PAN FILE DEVELOPMENT REPORT

REC245PE

B&V PROJECT NO. 176585

PREPARED FOR

REC Solar US LLC

2 MAY 2012

BLACK & VEATCH
Building a world of difference.®

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Executive Summary

REC Solar US LLC (REC) contracted Black & Veatch to create a photovoltaic (PV) module characterization file (known as a "PAN" File) for use in PVsyst energy production simulation software for the REC245PE module. REC provided Black & Veatch with third-party test measurements from TÜV Rheinland labs (TÜV) which quantified various performance metrics of 220W, 225W, 235W, and 240W REC modules (in a pre-LID condition) at multiple irradiance and temperature conditions. In order to create a PAN file for the REC245PE module, Black & Veatch scaled the test result data from a REC240PE module and utilized data from the REC245PE module datasheet. The Optimized PAN file is to be used in PVsyst software version 5.55 for modeling the expected performance of the REC245PE.

Black &Veatch found that the Base Case PAN file (pre-optimization) resulted in efficiency curves that did not accurately represent the laboratory-measured efficiencies of the modules. The Base Case efficiency curves had a corresponding root sum square (RSS) deviation of 1.94% from the measured curves. Black & Veatch used the meteorological profile of Las Vegas, NV as a Test Case to assess the potential impact on estimated energy production that results from differences between the measured and Base Case efficiency curves. The Base Case PAN file underestimated expected energy production by 3.69% when compared to measured efficiency curves for the Las Vegas scenario. With the optimized PAN file developed by Black & Veatch, the magnitude and shape of the efficiency curves are more accurately represented, lowering RSS deviation to 0.23% and reducing forecasted Las Vegas energy production difference to only 0.35% below measured efficiency curves.

The optimized PAN file is provided separately as a ".PAN" file.

Note to PAN file users: This PAN file was derived from pre-LID laboratory measurements: therefore, an additional loss for LID *must* be factored in to the Module Quality Loss estimate within PVsyst.

1.0 Approach

The purpose of this effort was to create a PVsyst-compatible PAN file that more accurately represents a REC245PE module in operational conditions reducing the risk of production estimation underperformance caused by misrepresentation of module performance. To improve the accuracy of the PAN files, Black & Veatch developed the following approach:

Step 1- Measured Data: Black & Veatch used measured data from the TÜV report for a REC240PE module to generate scaled Measured efficiency curves for a REC245PE module. The TÜV test used REC240PE modules before light-induced degradation (LID); therefore the resulting efficiency curves are for pre-LID conditions. The efficiency curves describe module efficiency as a function of module temperature and irradiance at various conditions spanning 200 watts per square meter (W/m^2) to 1,000 W/m^2 and temperatures of 25˚C (Standard Test Conditions, STC) and 45.72˚C (Normal Operating Cell Temperature, NOCT).

Step 2 – Base Case: The Module datasheet values were used to create a Base Case PAN file, which PVsyst runs through its modified single diode model in order to generate expected module efficiency curves. These modeled efficiency curves are compared to the measured efficiency curves during the optimization process.

The expected performance difference between the measured curves and the Base Case curves was assessed using two metrics for comparison:

1. **Root Sum Square (RSS) Deviation**: The agreement between the modeled (PAN file) and measured efficiency curves was evaluated by analyzing the sum of the square of the differences, called the root sum square (RSS).

2. **Energy Production Test Case**: The estimated energy production difference between the measured and modeled scenarios was assessed using the temperature and irradiance-weighted profile of a 20 degree fixed tilt system in Las Vegas, Nevada, known as the Test Case. This provides a basis for comparison between the estimated measured energy production and modeled PAN file energy production. *Note that this metric is used in order to characterize the potential impact to energy production estimates and may vary based on site, design, and other system details.*

Step 3 – Optimization: Black & Veatch adjusted PAN file parameters in order to adjust the modeled efficiency curves generated by PVsyst to better match the measured efficiency curves.

Through an iterative process, the PAN file was optimized to minimize the deviation between these curves, which was assessed using the RSS deviation and Test Case comparison described in Step 2.

2.0 Results

2.1 MEASURED DATA

Black & Veatch used the TÜV test data supplied by REC to generate measured efficiency curves of the module as a function of irradiance and module temperature. The rated power (P_{mpp}) of TÜV test samples varied from the module's nominal power on the datasheet, but this variation was reduced by scaling each sample to achieve its precise nominal power at STC.

Measured test data was not available for the REC245PE module, therefore Black & Veatch used the measured test data for a REC240PE module and then scaled the data to reflect expected efficiency curves for a REC245PE module. The scaled REC240PE data was used to calculate the module efficiencies at test conditions. Efficiency is calculated as:

$$\text{Efficiency} = \frac{\text{Module Rating [Wp]}}{\text{Module Area [m}^2\text{]} * \text{Irradiance } \left[\frac{\text{W}}{\text{m}^2}\right]}$$

Figure 1 shows the scaled measured curves which define efficiency as a function of irradiance and module temperature for a REC245PE module. A comparison of measured maximum power at STC (25°C) and (NOCT) (45.72°C) is shown in

Table 1 below.

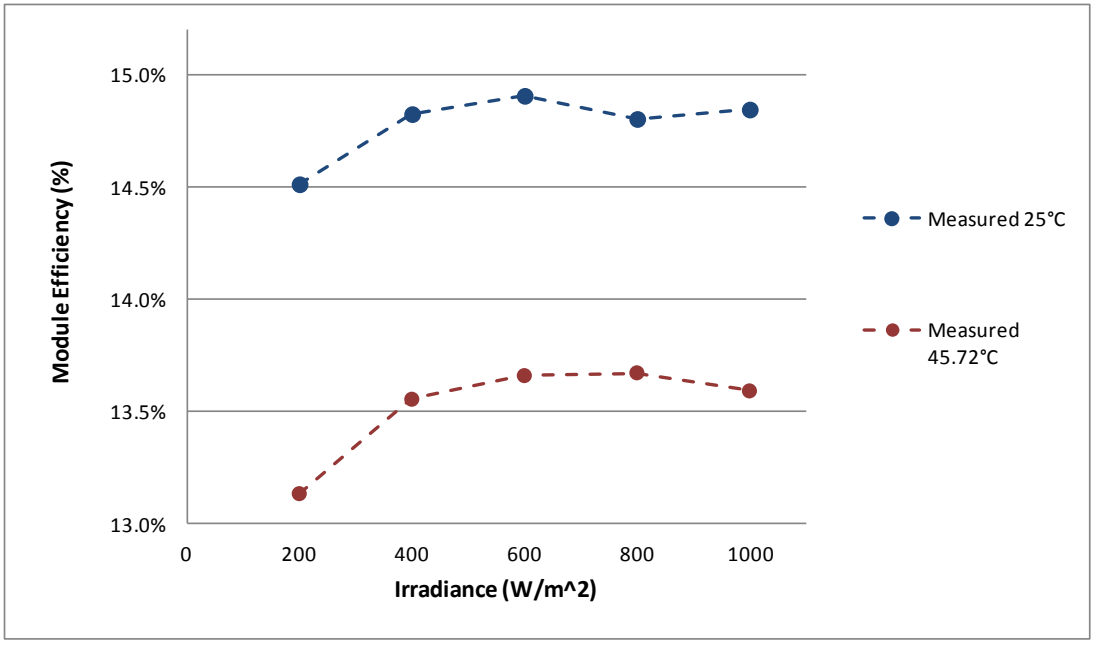


Figure 1 Measured (REC245PE) Efficiency Curves

Table 1 Measured Maximum Power (P_{mpp}) for a REC245PE module

IRRADIANCE (W/M^2)	MEASURED AT STC 25°C (W)	MEASURED AT NOCT 45.72°C (W)
200	47.9	43.3
400	97.9	89.5
600	147.6	135.2
800	195.4	180.5
1000	245.0	224.3

2.2 BASE CASE

In order to create a Base Case PAN file the values for module area, short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), maximum power current (I_{mpp}), maximum power voltage (V_{mpp}), and temperature coefficient of I_{sc} and P_{mpp} were taken from the module datasheet and input into PVsyst. All other module parameters remained at the PVsyst default values. The inputs to PVsyst are summarized in Table 2. The efficiency curves of the Base Case PAN files are shown in Figure 2 (PVsyst output) and are compared with the scaled measured curves in Figure 3.

Table 2 Summary of Inputs and Sources for the REC245PE Base Case Model

REC245PE	VALUE	SOURCE
I_{sc} (A)	8.68	Datasheet
V_{oc} (V)	37.2	Datasheet
I_{mpp} (A)	8.12	Datasheet
V_{mpp} (V)	30.2	Datasheet
Temp. Coeff. I_{sc} (mA/°C)	6.42	Datasheet
Temp. Coeff. P_{mpp} (%/°C)	-0.43	Datasheet
Shunt Resistance R_{sh} (Ohm)	250	PVsyst Default
Series Resistance R_s (Ohm)	0.139	PVsyst Default
Rshunt at Ginc=0 (Ohm)	1000	PVsyst Default
Rshunt Exponential Parameter	5.5	PVsyst Default

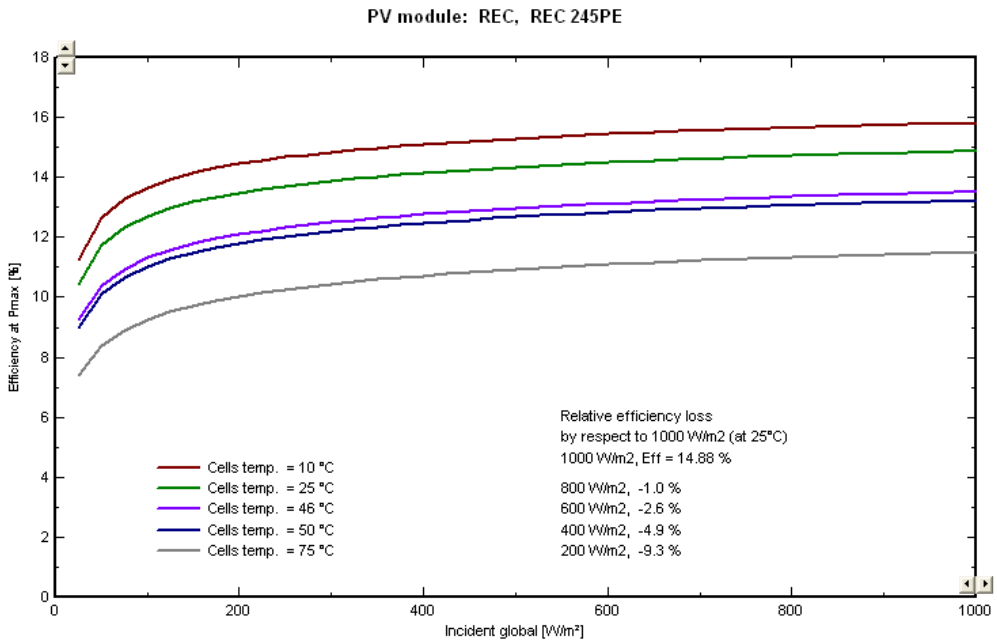


Figure 2 Base Case PAN File Efficiency Curves for REC245PE

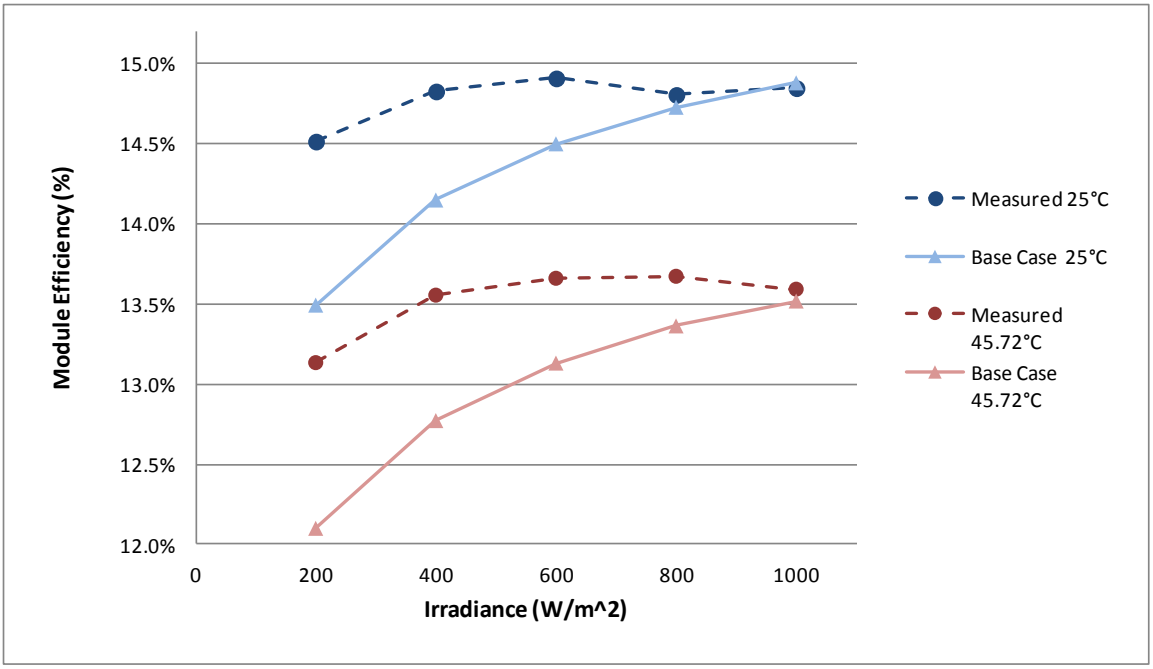


Figure 3 Measured (Scaled) and Based Case Efficiency Curves for REC245PE

The results of Black & Veatch's comparative metrics for the Base Case PAN File (as defined in Section 1.3) are shown in Table 3 below.

Table 3 Base Case PAN File Results

REC245PE	ROOT SUM SQUARE (RSS) DEVIATION	ENERGY PRODUCTION DIFFERENCE FROM LAS VEGAS TEST CASE*
Base Case	1.94%	-3.69%

*** A negative value indicates that the PAN file as generated will tend to underestimate performance, while a positive value indicates that the PAN file will overestimate performance**

As shown in Table 3, the root sum square deviation between the Base Case and measured curves is 1.94%. Due to the deviation between the curves ,the Base Case efficiency curves underestimate performance by 3.69% as compared to the measured curves using the temperature and plane-of-array irradiance profile generated from the Las Vegas, NV Test Case.

2.3 OPTIMIZATION

Black & Veatch used a process to minimize RSS by refining the parameters which define the optimized PAN file. This was done by varying series resistance, shunt resistance, P_{mpp} temperature coefficient and I_{sc} temperature coefficient in PVsyst in order to adjust the optimized PAN file efficiency curves to better represent the measured efficiency curves. Through this process Black & Veatch identified series resistance as the key parameter that required adjustment in order to achieve optimization. This optimized input into PVsyst is summarized in Table 4. The efficiency curves of the optimized PAN file from PVsyst are shown in Figure 4 and these are compared with the measured and Base Case curves in Figure 5.

Table 4 Summary of Adjusted Inputs for Optimized PAN File

REC245PE	VALUE
Series Resistance R_s (Ohm)	0.350

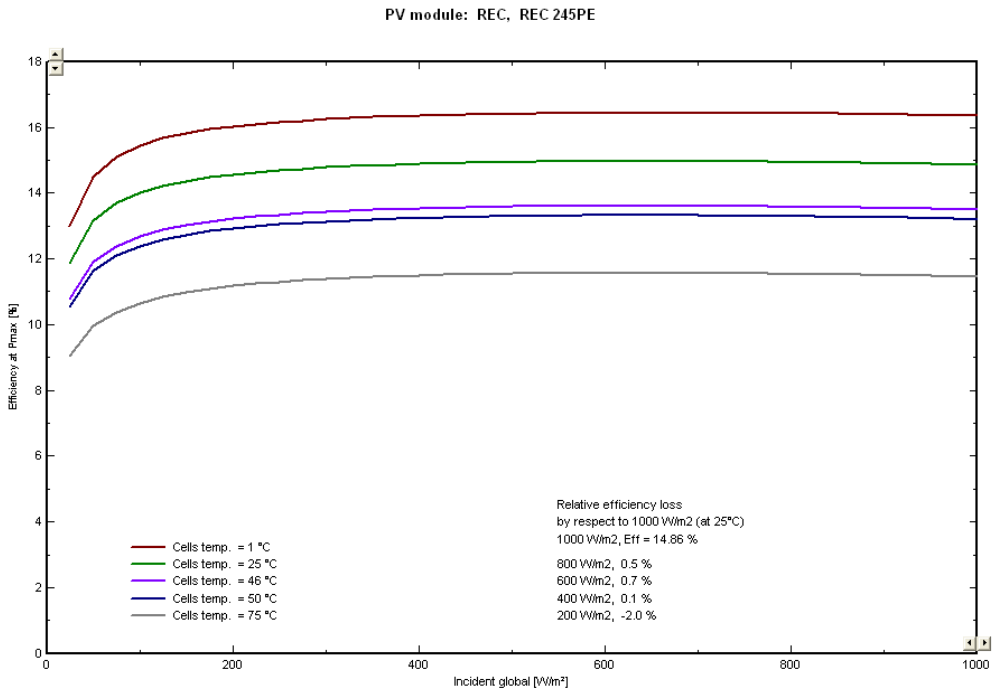


Figure 4 Efficiency Curves for the Optimized REC245PE PAN File

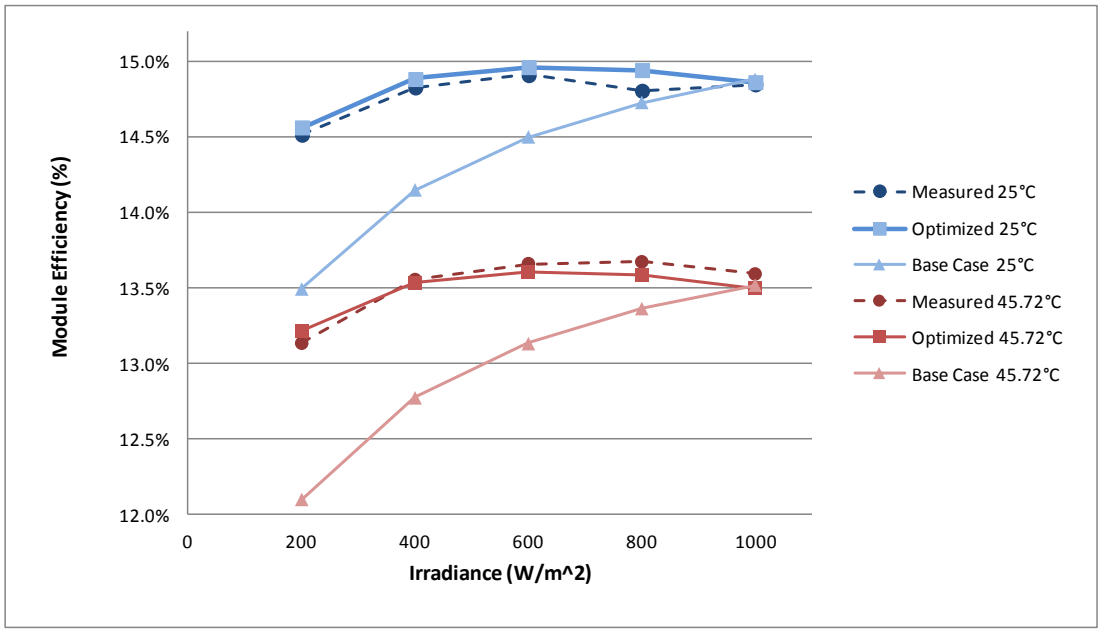


Figure 5 Measured, Base Case and Optimized Efficiency Curves for REC245PE

Table 5 compares the Base Case efficiency curves to the optimized efficiency curves. The RSS deviation between the optimized and measured curves is 0.23% after the optimization process, showing a reduction in deviation by approximately a factor of eight from the Base Case. The optimized PAN file energy production was compared to the expected measured energy production by using temperature and irradiance weights derived from the Las Vegas Test Case. The difference in expected performance between the measured curves and Optimized curves is -0.35%, a reduction in deviation by approximately a factor of ten over the Base Case.

Table 5 Optimized PAN File vs. Base Case

REC245PE	ROOT SUM SQUARE (RSS) DEVIATION FROM MEASURED EFFICIENCY CURVES	ENERGY PRODUCTION DIFFERENCE FROM LAS VEGAS TEST CASE*
Base Case	1.94%	-3.69%
Optimized	0.23%	-0.35%

*** A negative value indicates that the Revised PAN file under estimates performance.**

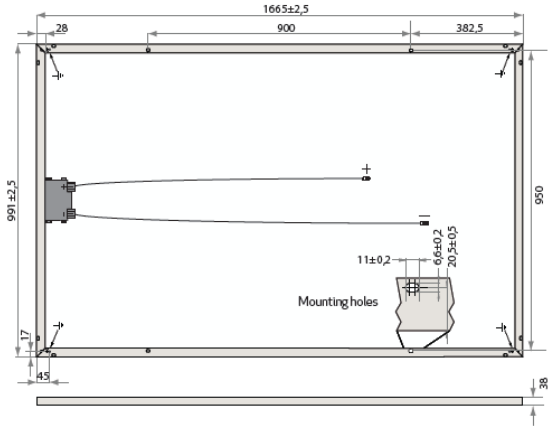
3.0 Conclusions

In summary, Black &Veatch found that the Base Case PAN file (pre-optimization) created from the module datasheet and PVsyst default settings resulted in efficiency curves that did not accurately represent the expected measured efficiencies of the modules. The Base Case efficiency curves had a corresponding root sum square (RSS) deviation of 1.94% from the measured data. For the Las Vegas Test Case used to assess accuracy in modeling actual production, the Base Case PAN file underestimated energy production at test conditions by 3.69% when compared to measured efficiency curves. With the optimized PAN file developed by Black & Veatch, the magnitude and shape of the efficiency curves are more accurately represented, lowering RSS deviation to 0.23% and reducing the difference in energy production to only 0.35% below measured efficiency curves for the Las Vegas Test Case.

Note to PAN file users: This PAN file was derived from pre-LID laboratory measurements, therefore an additional loss for LID *must* be factored in to the Module Quality Loss estimate within PVsyst.

Appendix A Module Datasheet

REC PEAK ENERGY SERIES



15.1% EFFICIENCY

10 YEAR PRODUCT WARRANTY

25 YEAR LINEAR POWER OUTPUT WARRANTY

TEMPERATURE RATINGS	
Nominal Operating Cell Temperature (NOCT)	47.9°C (±2°C)
Temperature Coefficient of P_{MPP}	-0.43 %/°C
Temperature Coefficient of V_{OC}	-0.33 %/°C
Temperature Coefficient of I_{SC}	0.074 %/°C

ELECTRICAL DATA @ STC	REC225PE	REC230PE	REC235PE	REC240PE	REC245PE	REC250PE
Nominal Power - P_{MPP} (Wp)	225	230	235	240	245	250
Watt Class Sorting - (W)	0/+5	0/+5	0/+5	0/+5	0/+5	0/+5
Nominal Power Voltage - V_{MPP} (V)	28.9	29.2	29.6	29.9	30.2	30.5
Nominal Power Current - I_{MPP} (A)	7.79	7.88	7.96	8.04	8.12	8.20
Open Circuit Voltage - V_{OC} (V)	36.2	36.5	36.7	37.0	37.2	37.5
Short Circuit Current - I_{SC} (A)	8.34	8.43	8.51	8.60	8.68	8.76
Module Efficiency (%)	13.6	13.9	14.2	14.5	14.8	15.1

Values at standard test conditions STC (airmass AM 1.5, irradiance 1000 W/m², cell temperature 25°C).
At low irradiance of 200 W/m² (AM 1.5 and cell temperature 25°C) at least 97% of the STC module efficiency will be achieved.

GENERAL DATA	
Cell Type	60 REC PE multi-crystalline cells 3 strings of 20 cells - 4 by-pass diodes
Glass	3.2 mm solar glass with anti-reflection surface treatment by Sunarc Technology
Back Sheet	Double layer highly resistant polyester
Frame	Anodized aluminium
Junction box	IP67
Cable	4mm² solar cable, 0.90m +1.20m
Connectors	Hosiden 4mm² (HSC 2009/2010) MC4 connectable

ELECTRICAL DATA @ NOCT	REC225PE	REC230PE	REC235PE	REC240PE	REC245PE	REC250PE
Nominal Power - P_{MPP} (Wp)	167	170	173	176	179	182
Nominal Power Voltage - V_{MPP} (V)	26.6	26.8	27.1	27.3	27.6	27.9
Nominal Power Current - I_{MPP} (A)	6.27	6.33	6.39	6.45	6.51	6.56
Open Circuit Voltage - V_{OC} (V)	33.4	33.6	33.8	34.1	34.3	34.5
Short Circuit Current - I_{SC} (A)	6.79	6.85	6.90	6.96	7.01	7.06

Nominal cell operating temperature NOCT (800 W/m², AM 1.5, windspeed 1 m/s, ambient temperature 20°C).

MAXIMUM RATINGS	
Operational Temperature	-40 ... +80°C
Maximum System Voltage	1000V
Maximum Snow Load	550 kg/m² (5400 Pa)
Maximum Wind Load	244 kg/m² (2400 Pa)
Maximum Series Fuse Rating	25A
Maximum Reverse Current	25A

CERTIFICATION

Certified to IEC 61215 & IEC 61730, IEC 62716 (ammonia resistance) & IEC 61701 (salt mist - severity level 6).

Member of PV Cycle

WARRANTY

10 year product warranty.
25 year linear power output warranty
(max. degression in performance of 0.7% p.a.).

MECHANICAL DATA	
Dimensions	1665 x 991 x 38 mm
Area	1.65 m²
Weight	18 kg

Note! Specifications subject to change without notice.

Rev K: 01.2012

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