MONTANA STATE UNIVERSITY

Department of Mechanical and Industrial Engineering

ETME 470: Renewable Energy Applications

Residential Photovoltaic System

Final Report

By

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Introduction

This document entails the analysis and design of a residential photovoltaic system. The system will be designed to meet at least 80% of the average yearly home power consumption. Located near Santa Fe New Mexico, the site location is positioned precisely at coordinates 5°39'20.2"N 105°53'45.5"W. In the sections to come, the location, system design, and cost analysis will be discussed in detail. Along with these aspects, a full system design will be presented which will include, parts list, drawings, and wiring schematic.

Location Assessment

The location to be analyzed is located approximately 3.3 miles Southeast of Santa Fe New Mexico. Based on the information obtained from Google maps, the location appears to have a flat topped roof, and minimal tree cover. Data from NREL's Renewable Resource Data Center data was examined and tabulated in table 1, and is used in order to asses the available energy resources near the site. This data is based on the data collected from the nearest location, which in this case is the Santa Fe County Municipal Airport. Although this data was not acquired from our exact location, it is still close enough approximation that we can make an accurate assessment of the available resources. Along with this data, NREL's PVWatts calculator was used to aid in determining the size of the system needed to meet at least 80% of the locations average monthly usage.

Due to the large available surface area of the roof there are multiple options on where to place the array. As seen in figure 1, the decided location of the array will be installed on the center roof location. This location can be seen in figure 1. This is chosen because of the ability of the array to span from east to west.

Table 1: Usage/Solar Stats.	
Usage Stats	
Average Monthly Usage for New Mexico (kWh)	635
Average Energy Price for New Mexico (Cents/kWh)	12.47
Average Monthly Bill (Dollars and Cents)	$79.18
Average Daily Usage (kWh)	20.82
Solar Stats	
Longitudinal Location (deg-N)	35
Direct Normal Irradiance (kWh/sq.m./day)	6.3418
Global Horizontal Irradiance (kWh/sq.m./day)	5.13655
Average Sun Hours Per Day	6.8
Azimuth (deg)	180

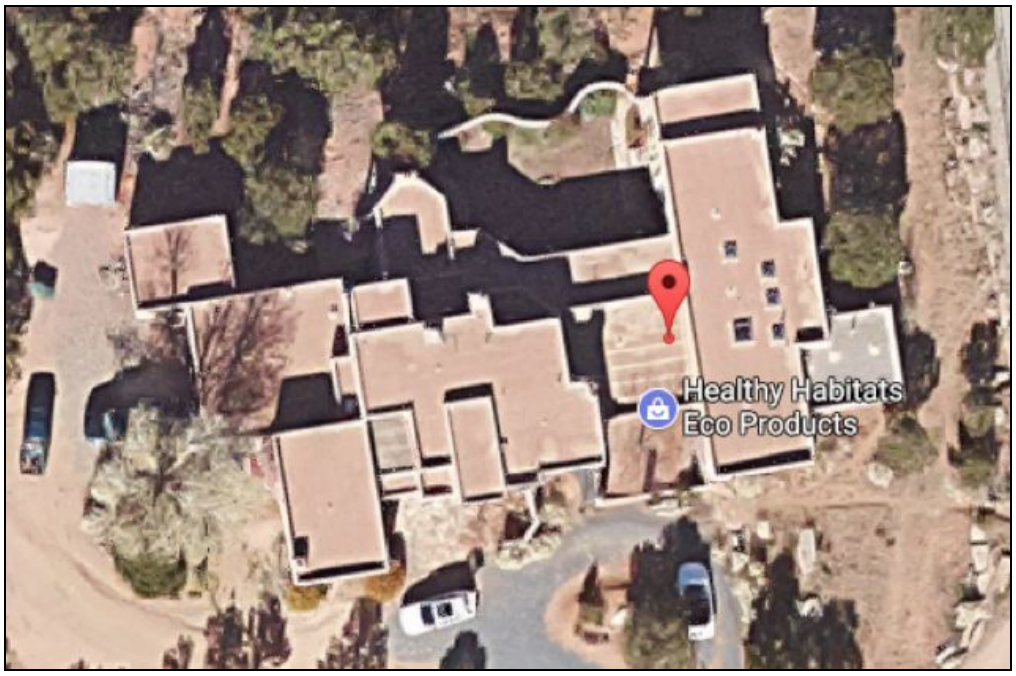


Figure 1. Proposed System Location

System Design

In order to insure the system meets the specifications stated above, the estimated output of the system was calculated using the PVWatts online tool. The results from this calculation can be seen in figure A.1. Due to individual panel output the system has been designed with a slightly larger output than needed to meet the 80% goal, with the total expected output of the system to account for 89% of energy needs. Each panel accounts for roughly 11% of the energy needs, by reducing the panel amount by 1 would drop the output to roughly 78% percent of the needs, therefore it was determined that it would be better to increase the panel count and allow for a system that would account for a larger share of the energy. This decision is made to allow for any unexpected system losses such as, panel degradation due to age, error in solar data, and various other unforeseen system losses.

Seen below in table 2 is an itemized list of system components. These components were chosen to allow for high performance and ease of install. Along with a List of components, is a detailed design drawing and wiring diagram. Due to the latitudinal location of the site, a panel tilt angle of 20^{o} was selected. This angle allows for an optimized direct solar irradiation on the panels throughout the year (figure 2).

Table 2: Component Information

Part Description	Quantity	Unit Price	Part No.
Panasonic Photovoltaic Panel	12	$332.00	VBHN315kAO1
Siemens DC Solar Disconnect Switch	1	$169.22	HNF362PV
SolarEdge Grid Tie Inverter	1	$1,399.00	SE5000H-USRGM
Siemens 60 Amp Non-Fusible AC Disconnect	1	$20.61	WF2060U
Link Solar Adjustable PV Panel Mounts	12	$99.99	B071CTVYNN
SouthWire 3 Black Stranded CU SIMpull THHN Wire	200 (ft)	$1.44	SW-24346999
SouthWire 10 Black Stranded CU THHN Wire	100 (ft)	$0.51	SW-22973299

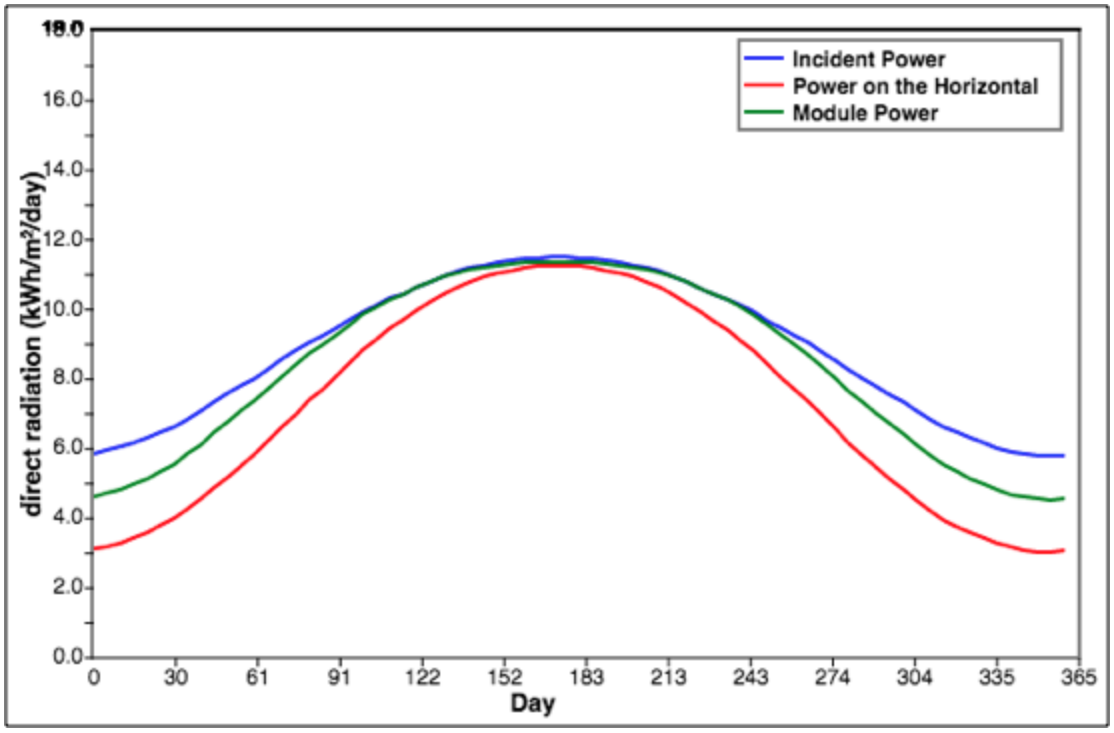


Figure 2. Direct Radiation Vs. Day

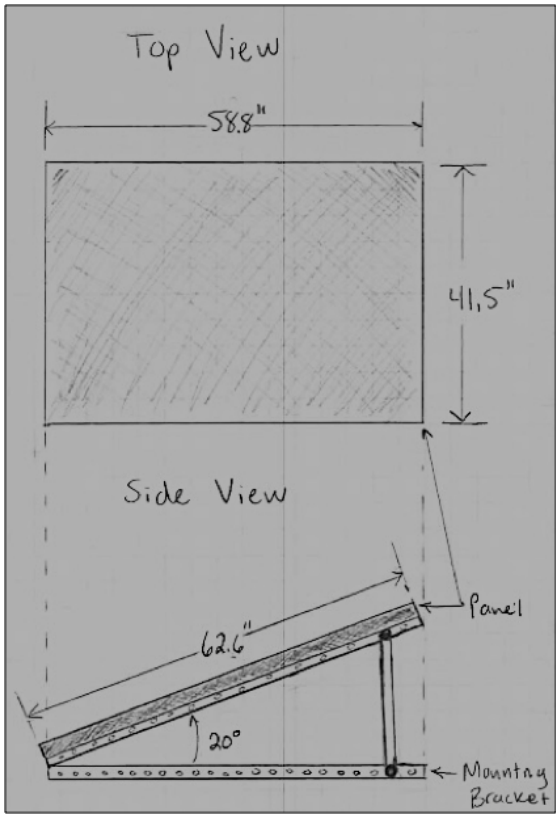


Figure 3. Panel Drawing.

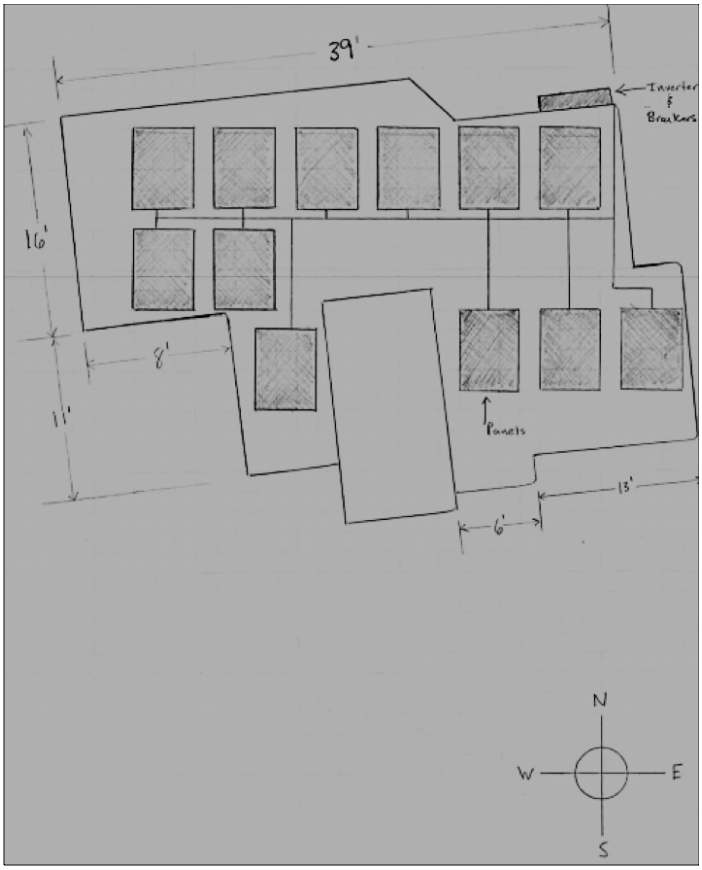


Figure 4. Array Placement on Roof.

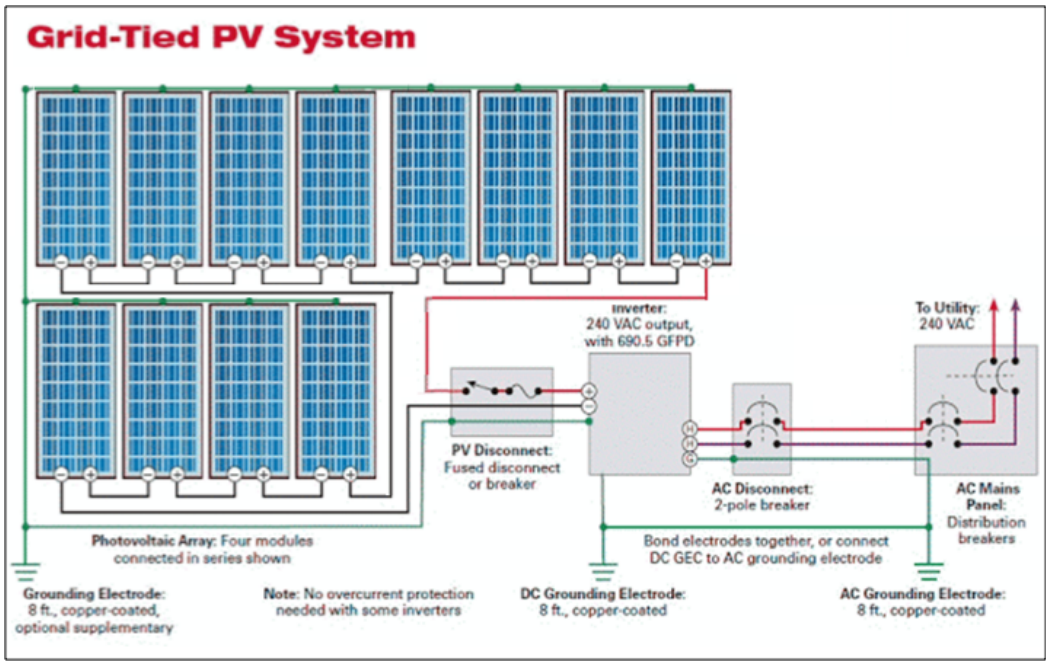


Figure 5. System Wiring Diagram.

Cost Analysis

Along with the design, a detailed cost analysis was conducted on the system. The analysis included such things as, cost of all system components, estimated cost of installation, and estimated tax brakes and subsidies. These figures, along with an estimated return on investment are tabulated in Table 3. The Return on investment is calculated based on the estimated annual system output and energy cost. The installation cost is estimated to cost approximately 0.33 $/Watt this estimation is based off of NREL's US Photovoltaic Cost Breakdown.

Table 3: Cost Analysis

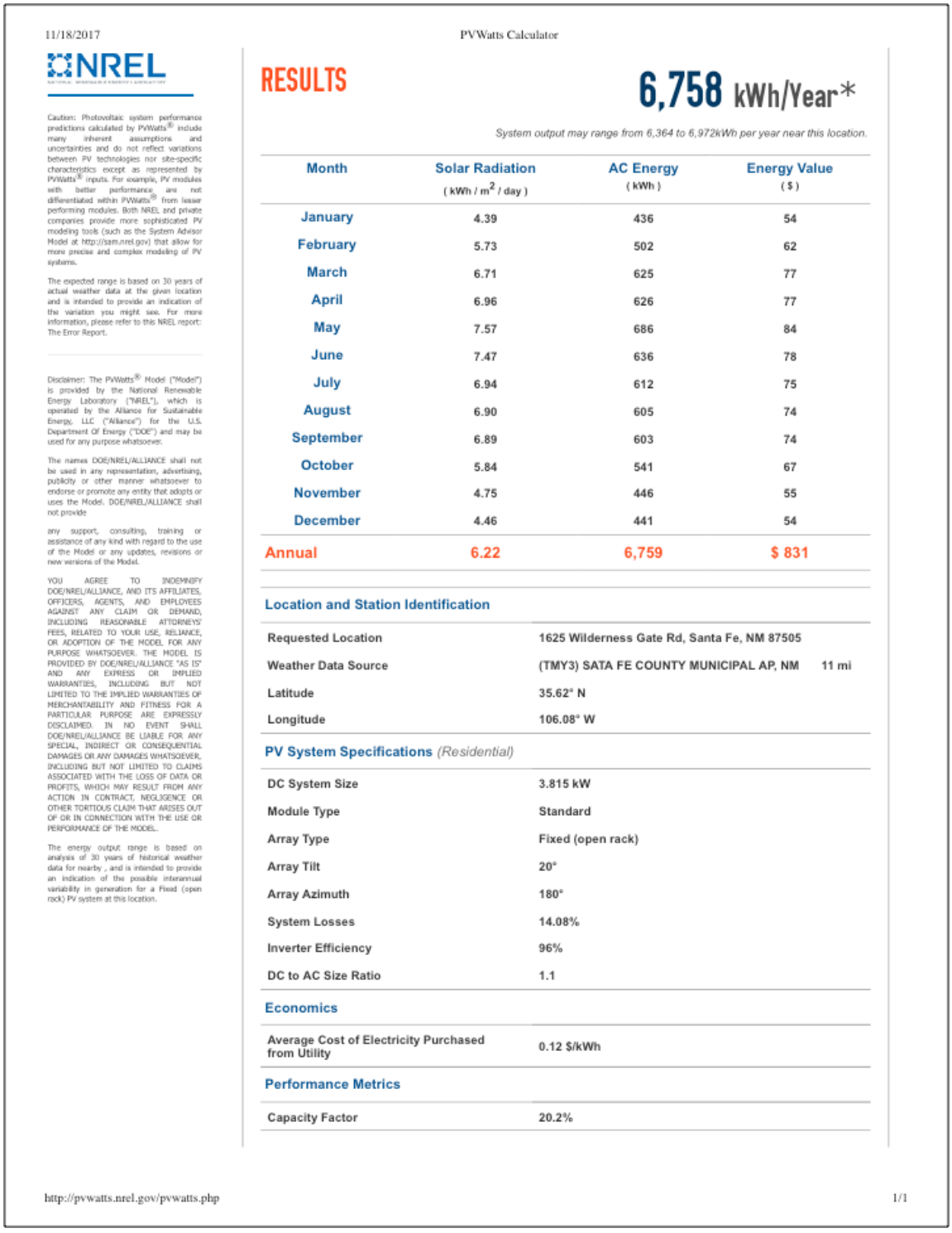
Part Description	**Quantity**	**Unit Price**	**Total Cost**
Panasonic VBHN315kAO1	12	$332.00	$4,020.89
DC Solar Disconnect Switch	1	$169.22	$169.22
SOLAREDGE SE5000H-USRGM GRID TIE INVERTER	1	$1,399.00	$1,399.00
Siemens WF2060U 60 Amp Non-Fusible AC Disconnect	1	$20.61	$20.61
Mounts	12	$99.99	$1,210.99
SouthWire 3 Black Stranded CU SIMpull THHN Wire	200	$1.44	$288.00
SouthWire 10 Black Stranded CU THHN Wire	100	$0.51	$51.00
Install ($/Watt)	3815	$0.33	$1,258.95
Tax Incentives/Subsities 20% of cost	1	-$1,626.13	-$1,626.13
Total System Cost			**$6,483.92**
Estimated Return on Investment (Years)			**7.8**

Executive Summary

Overall this location is well suited for a photovoltaic system. With its flat large roof, it has the capability to incorporate a large array of panels. Furthermore, the desert location and low latitude allows for large amounts of available power. Due to the desert location, the array will be capable of offsetting large amounts of power due to a large majority of power usage going to indoor climate control. This means that during days when the residence will be using Air Conditioning there will likely be large amounts of available solar energy.

The Proposed System will be capable of providing approximately 89% of the annual energy usage. With the system costing an estimated $6,484, and the average price per kilowatt around $0.12 per kWh, the system should pay for itself in about 7.8 years.

Appendix A:



11/18/2017 PVWatts Calculator

NREL

Caution: Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules. Both NREL and private companies provide more sophisticated PV modeling tools (such as the System Advisor Model at http://sam.nrel.gov) that allow for more precise and complex modeling of PV systems.

The expected range is based on 30 years of actual weather data at the given location and is intended to provide an indication of the variation you might see. For more information, please refer to this NREL report: The Error Report.

Disclaimer: The PVWatts® Model ("Model") is provided by the National Renewable Energy Laboratory ("NREL"), which is operated by the Alliance for Sustainable Energy, LLC ("Alliance") for the U.S. Department Of Energy ("DOE") and may be used for any purpose whatsoever.

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The energy output range is based on analysis of 30 years of historical weather data for nearby , and is intended to provide an indication of the possible interannual variability in generation for a Fixed (open rack) PV system at this location.

RESULTS

6,758 kWh/Year*

System output may range from 6,364 to 6,972kWh per year near this location.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value ($)
January	4.39	436	54
February	5.73	502	62
March	6.71	625	77
April	6.96	626	77
May	7.57	686	84
June	7.47	636	78
July	6.94	612	75
August	6.90	605	74
September	6.89	603	74
October	5.84	541	67
November	4.75	446	55
December	4.46	441	54
Annual	6.22	6,759	$ 831

Location and Station Identification

Requested Location	1625 Wilderness Gate Rd, Santa Fe, NM 87505	
Weather Data Source	(TMY3) SATA FE COUNTY MUNICIPAL AP, NM	11 mi
Latitude	35.62° N	
Longitude	106.08° W	

PV System Specifications *(Residential)*

DC System Size	3.815 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	1.1

Economics

Average Cost of Electricity Purchased from Utility	0.12 $/kWh

Performance Metrics

Capacity Factor	20.2%

http://pvwatts.nrel.gov/pvwatts.php 1/1

Table A.1. PVWatts Calculations

HIT®
Photovoltaic Module

Panasonic

N320K/N315K/N310K

ELECTRICAL SPECIFICATIONS

Model	VBHN320KA01	VBHN315KA01	VBHN310KA01
Rated Power (Pmax)[1]	320W	315W	310W
Maximum Power Voltage (Vpm)	58.7V	58.4V	58.1V
Maximum Power Current (Ipm)	5.46A	5.40A	5.34A
Open Circuit Voltage (Voc)	70.5V	70.2V	69.9V
Short Circuit Current (Isc)	5.89A	5.83A	5.76A
Temperature Coefficient (Pmax)	-0.258%/°C	-0.258%/°C	-0.258%/°C
Temperature Coefficient (Voc)	-0.16V/°C	-0.16V/°C	-0.16V/°C
Temperature Coefficient (Isc)	3.21mA/°C	3.21mA/°C	3.21mA/°C
NOCT	44.0°C	44.0°C	44.0°C
CEC PTC Rating	301.7	296.9	292.1
Cell Efficiency	21.6%	21.2%	20.9%
Module Efficiency	19.1%	18.8%	18.5%
Watts per Ft.²	17.8W	17.5W	17.2W
Maximum System Voltage	600V	600V	600V
Series Fuse Rating	15A	15A	15A
Warranted Tolerance (-/+)	+10%/-0%*	+10%/-0%*	+10%/-0%*

MECHANICAL SPECIFICATIONS

Model	VBHN320KA01, VBHN315KA01, VBHN310KA01
Internal Bypass Diodes	4 Bypass Diodes
Module Area	18.02 Ft.² [1.67m²]
Weight	40.81 Lbs. [18.5kg]
Dimensions LxWxH	62.6x41.5x1.4 in. [1590x1053x35 mm]
Cable Length +Male/-Female	40.2/40.2 in. [1020/1020 mm]
Cable Size / Type	No. 12 AWG / PV Cable
Connector Type[2]	Multi-Contact® Type IV (MC4™)
Static Wind / Snow Load	50 PSF [2400 Pa]
Pallet Dimensions LxWxH	63.7x42.2x65.4 in.
Quantity per Pallet / Pallet Weight	40 pcs. /1719 Lbs. [780 kg]
Quantity per 40' Container	560 pcs.
Quantity per 20' Container	240 pcs.

Operating Conditions & Safety Ratings

Model	VBHN320KA01, VBHN315KA01, VBHN310KA01
Operating Temperature	-40°F to 185°F [-40°C to 85°C]
Hail Safety Impact Velocity	1" hailstone [25mm] at 52 mph [23m/s]
Safety & Rating Certifications	UL 1703, cUL, CEC
UL 1703 Fire Classification	Type 2
Limited Warranty	25** Yrs Workmanship and Power Output (Linear)***

NOTE: Standard Test Conditions: Air mass 1.5; irradiance = 1000W/m²; cell temp. 25°C

* Maximum power at delivery. For guarantee conditions, please check our guarantee document.

** Installation need to be registered through our website www.panasonicsolarwarranty.com within 60 days in order to receive twenty-five (25) year Product workmanship. Otherwise, Product Workmanship will be only fifteen (15) years.

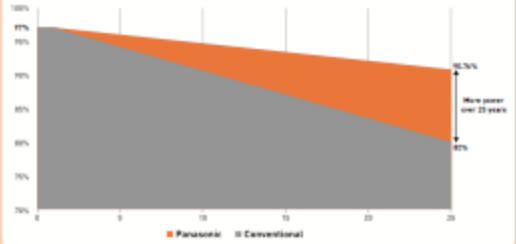
*** 1st year 97%, after 2nd year 0.26% annual degradation to year 25.

[1] STC: Cell temp. 25°C, AM1.5, 1000W/m²

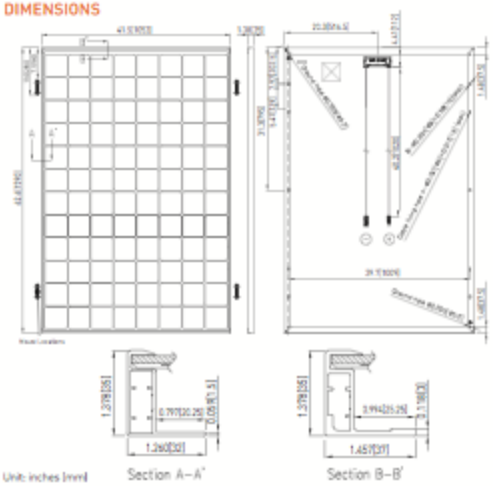
[2] Safety locking clip (PV-SSH4) is not supplied with the module.

NOTE: Specifications and information above may change without notice.

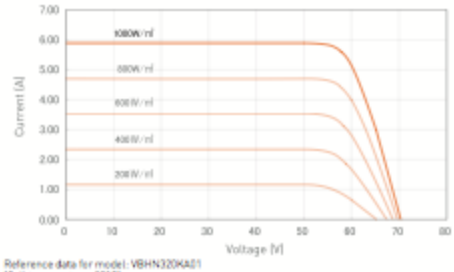
PERFORMANCE WARRANTY



DIMENSIONS



DEPENDENCE ON IRRADIANCE



Reference data for model: VBHN320KA01
(Cell temperature: 25°C)

⚠ CAUTION! Please read the installation manual carefully before using the products.

Used electrical and electronic products must not be mixed with general household waste. For proper treatment, recovery and recycling of old products, please take them to applicable collection points in accordance with your national legislation.

Panasonic

Panasonic Eco Solutions of North America
Two Riverfront Plaza, 5th Floor, Newark, NJ 07102
panasonicHIT@us.panasonic.com
business.panasonic.com/solarpanels

RS1717BK_DS

Figure A.2. Solar Panel Specifications

Appendix B: Sources

"National Renewable Energy Laboratory (NREL) Home Page | NREL." National Renewable Energy Laboratory (NREL) Home Page | NREL, www.nrel.gov/.

"Solar Radiation on a Tilted Surface." Solar Radiation on a Tilted Surface | PVEducation, www.pveducation.org/pvcdrom/properties-sunlight/solar-radiation-tilted-surface.

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Chung, Donald, et al. "U.S. Photovoltaic Prices and Cost Breakdowns." 2015, www.nrel.gov/docs/fy15osti/64746.pdf.

"SolarEdge HD Wave Single Phase Inverters." AltEstore.com, www.altestore.com/store/inverters/grid-tie-inverters/solaredge-hd-wave-single-phase-grid-tie-inverters-p40704/#SEDSE5000HRGM.

"Panasonic VBHN315KA01 HIT Black Solar Panel." RES Supply, ressupply.com/solar-panels/panasonic-vbhn315ka01-hit-black-solar-panel?gclid=Cj0KCQiA0b_QBRCeARIsAFntQ9oYP-1XrfNgj1vo7FDkCOHLxLhx1ewp-QPLvq43bc5UG67crEfcK5caAo3VEALw_wcB.

Google Maps, Google, www.google.com/maps/place/35%C2%B039'20.2%22N+105%C2%B053'45.5%22W/@35.6556111,-105.8959722,17z/data=!3m1!4b1!4m5!3m4!1s0x0:0x0!8m2!3d35.6556111!4d-105.8959722.