.8296	0	0	0	0	0	0	0	0	0.0363876	95.5534	100	100	100	100	100	100
Oct	100	100	100	100	100	100	100	6.53675	0	0	0	0	0	0	0	4.1268	100	100	100	100	100	100	100	100
Nov	100	100	100	100	100	100	100	0	0	0	0	0	0	0	0	40.8157	99.9381	100	100	100	100	100	100	100
Dec	100	100	100	100	100	100	100	0	0	0	0	0	0	0	0.00117603	41.2226	83.3976	100	100	100	100	100	100	100

Subarray 1, String 2 — Shade Loss (%): 0=no shade, 100=fully shaded

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	100	100	100	100	100	100	100	78.3495	31.6852	15.8896	10.0708	6.53271	4.71397	2.54548	2.0098	3.49737	86.4112	100	100	100	100	100	100	100
Feb	100	100	100	100	100	100	100	56.2716	35.1073	17.0317	9.89079	6.4482	4.00102	2.31258	1.85157	1.61538	41.6202	99.9311	100	100	100	100	100	100
Mar	100	100	100	100	100	100	100	29.1048	25.8658	15.2276	9.41153	5.90167	3.39398	1.40905	1.48153	1.80925	2.09976	84.6156	100	100	100	100	100	100
Apr	100	100	100	100	100	100	100	18.0589	18.1542	12.0455	7.7443	4.88971	2.47456	1.11331	1.2013	1.69382	1.17316	1.31826	2.30794	100	100	100	100	100
May	100	100	100	100	100	100	8.70555	13	13.6113	9.61926	6.23778	3.37078	1.4755	1.37486	1.21952	1.17871	1.38976	0.955026	1.18527	100	100	100	100	100
Jun	100	100	100	100	100	100	8.12898	10.8441	11.9985	9.82846	6.04416	3.98407	1.15014	1.03111	1.20815	1.22793	1.14052	1.54007	0.723337	100	100	100	100	100
Jul	100	100	100	100	100	100	21.4162	11.235	12.8491	10.2205	6.7773	3.97994	1.68276	1.0694	1.11859	1.21021	1.36753	1.19354	0.976274	100	100	100	100	100
Aug	100	100	100	100	100	100	100	14.6717	16.1392	11.1511	7.19818	4.80439	2.05039	0.82807	1.70312	1.23934	1.19383	1.36119	1.75896	100	100	100	100	100
Sep	100	100	100	100	100	100	100	25.2862	20.6461	12.8443	8.20394	5.40757	2.59148	1.38944	1.70179	1.1973	2.08203	35.084	100	100	100	100	100	100
Oct	100	100	100	100	100	100	100	48.6042	23.1554	13.068	8.16767	5.05996	3.09535	1.77817	1.87921	1.67651	88.1981	100	100	100	100	100	100	100
Nov	100	100	100	100	100	100	100	69.5814	23.2443	13.0036	8.11265	5.36148	3.39316	1.89715	1.96313	20.0015	100	100	100	100	100	100	100	100
Dec	100	100	100	100	100	100	100	62.1953	24.4157	13.1591	8.81242	5.77304	3.94217	2.33529	2.08202	24.7504	94.3109	100	100	100	100	100	100	100

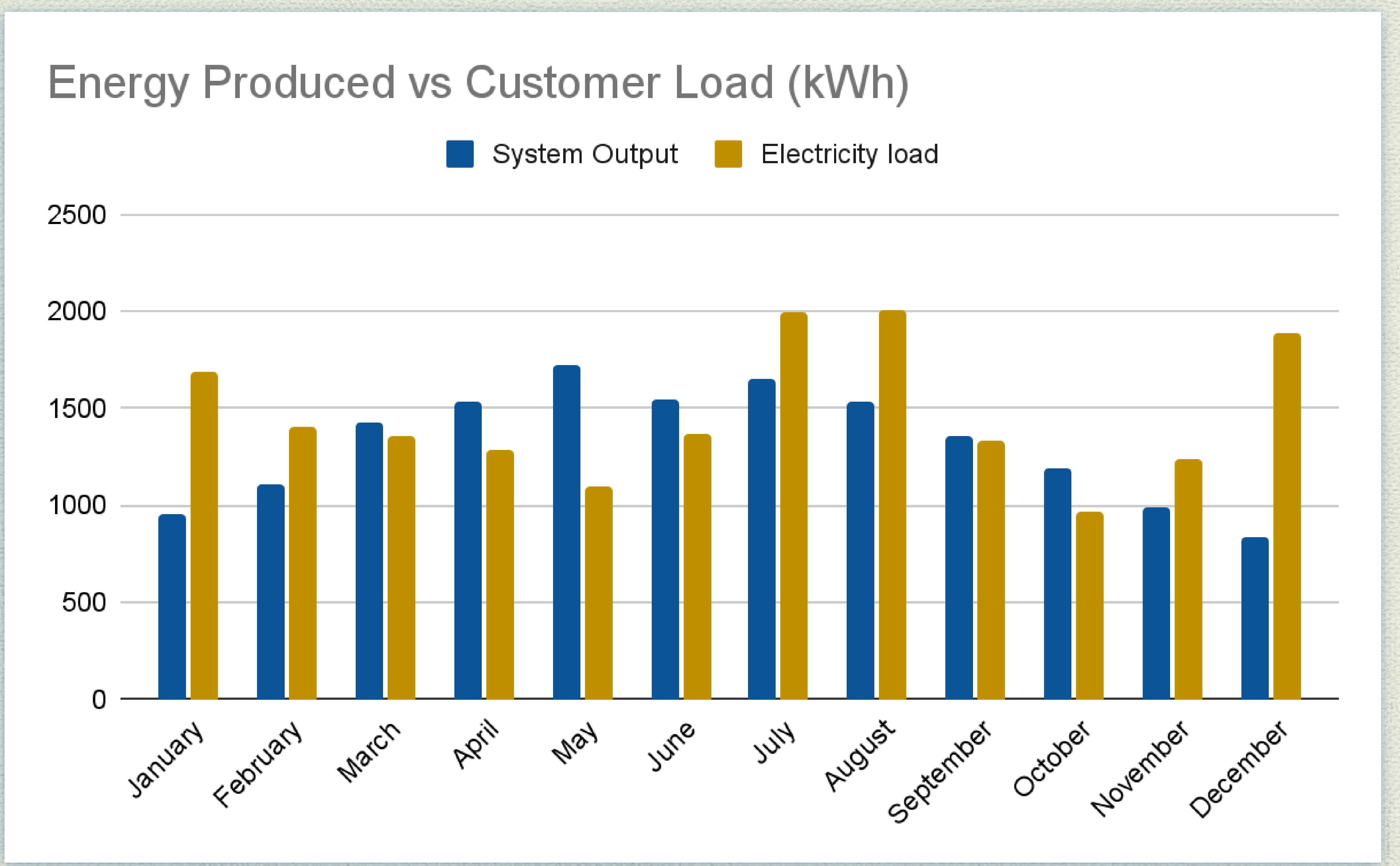
SAM Simulation

Shading of Array on Garage Roof

Subarray 2, String 1 — Shade Loss (%): 0=no shade, 100=fully shaded

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	100	100	100	100	100	100	100	0	0	0	0	0	0	0	0	1.9152	26.5861	100	100	100	100	100	100	100
Feb	100	100	100	100	100	100	100	0	0	0	0	0	0	0	0	3.7487	24.9822	100	100	100	100	100	100	100
Mar	100	100	100	100	100	100	100	0	0	0	0	0	0	0	1.18132	9.19712	30.0749	100	100	100	100	100	100	100
Apr	100	100	100	100	100	100	100	0	0	0	0	0	0	0	5.53689	18.0922	40.1534	90.5798	100	100	100	100	100	100
May	100	100	100	100	100	100	0	0	0	0	0	0	0	0.77507	9.5307	25.3044	50.7883	85.4122	100	100	100	100	100	100
Jun	100	100	100	100	100	100	0	0	0	0	0	0	0	1.1445	10.2262	26.2483	52.449	82.0617	100	100	100	100	100	100
Jul	100	100	100	100	100	100	0	0	0	0	0	0	0	0.191702	8.70424	23.5255	48.0631	79.014	100	100	100	100	100	100
Aug	100	100	100	100	100	100	0	0	0	0	0	0	0	0	6.48571	19.6052	41.5624	78.9364	100	100	100	100	100	100
Sep	100	100	100	100	100	100	100	0	0	0	0	0	0	0	3.72688	15.3708	38.8456	99.8661	100	100	100	100	100	100
Oct	100	100	100	100	100	100	100	0	0	0	0	0	0	0	1.57274	13.3951	79.9331	100	100	100	100	100	100	100
Nov	100	100	100	100	100	100	100	0	0	0	0	0	0	0	0.23021	10.7482	45.1789	100	100	100	100	100	100	100
Dec	100	100	100	100	100	100	100	0	0	0	0	0	0	0	0	5.40911	35.3424	100	100	100	100	100	100	100

SAM Results



Energy Produced vs Customer Load (kWh)
System Output
Electricity load
2500
2000
1500
1000
500
0
January
February
March
April
May
June
July
August
September
October
November
December

SAM Financials

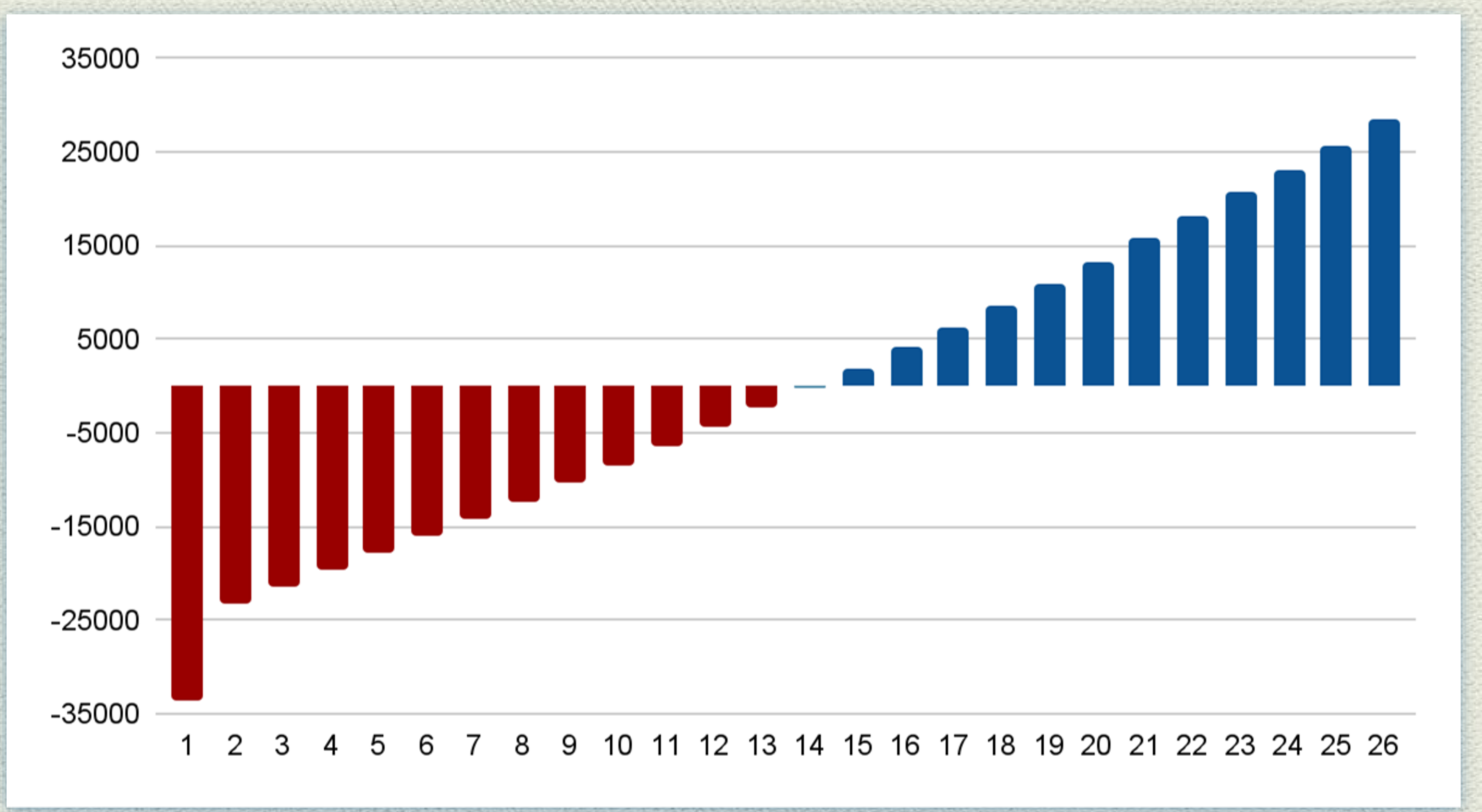
Incentives	
Federal ITC 26%	SRECS

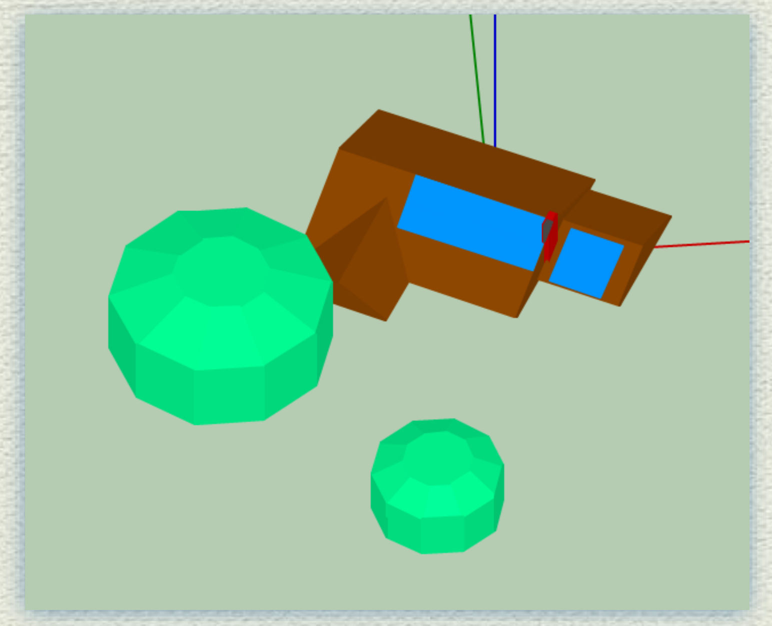
Electricity Demand and Rate Summary	
Fixed charge	$10.02/month
Monthly excess kWh rollover	
Flat energy buy rate	$0.13245/kWh

System Overview	
Annual Energy	15,858kWh
Performance Ratio	0.73
Energy bill without system	$2,455/year
Energy bill with system	$414/year
Net Savings	$2,041/year
Net Present Value	$8,309
Simple payback period	13.1years
Net capital cost	$33,535

Conclusions

Payback Cashflow ($)





Renewable Factor: 89.9%

NPV: $8,300

Electricity Bill Savings: 83.1%

References

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https://sam.nrel.gov/

THANK YOU!

Questions?