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Technical Report

Validation of a Photovoltaic Module Energy Ratings Procedure at NREL

B. Marion, B. Kroposki, K. Emery, J. del Cueto,
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National Renewable Energy Laboratory

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Prepared under Task No. PV907101

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1.0 Background and Overview

Photovoltaic (PV) module manufacturers have typically supplied a module's rating (power, open-circuit voltage, short-circuit current, peak-power voltage and current) at Standard Reporting Conditions (SRC) (also called Standard Test Conditions or STC (1000 W/m^2 Irradiance, 25°C cell temperature, and AM1.5 Spectrum)). However, these conditions are rarely encountered in the field. The power that a module produces at SRC is a useful number for comparing the performance of modules under fixed conditions, but is not particularly helpful in describing how a module will perform under a range of actual conditions. PV manufacturers may also provide the module's voltage and current temperature coefficients. With these parameters, a user can translate the module's I-V curve to another set of conditions using ASTM E 1036-96 [1], but translation accuracy is strongly dependent on the translation range. This document will show that with a few modifications to the ASTM procedure, a more accurate way to translate I-V curves can be used to predict module performance under all conditions. This procedure will be applied to selected reference days for the purpose of determining module energy ratings.

The need for something beyond an STC power rating goes back to Gay's AM/PM approach [2]. AM/PM is simply the module energy produced for a standard day as defined by profiles of irradiance, ambient temperature, and air mass. Through AM/PM, Gay was trying to characterize the module's thermal response to ambient conditions and its power production as a function of irradiance, air mass, and module temperature. This approach was a step toward defining PV module power output over time or energy.

Pacific Gas and Electric Co. and others [3] found that most PV modules mounted outdoors rarely, if ever, produced their rated power [4]. This discrepancy is due, in large part, because under irradiance conditions greater than 500 W/m^2, PV modules typically operate much hotter that the 25°C cell temperature specified by SRC. Based on this experience, systems procured by the Photovoltaics for Utility Scale Applications (PVUSA) project are rated at PVUSA Test Conditions (PTC) (1000 W/m^2 irradiance, 20°C ambient temperature, and 1 m/s wind speed) which are more indicative of peak performance conditions in a particular location, (Davis CA). By specifying ambient conditions rather than module conditions, PTC also allows for a more realistic comparison of modules and array designs having different thermal characteristics. PTC ratings were based on regression analysis of the module's performance over a period of 30 days.

Although PTC does give performance at conditions that are more representative of actual outdoor exposure, a single point rating does not account for variations in performance with changing conditions. Specifically, different technologies have different temperature coefficients (change in device performance due to changing temperatures) and spectral response characteristics that cause their performance to vary with changing conditions.

In 1990, a rating based on realistic reporting conditions (RRC) was proposed [5]. This method uses the 2-diode model to describe the performance of a solar cell. This model incorporates temperature and irradiance effects. Then a spectral correction is made based on the spectral response function of the device. The module's output is then calculated under various operating conditions. This method used efficiency under different operating conditions to differentiate the performance of different modules.

In 1994, Sandia National Laboratories began developing a method to predict module output under any operating conditions [6]. The Sandia method compensates for the influences of irradiance, temperature, air mass, and angle-of-incidence on module performance. Module characterization is developed from data collected on module performance outdoors on a two-axis tracker during a period of one or more days.

In 1994, the National Renewable Energy Laboratory (NREL) conducted research to determine how well current module energy rating techniques predicted power output [7]. From this research, NREL then initiated an effort to develop a consensus-based approach to rating photovoltaic modules, based on results of previous energy ratings research. This new approach was intended to address the limitations of the de facto standard module power rating at Standard Reporting Conditions. Using technical input from a number of sources and under the guidance of an industry-based Technical Review Committee, the approach described by Whitaker (1998) [8] was developed.

Based on work done by Anderson [9], a module energy rating (MER) was developed that consists of 10 estimates of how much energy a module of a particular type will produce in one day: one estimate for each of five different weather/location combinations and two load-types. The five weather and location combinations are representative of the range of environmental conditions anticipated for typical uses of PV modules in the United States.

The MER makes the following assumptions for all modules. The modules are mounted in an open rack and face due south. For flat-plate modules, the module is assumed to be fixed at latitude tilt. For concentrating systems, the modules are assumed to be tracking in the 1 or 2 axis configuration per the system design. For flat-plate tracking systems, a modifier based on amount of increased irradiance can be used.

One of the key ingredients of the MER is the selection of appropriate weather data. The weather data should define extreme conditions that will allow differences in module design and performance to be discernable. To emphasize the standardization of the input weather data, the National Solar Radiation Database was selected as the source of the data [10]. It is available on CD-ROM and provides a complete set of hourly data specified by a site (city name) and date. The final locations were chosen based on criteria developed by the Technical Review committee for describing the following day types: Hot Sunny, Hot Cloudy, Cold Sunny, Cold Cloudy, and Nice (Cool Sunny). It was decided that users might find actual data from specific dates and locations a bit more descriptive and useful. The days that were chosen from the database are described below.

***Hot Sunny*:** Phoenix, AZ, June 24, 1976. This day exemplifies the summer in the desert southwest: hot, dry, and clear.

***Cold Sunny*:** Alamosa, CO, February 8, 1961. With the extremely high direct normal irradiance (DNI) and low temperature, this day should produce peak power values. However, because it is in the winter, the short length of day will limit module energy.

***Hot Cloudy*:** Brownsville, TX, July 4, 1983. The medium irradiance levels and high temperatures of these conditions will emphasize low sensitivity to temperature.

***Cold Cloudy*:** Buffalo, NY, December 6, 1985. Cold and cloudy conditions are particularly severe for photovoltaic energy generation because of the generally lower irradiance levels. These conditions will allow performance comparisons for wintertime carry-through capability.

***Nice*:** Sacramento, CA, May 4, 1967. This is intended to be an average day, not too hot and not too cold. It also has lots of sun and is therefore an ideal day for photovoltaic energy production.

The environmental conditions include: location, time, date, global horizontal irradiance, direct normal irradiance, diffuse irradiance, plane-of-array irradiance, ambient temperature, wind speed, relative humidity, and a spectral distribution.

The spectral distribution tables were developed using the SEDES2 model developed by Nann and Riordan [11]. The model uses pressure, dewpoint temperature, solar geometry, diffuse horizontal and plane-of-array irradiance, and direct irradiance, as well as exoatmospheric spectrum, typical clear sky absorption characteristics, and a set of empirically derived, spectral cloud-cover model coefficients to calculate the spectrum at the site.

Two load types are assumed, corresponding to the two most common loads connected to PV modules: maximum power tracking for grid-tied applications, and a voltage profile for battery charging. For purposes of rating comparison, a nominal 12 volts per battery is assumed. The nominal 12 V value may be divided by the recommended number of modules and multiplied by the recommended number of batteries to obtain a battery profile for purposes of rating. If the manufacturer does not recommend this module for battery application, then the modules need not be rated for battery charging. It is assumed that there is no voltage drop between the PV module and battery.

The battery voltage tables for each reference day were developed by maximizing the total amount of current delivered from the module. Therefore, the battery is assumed to be fully discharged at the beginning of the day and is charged based on the irradiance level divided by the total irradiance on the peak sun-hour reference day. Although this may not actually happen under actual operating conditions, it provides a consistent way of measuring module performance.

The method currently incorporated into ASTM E 1036-96 for translating I-V curves was developed by Anderson [12]. One problem with these equations is that they do not vary fill factor over the translation range. Work at NREL found that with a few modifications to address fill factor changes, the ASTM method could be used for module energy ratings. This new revised procedure is described in this document and is given in procedural form in Appendix A.

2.0 Reference Days

2.1 Selecting Representative Reference Day Data

The rating methodology reports energy production under five selected types of days ***representativ**e* of possible operational environments. We describe the development and application of qualitative and quantitative criteria for identifying and selecting these representative days from the 30-year U.S. National Solar Radiation Data Base.

2.2 Reference Day Selection Criteria

Following the ideas of Anderson [9], the proposed methodologies play module performance characteristics (e.g., temperature and irradiance coefficients, spectral response) against environmental factors represented by five characteristic days. The days are qualitatively described as *Hot Sunny*, *Hot Cloudy*, *Cold Sunny*, *Cold Cloudy*, and *Nice*. After discussion with experienced professionals involved in PV performance testing, initial guidelines for each of the five reference days shown in Table 2-1 were established. Parameters examined were ambient temperature, wind speed, relative humidity, cloud cover, and global horizontal solar irradiance.

Table 2-1. Initial *Subjective* Parameter Estimates for Reference Day Parameters

Profile	Peak W/m²	Daytime °C	Wind Speed (m/s)	Humidity (Percent)	Cloud Cover (tenths)
Hot Sunny	> 1000	>35	Low	Low	0
Cold Sunny	>900	Max 0	Avg	High	<3
Hot Cloudy	<400	>30	Avg	High	>5
Cold Cloudy	200-400	Max 0	High	High	>9
Nice	800-900	20	Avg	Avg	<3

2.3 Searching for Reference Days

We searched for historical meteorological and solar irradiance data that might match these initial criteria, and checked that the conditions found were self-consistent. NREL and the National Climatic Data Center (NCDC) had jointly developed the Solar and Meteorological Surface Observation Network (SAMSON) CD-ROM data set, also referred to as the National Solar Radiation Data Base (NSRDB) [13]. NSRDB contains 30 years (1961-1990) of hourly solar radiation and meteorological data for 239 cities in the United States, or over 2.5 million site-days. We felt sufficient representative days could be extracted to compare with the proposed parameter limits. Each of the 239 sites' 30-year hourly data files contains 16 megabytes. Rather than directly search this huge volume of data, we took advantage of statistical summaries produced as the data base was constructed. We examined so-called "Daily Statistics Files," which contain the monthly average daily values for every site-month [14].

We established reasonable quantitative bounds shown in Table 2-2 for the monthly mean values of the parameters in Table 2-1. A search program was written to examine the monthly average daily statistical files for data within the range of these values. If the mean values fell within our prescribed limits, that particular site-month was added to a list comprising all site months where the criteria were met. The total number of candidate site-months meeting the criteria are also listed in Table 2-2. These search and list operations were performed for each of the five types of days. Table 2-3 is an example of the contents of a daily statistics file.

Table 2-2. Bounds on Daily Average Parameters to Identify Candidate Months

Profile	Daily Avg. Wh/m²	Daytime Avg. °C	Wind Speed (m/s)	Relative Humidity (Percent)	# of Candidate Site Months
Hot Sunny	Direct> 10000	>35	<3	N/A	39
Cold Sunny	Direct>6500	< 2	>3	60<RH<70	24
Hot Cloudy	Global <3500	>30	<4	RH>80	127
Cold Cloudy	1200<Global	<1	N/A	N/A	476
Nice	6000<GH<6500	19.5<T<20.5	<4	RH<30	70

The summary list of candidate stations-months, with the quantitative data for each parameter, became an input file to a program to compute the arithmetic mean for the parameters for all candidate site-months. Specific site-months with values of the monthly daily means near the overall mean of all monthly daily mean were identified. The identified site months (one for each type of day) were extracted from the full NSRDB hourly data set. Individual days within the selected site-months were examined to identify days that agreed reasonably well with the criteria of Table 2-2, and a single day with parameter values nearest the Table 2-2 criteria was selected.

2.4 Results: Selected Reference Days

Table 2-4 compares the overall candidate site-month daily mean values (**bold**) with the irradiance totals for the day. Average values of the other parameters through the selected day are compared with the overall candidate site-month daily mean values. In Table 2-5, we compare the desired subjective criteria with the selected day parameters. Note that in some cases, the subjective criteria are not met.

The main reason for this result is that for the combination of all subjective parameters we established, such as low wind speeds and high irradiances, these conditions just did not occur. That is, no single candidate site month met all of the criteria simultaneously. Thus restrictions on the range of parameters (especially wind speed and global horizontal irradiance) were relaxed a little at a time (in steps of 10% of the maximum value), until a reasonable sample size (more than 20) of candidate site-months was available.

Table 2-3. Example Daily Statistics File Showing Monthly Daily Average Values for NSRDB/SAMSON Data Base Parameters.

```
94918 OMAHA                    NE  -6  N41 22  W 96 31   404   976
 1961-1990
 MO AVGLO FL SDGLO AVDIR FL SDDIR AVDIF FL SDDIF AVETR AETRN  TOT  OPQ   H2O   TAU  MAX_T  MIN_T  AVG_T  AVGDT  RH  HTDD  CLDD AVWS
  1  2109 F4   172  3255 F4   766   963 F5   137  4103 13264  5.9  4.9  0.63  0.06  -0.41 -11.73  -6.06  -4.49  71   763     0  4.6
  2  2899 F4   241  3565 F4   807  1331 F5   177  5587 14626  6.3  5.3  0.69  0.07   2.81  -8.52  -2.84  -1.24  71   610     0  4.6
  3  3893 F4   441  3924 F4   960  1758 F5   143  7638 16258  6.5  5.5  0.90  0.10   9.69  -2.37   3.68   5.36  67   471     1  5.1
  4  5014 F4   452  4508 F4   888  2168 F5   169  9631 17852  6.1  5.3  1.27  0.12  17.68   4.40  11.06  12.96  61   236    12  5.2
  5  5926 F4   417  4903 F4   823  2574 F5   199 11069 19140  6.1  5.1  1.83  0.14  23.33  10.49  16.91  19.03  64    83    35  4.5
  6  6675 F4   401  5678 F4   837  2673 F5   205 11647 19778  5.5  4.3  2.53  0.16  28.74  15.75  22.26  24.14  65     9   131  4.0
  7  6552 F4   386  5675 F4   731  2576 F5   189 11346 19403  4.9  4.0  3.05  0.17  31.06  18.85  24.97  26.91  68     1   211  3.6
  8  5719 F4   372  5215 F4   771  2280 F5   181 10197 18217  5.0  4.1  2.89  0.16  29.56  17.16  23.38  25.17  70     4   165  3.6
  9  4458 F4   430  4550 F4  1013  1785 F5   181  8392 16699  5.1  4.4  2.25  0.14  24.72  11.99  18.37  20.44  71    60    73  3.8
 10  3282 F4   362  4080 F4   967  1294 F5   147  6326 15099  5.3  4.4  1.48  0.11  18.68   5.11  11.91  14.15  67   205     4  4.1
 11  2118 F4   190  2924 F4   726   998 F5   110  4535 13614  6.3  5.3  1.00  0.08   9.61  -1.81   3.91   5.75  71   439     0  4.4
 12  1714 F4   128  2619 F4   567   857 F5   101  3678 12817  6.5  5.5  0.73  0.06   1.45  -9.09  -3.81  -2.34  73   697     0  4.4
 13  4202 F4   172  4245 F4   439  1773 F5    78  7855 16404  5.8  4.8  1.61  0.12  16.41   4.18  10.31  12.21  68  3586   636  4.3
 1961
  1  2362 C4   624  4607 E4  2423   734 E5   287  4103 13264  4.9  3.4  0.50  0.05   3.39 -11.67  -4.11  -2.79  66   734  9999  4.7
  2  3312 C4  1059  3842 E4  2360  1430 E5   313  6342 15111  4.1  3.5  1.36  0.16  20.17   5.50  12.83  14.96  69   179  9999  4.9
       :      :      :      :      :      :      :      :      :      :      :      :      :      :      :      :      :      :
 10  3312 C4  1059  3842 E4  2360  1430 E5   313  6342 15111  4.1  3.5  1.36  0.16  20.17   5.50  12.83  14.96  69   179  9999  4.9
 11  2048 E4   797  2622 E4  2405  1035 E5   259  4545 13624  6.2  5.6  0.93  0.09   7.83  -1.83   3.00   4.70  78   471  9999  5.3
 12  1712 C4   549  2285 E4  2559   972 E5   327  3680 12819  6.8  6.4  0.61  0.06  -0.94 -11.28  -6.11  -5.23  80   801  9999  5.4
 13  4211 E4  2201  4317 E4  3183  1745 E5   814  7858 16406  5.8  5.0  1.49  0.10  16.11   3.94  10.06  11.55  70  3768 99999  5.2
 1962
  1  2241 C4   516  3481 E4  2333  1003 E5   338  4103 13264  6.4  5.1  0.59  0.05  -2.78 -12.72  -7.72  -6.65  73   837  9999  5.4
         :      :      :      :      :      :      :      :      :      :      :      :      :      :      :      :      :      :
```

KEY TO COLUMN HEADINGS:

MO = Month, 1-13, month 13 = annual average
AVGLO, AVDIR, AVDIF = Daily Average Global Horizontal, Direct Beam and Diffuse Horizontal Irradiance Wh/m²
FL = Quality Assessment/Data Source Indicator Flags for Global, Direct, and Diffuse Data
SDGLO, SDDIR, SDDIF = Standard Deviations of Global, Direct, and Diffuse Data
AVETR AETRN = Average Extraterrestrial (ETR) Irradiance on a Horizontal Surface and Direct Beam ETR, respectively.
TOT OPQ = Total and Opaque Cloud Cover in Tenths
H2O = Total Precipitable Water in mm
TAU = Estimated Broadband Aerosol Optical Depth
MAX_T MIN_T AVG_T AVGDT = Maximum, Minimum, Daily average, and Daylight Average Temperatures, (deg Celsius)
RH = Relative Humidity, Percent
HTDD CLDD = Heating and Cooling Degree Days
AVWS = Average Wind Speed in m/s

Table 2-4. Comparison of Reference Day Average Parameter Values and Daily Averages for Month (in Bold)

Profile[1]	Global Hz W/m²	Direct W/m²	Diffuse W/m²	Temp °C	Relative Humidity %	Wind Speed M/s	Cloud Cover (tenths)
Hot Sunny	**8424**	**10248**	**1385**	**30.4**	**25**	**4.8**	**1.2**
Phoenix AZ 6/24/76	9144	11876	999	36.3	6.3	3.9	0.0
Cold Sunny	**4120**	**6887**	**974**	**-1.5**	**58**	**3.1**	**3.8**
Alamosa CO 2/8/61	4340	9440	330	-0.6	50.9	2.2	0.4
Hot Cloudy	**5942**	**4582**	**2616**	**30.4**	**72**	**3.8**	**5.6**
Brownsville TX 7/4/83	3465	292	3265	32.1	59.8	7.9	9.0
Cold Cloudy	**1306**	**762**	**1062**	**-2.0**	**79**	**4.7**	**8.9**
Buffalo NY 12/6/85	1319	8	1317	-0.1	93.4	3.7	10.0
Nice	**6814**	**7737**	**1784**	**20.0**	**45**	**4.0**	**3.7**
Sacramento CA 5/4/67	7117	8347	1529	17.3	65.4	5.0	4.7

Table 2-5. Comparison of Subjective Criteria and Selected Day Parameters

	Irradiance (W/m²)		**Ambient Temperature (°C)**		**Wind Speed (m/s)**		**Relative Humidity (%)**	
Profile	**Criteria**	**Selected**	**Criteria**	**Selected**	**Criteria**	**Selected**	**Criteria**	**Selected**
Hot Sunny	> 10000 (Direct beam)	11876 (Direct)	>35	36.3	<3	3.9	N/A	6.3
Cold Sunny	>6500 (Direct Beam)	9440 (Direct)	< 2	-1.5	>3	2.2	60<RH<70	50.9
Hot Cloudy	<3500 (Global hz)	3465 (GH)	>30	32.1	<4	7.9	RH>80	59.8
Cold Cloudy	1200<GH	1319	<1	-0.1	N/A	3.7	N/A	93.4
Nice	6000<GH <6500	7117	19.5<T <20.5	17.3	<4	5.0	RH<30	65.4

The selected days represent the wide range of operating conditions under which PV systems may be deployed. Because the reference days were selected from a candidate month with parameter values near the monthly average, they represent longer periods (such as month) when the subjective criteria occur. Days with extreme values of any of the parameters were ruled out so that the reference days would be "middle of the road" representatives for the qualitative descriptions of the profiles. The plane-of-array irradiances for flat-plate PV collectors at latitude tilt in open rack mounts were modeled using the anisotropic algorithm of Perez [15].

Tables 2-6 through 2-10 list the complete parameters for each reference day. The f1 and f2 on each day are numbers used in determining the module operating temperature. This is described in Section 3. For each day, a spectrum from 300-1400nm is included. Because measured spectra do not exist for the reference days, these parameters are modeled with SEDES2 [11]. These data are now used in conjunction with the rest of the energy rating methodology and PV module performance coefficients to estimate a reasonable energy rating for the reference days.

2.4.1 Hot Sunny

Date:	June 24, 1976
Latitude:	33.43°N
Longitude:	112.02°W
Elevation	339 m

Table 2-6 Data for Hot-Sunny Reference Day

Hour	GHI (Wh/m^2)	DNI (Wh/m^2)	Diff (Wh/m^2)	POA (Wh/m^2)	Tamb (ºC)	WS (m/s)	RH (%)	AM$_a$	AOI (°)	Spectral Table	f1 (dimensionless)	f2 (°C)	Battery Voltage
1	0	0	0	0	-	-	-			-			-
2	0	0	0	0	-	-	-			-			-
3	0	0	0	0	-	-	-			-			-
4	0	0	0	0	-	-	-			-			-
5	0	0	0	0	-	-	-			-			-
6	32	166	15	12	24.4	3.1	16	13.0	100.9	4.3.1	-0.057	25.7	11.0
7	172	624	35	28	25.6	1.5	15	4.32	90.0	4.3.1	-0.042	26.5	11.0
8	388	802	53	247	27.8	4.6	16	2.30	76.3	4.3.1	0.210	23.0	11.1
9	608	893	70	489	31.7	4.1	11	1.60	62.8	4.3.1	0.474	21.0	11.3
10	805	949	84	713	33.9	4.1	7	1.26	49.6	4.3.1	0.697	18.4	11.7
11	959	982	93	889	35.0	6.2	5	1.09	37.5	4.3.1	0.774	17.1	12.1
12	1049	992	98	993	36.0	3.6	6	1.00	27.6	4.3.1	0.985	15.4	12.5
13	1080	995	101	1030	37.2	4.1	6	0.98	23.4	4.3.1	0.991	15.6	13.0
14	1061	1003	99	1005	38.3	2.6	4	1.00	27.5	4.3.1	1.052	16.5	13.4
15	960	982	93	891	38.9	2.6	5	1.09	37.3	4.3.1	0.941	19.3	13.8
16	807	950	84	716	39.4	3.1	5	1.26	49.4	4.3.1	0.740	23.5	14.1
17	617	906	71	499	39.4	3.1	4	1.59	62.5	4.3.1	0.517	28.1	14.4
18	397	821	53	255	38.9	5.7	5	2.28	76.1	4.3.1	0.213	34.0	14.5
19	175	636	35	31	38.3	9.8	5	4.25	89.8	4.3.1	-0.005	38.4	14.5
20	34	175	15	12	36.1	3.1	7	12.7	100.8	4.3.1	-0.036	36.9	14.5
21	0	0	0	0	-	-	-			-			-
22	0	0	0	0	-	-	-			-			-
23	0	0	0	0	-	-	-			-			-
24	0	0	0	0	-	-	-			-			-

2.4.2 Cold Sunny

Date: February 8, 1961
Latitude: 37.45°N
Longitude: 105.87°W
Elevation: 2297 m

Table 2-7 Data for Cold-Sunny Reference Day

Hour	GHI (Wh/m^2)	DNI (Wh/m^2)	Diff (Wh/m^2)	POA (Wh/m^2)	Tamb (ºC)	WS (m/s)	RH (%)	AM$_a$	AOI (°)	Spectral Table	f1 (dimensionless)	f2 (°C)	Battery Voltage
1	0	0	0	0	-	-	-			-			-
2	0	0	0	0	-	-	-			-			-
3	0	0	0	0	-	-	-			-			-
4	0	0	0	0	-	-	-			-			-
5	0	0	0	0	-	-	-			-			-
6	0	0	0	0	-	-	-			-			-
7	0	0	0	0	-	-	-			-			-
8	67	548	12	194	-14.4	1.5	76	7.65	71.9	4.3.2	0.212	-19.2	11.1
9	251	882	22	504	-10	1.5	73	2.86	58.1	4.3.2	0.680	-24.7	11.3
10	434	979	31	758	-6.1	2.1	68	1.83	44.0	4.3.2	0.953	-26.9	11.7
11	566	1008	38	934	-1.7	1.5	53	1.44	30.5	4.3.2	1.202	-26.2	12.1
12	650	1032	42	1048	-0.6	1.5	56	1.28	19.0	4.3.2	1.327	-27.3	12.5
13	671	1027	49	1073	1.7	1.5	47	1.25	15.2	4.3.2	1.343	-25.2	13.0
14	624	1027	41	1014	2.2	2.6	48	1.33	23.2	4.3.2	1.178	-23.3	13.5
15	523	1012	35	880	3.3	2.6	32	1.56	35.9	4.3.2	1.026	-19.1	13.9
16	357	925	31	650	1.7	4.6	42	2.12	49.7	4.3.2	0.658	-13.7	14.2
17	165	774	20	375	1.1	3.1	38	3.85	64.0	4.3.2	0.397	-8.0	14.3
18	34	226	9	75	-3.9	3.1	62	11.2	74.7	4.3.2	0.005	-4.0	14.4
19	0	0	0	0	-	-	-			-			-
20	0	0	0	0	-	-	-			-			-
21	0	0	0	0	-	-	-			-			-
22	0	0	0	0	-	-	-			-			-
23	0	0	0	0	-	-	-			-			-
24	0	0	0	0	-	-	-			-			-

2.4.3 Hot Cloudy

Date:	July 4, 1983
Latitude:	25.90°
Longitude:	97.43°W
Elevation:	6 m

Table 2-8 Data for Hot-Cloudy Reference Day

Hour	GHI (Wh/m^2)	DNI (Wh/m^2)	Diff (Wh/m^2)	POA (Wh/m^2)	Tamb (ºC)	WS (m/s)	RH (%)	AM$_a$	AOI (°)	Spectral Table	f1 (dimensionless)	f2 (°C)	Battery Voltage
1	0	0	0	0	-	-	-			-			-
2	0	0	0	0	-	-	-			-			-
3	0	0	0	0	-	-	-			-			-
4	0	0	0	0	-	-	-			-			-
5	0	0	0	0	-	-	-			-			-
6	5	2	5	5	27.8	3.6	79	21.6	99.0	4.3.3	-0.057	29.1	11.0
7	71	16	68	58	28.9	5.7	77	6.13	90.8	4.3.3	0.006	28.8	11.0
8	172	27	162	151	30.0	6.7	72	2.68	77.1	4.3.3	0.093	27.8	11.1
9	340	81	294	304	31.7	8.2	63	1.74	63.4	4.3.3	0.209	26.7	11.2
10	381	51	343	352	31.7	9.3	63	1.34	50.2	4.3.3	0.230	26.2	11.4
11	480	69	419	449	33.3	8.2	56	1.13	37.8	4.3.3	0.326	25.5	11.6
12	405	12	393	378	32.8	8.8	56	1.03	27.7	4.3.3	0.259	26.6	11.8
13	367	9	358	344	32.2	8.8	59	1.00	22.9	4.3.3	0.232	26.6	11.9
14	426	15	411	398	32.8	8.2	56	1.03	26.6	4.3.3	0.285	26.0	12.1
15	329	5	325	307	32.2	6.7	54	1.12	36.3	4.3.3	0.236	26.6	12.2
16	225	2	223	208	32.2	7.2	57	1.30	48.5	4.3.3	0.141	28.8	12.3
17	152	1	151	140	31.1	5.2	65	1.67	61.6	4.3.3	0.095	28.9	12.4
18	88	1	88	82	30.6	7.2	70	2.49	75.2	4.3.3	0.029	29.9	12.4
19	24	1	24	22	29.4	5.2	75	5.24	89.0	4.3.3	-0.030	30.1	12.4
20	1	1	1	1	28.9	4.6	74	17.6	98.2	4.3.3	-0.056	30.2	12.4
21	0	0	0		-	-	-			-			-
22	0	0	0		-	-	-			-			-
23	0	0	0		-	-	-			-			-
24	0	0	0		-	-	-			-			-

2.4.4 Cold Cloudy

Date:	December 6, 1985
Latitude:	42.93°
Longitude:	78.73°W
Elevation:	215 m

Table 2-9 Data for Cold-Cloudy Reference Day

Hour	GHI (Wh/m^2)	DNI (Wh/m^2)	Diff (Wh/m^2)	POA (Wh/m^2)	Tamb (ºC)	WS (m/s)	RH (%)	AM_a	AOI (°)	Spectral Table	f1 (dimensionless)	f2 (°C)	Battery Voltage
1	0	0	0	0	-	-	-			-			-
2	0	0	0	0	-	-	-			-			-
3	0	0	0	0	-	-	-			-			-
4	0	0	0	0	-	-	-			-			-
5	0	0	0	0	-	-	-			-			-
6	0	0	0	0	-	-	-			-			-
7	0	0	0	0	-	-	-			-			-
8	12	0	12	10	0.0	4.6	100	66.2	66.2	4.3.4	-0.072	1.7	11.0
9	73	1	73	89	0.0	3.6	100	57.0	57.0	4.3.4	0.023	-0.5	11.0
10	134	0	134	145	0.0	3.6	96	44.1	44.1	4.3.4	0.095	-2.2	11.1
11	187	2	187	200	0.0	3.1	96	32.4	32.4	4.3.4	0.174	-4.0	11.2
12	221	2	220	235	0.0	3.6	92	24.2	24.2	4.3.4	0.210	-4.9	11.3
13	237	0	237	257	0.0	3.6	92	23.3	23.3	4.3.4	0.236	-5.5	11.4
14	196	1	196	209	0.0	4.1	92	30.4	30.4	4.3.4	0.170	-4.0	11.5
15	146	1	145	156	0.0	4.1	92	41.6	41.6	4.3.4	0.105	-2.5	11.6
16	91	1	91	110	-0.6	3.6	92	54.4	54.4	4.3.4	0.050	-1.8	11.6
17	22	0	22	22	-0.6	2.6	89	64.9	64.9	4.3.4	-0.071	1.1	11.6
18	0	0	0	0	-	-	-			-			-
19	0	0	0	0	-	-	-			-			-
20	0	0	0	0	-	-	-			-			-
21	0	0	0	0	-	-	-			-			-
22	0	0	0	0	-	-	-			-			-
23	0	0	0	0	-	-	-			-			-
24	0	0	0	0	-	-	-			-			-

2.4.5 Nice

Date:	May 4, 1967
Latitude:	38.52°
Longitude:	121.50°W
Elevation:	8 m

Table 2-10 Data for Nice Reference Day

Hour	GHI (Wh/m^2)	DNI (Wh/m^2)	Diff (Wh/m^2)	POA (Wh/m^2)	Tamb (ºC)	WS (m/s)	RH (%)	AM_a	AOI (°)	Spectral Table	f1 (dimensionless)	f2 (°C)	Battery Voltage
1	0	0	0	0	-	-	-			-			-
2	0	0	0	0	-	-	-			-			-
3	0	0	0	0	-	-	-			-			-
4	0	0	0	0	-	-	-			-			-
5	0	0	0	0	-	-	-			-			-
6	38	101	28	22	9.1	3.8	90	10.9	96.5	4.3.5	-0.057	10.5	11.0
7	163	303	85	109	10.0	4.6	89	3.79	83.4	4.3.5	0.047	8.9	11.1
8	344	491	123	298	11.9	5.0	83	2.21	69.0	4.3.5	0.257	5.9	11.2
9	513	594	145	504	13.7	5.3	78	1.60	54.8	4.3.5	0.460	2.9	11.4
10	708	732	151	730	15.6	5.7	72	1.31	40.9	4.3.5	0.665	-0.0	11.7
11	811	693	214	863	16.9	5.3	68	1.16	27.9	4.3.5	0.819	-2.1	12.1
12	905	846	132	962	18.1	5.0	65	1.09	17.9	4.3.5	0.927	-3.0	12.6
13	811	689	179	871	19.4	4.6	61	1.09	17.3	4.3.5	0.851	0.1	13.0
14	854	833	132	900	19.4	4.8	59	1.15	26.8	4.3.5	0.869	-0.3	13.4
15	733	832	91	754	19.4	5.0	56	1.29	39.7	4.3.5	0.719	2.9	13.7
16	588	785	91	578	19.4	5.2	54	1.57	53.5	4.3.5	0.539	6.8	14.0
17	400	712	69	349	17.4	4.8	61	2.13	67.7	4.3.5	0.313	10.1	14.1
18	200	491	64	128	15.3	4.5	67	3.53	82.1	4.3.5	0.073	13.6	14.2
19	49	245	25	20	13.3	4.1	74	9.86	95.9	4.3.5	-0.055	14.6	14.2
20	0	0	0	0	-	-	-			-			-
21	0	0	0	0	-	-	-			-			-
22	0	0	0	0	-	-	-			-			-
23	0	0	0	0	-	-	-			-			-
24	0	0	0	0	-	-	-			-			-

Spectral Tables

Tables 2-11 through 2-15 list spectral content by wavelength (nm) in the rows and hour in the columns.

Table 2-11 Spectral Data for the Hot-Sunny Reference Day

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
300	0	0	0	0.0007	0.0027	0.0061	0.0092	0.0104	0.0092	0.0061	0.0027	0.0007	0	0	0
310	0	0.0007	0.0115	0.0365	0.0703	0.1034	0.127	0.1349	0.1272	0.1038	0.0704	0.0365	0.0115	0.0007	0
320	0	0.0101	0.0558	0.118	0.1869	0.2478	0.2885	0.3016	0.289	0.2485	0.187	0.1179	0.0561	0.0102	0
330	0	0.0311	0.1164	0.2176	0.3248	0.4165	0.4768	0.496	0.4777	0.4178	0.325	0.2175	0.117	0.0313	0
340	0	0.0362	0.1232	0.2264	0.3347	0.4262	0.486	0.505	0.487	0.4277	0.3349	0.2263	0.1237	0.0364	0
350	0.0018	0.0437	0.1407	0.2578	0.3795	0.4811	0.5474	0.5684	0.5485	0.4829	0.3797	0.2576	0.1413	0.0439	0.0015
360	0.0046	0.0481	0.1493	0.2732	0.4005	0.5058	0.5742	0.5959	0.5755	0.5078	0.4008	0.273	0.15	0.0484	0.0044
370	0.0094	0.0598	0.1795	0.3272	0.477	0.5996	0.679	0.7043	0.6806	0.6021	0.4773	0.327	0.1804	0.06	0.0092
380	0.0126	0.0623	0.1844	0.3352	0.4859	0.6082	0.6872	0.7123	0.6889	0.6108	0.4862	0.3348	0.1853	0.0626	0.0125
390	0.0144	0.0615	0.182	0.3302	0.4764	0.594	0.6698	0.694	0.6716	0.5967	0.4767	0.3299	0.1829	0.0617	0.0144
400	0.0231	0.0898	0.2685	0.4867	0.6993	0.869	0.9782	1.013	0.9809	0.8731	0.6997	0.4861	0.2698	0.0902	0.0232
410	0.0297	0.1059	0.3197	0.5782	0.8269	1.0241	1.1509	1.1912	1.1541	1.0291	0.8274	0.5774	0.3212	0.1063	0.0298
420	0.0332	0.11	0.3352	0.604	0.8597	1.0611	1.1904	1.2316	1.1939	1.0664	0.8601	0.6032	0.3368	0.1105	0.0335
430	0.0329	0.1026	0.3163	0.5678	0.8044	0.9897	1.1086	1.1465	1.112	0.9948	0.8048	0.567	0.3179	0.1031	0.0332
440	0.0403	0.12	0.3744	0.6695	0.9445	1.1588	1.2961	1.34	1.3002	1.1649	0.945	0.6686	0.3763	0.1205	0.0407
450	0.0452	0.1316	0.419	0.7482	1.0524	1.2884	1.4396	1.4879	1.4442	1.2953	1.0529	0.7471	0.4211	0.1323	0.0457
460	0.0453	0.1309	0.4301	0.7706	1.0837	1.326	1.4813	1.5311	1.4861	1.3331	1.0842	0.7695	0.4323	0.1316	0.0458
470	0.0432	0.1249	0.4239	0.7622	1.0719	1.3111	1.4645	1.5137	1.4692	1.3183	1.0724	0.7611	0.4261	0.1256	0.0437
480	0.0437	0.1248	0.4363	0.7862	1.1051	1.3509	1.5086	1.5594	1.5136	1.3584	1.1056	0.7851	0.4385	0.1256	0.0442
490	0.0408	0.115	0.4131	0.7459	1.0478	1.2801	1.4292	1.4773	1.434	1.2873	1.0483	0.7448	0.4152	0.1156	0.0413
500	0.0403	0.1126	0.4169	0.7543	1.0594	1.2938	1.4443	1.493	1.4492	1.3011	1.0599	0.7532	0.419	0.1134	0.0408
510	0.0392	0.1096	0.419	0.7609	1.069	1.3055	1.4574	1.5067	1.4624	1.313	1.0695	0.7597	0.4212	0.1103	0.0397
520	0.0358	0.1007	0.3984	0.7263	1.0212	1.2473	1.3927	1.44	1.3976	1.2545	1.0217	0.7252	0.4005	0.1014	0.0362
530	0.0349	0.0996	0.4095	0.7505	1.0568	1.2915	1.4426	1.4918	1.4476	1.299	1.0573	0.7494	0.4116	0.1003	0.0353
540	0.0334	0.0959	0.4086	0.752	1.06	1.2959	1.4478	1.4974	1.4529	1.3035	1.0605	0.7508	0.4107	0.0966	0.0339
550	0.0317	0.0913	0.4036	0.7461	1.053	1.2879	1.4392	1.4888	1.4444	1.2955	1.0535	0.745	0.4057	0.0921	0.0321
560	0.0291	0.0852	0.3919	0.7288	1.0307	1.2618	1.4107	1.4596	1.4158	1.2692	1.0311	0.7277	0.3939	0.086	0.0295
570	0.0264	0.0794	0.3821	0.7156	1.0146	1.2436	1.3913	1.4399	1.3963	1.251	1.0151	0.7146	0.384	0.0801	0.0267
580	0.0252	0.0754	0.3753	0.7061	1.0033	1.2311	1.3768	1.425	1.3828	1.2378	1.0039	0.7064	0.3781	0.0763	0.0255
590	0.0242	0.0713	0.3669	0.6928	0.9861	1.211	1.3537	1.4011	1.3605	1.217	0.9867	0.6945	0.3705	0.0724	0.0246
600	0.0239	0.0685	0.3638	0.6874	0.9774	1.1995	1.3412	1.3883	1.3474	1.2059	0.978	0.6882	0.3668	0.0694	0.0243
610	0.0236	0.0657	0.3605	0.6809	0.9662	1.1841	1.3249	1.3715	1.3298	1.1913	0.9666	0.6799	0.3623	0.0665	0.0239
620	0.0235	0.0628	0.3546	0.6697	0.9495	1.1631	1.3012	1.3469	1.306	1.1702	0.95	0.6687	0.3564	0.0636	0.0237
630	0.0234	0.0601	0.3492	0.6594	0.9342	1.1437	1.2792	1.3241	1.2839	1.1507	0.9347	0.6585	0.351	0.0609	0.0236
640	0.0238	0.0578	0.3437	0.6476	0.916	1.1204	1.2525	1.2963	1.2571	1.1272	0.9164	0.6467	0.3454	0.0586	0.0241
650	0.0242	0.0552	0.3373	0.6345	0.8962	1.0952	1.2238	1.2666	1.2284	1.1019	0.8966	0.6337	0.339	0.056	0.0244
660	0.0251	0.0538	0.3383	0.6354	0.8962	1.0942	1.2222	1.2648	1.2268	1.1009	0.8966	0.6346	0.34	0.0546	0.0253
670	0.0255	0.0523	0.3408	0.6409	0.9038	1.1035	1.2325	1.2755	1.2372	1.1102	0.9042	0.6401	0.3426	0.0532	0.0257
680	0.023	0.047	0.3212	0.6085	0.8614	1.0538	1.178	1.2195	1.1827	1.0601	0.8618	0.6082	0.3232	0.0478	0.0232
690	0.0191	0.0402	0.2934	0.5623	0.8005	0.9824	1.0995	1.1388	1.1041	0.9879	0.8009	0.5625	0.2956	0.041	0.0193
700	0.0213	0.0407	0.3026	0.575	0.8145	0.9966	1.1138	1.1531	1.1184	1.0022	0.8149	0.5751	0.3047	0.0415	0.0216
710	0.0226	0.0405	0.309	0.5843	0.8247	1.0069	1.1241	1.1633	1.1286	1.0126	0.8251	0.5844	0.3111	0.0414	0.0228
720	0.0158	0.0316	0.2645	0.5178	0.75	0.9296	1.0327	1.0691	1.0464	0.9288	0.7514	0.5304	0.2741	0.0333	0.0163
730	0.0159	0.0305	0.2679	0.523	0.7544	0.9326	1.0377	1.0744	1.0491	0.9332	0.7555	0.5326	0.2756	0.0319	0.0163
740	0.018	0.0315	0.285	0.5478	0.7788	0.9544	1.066	1.1037	1.0713	0.959	0.7793	0.5494	0.2878	0.0324	0.0182
750	0.0179	0.0298	0.2842	0.5461	0.7747	0.9481	1.0598	1.0974	1.0639	0.9534	0.775	0.546	0.286	0.0306	0.018
760	0.0107	0.0198	0.2156	0.4305	0.6238	0.773	0.8701	0.9029	0.8732	0.7774	0.6241	0.4302	0.2166	0.0204	0.0108
770	0.0121	0.0211	0.2382	0.4696	0.6743	0.8309	0.9325	0.9668	0.9358	0.8357	0.6746	0.4692	0.2394	0.0217	0.0121
780	0.0151	0.0233	0.266	0.5156	0.7331	0.898	1.0047	1.0406	1.0083	0.9032	0.7334	0.5152	0.2674	0.024	0.0151
790	0.0142	0.0214	0.2602	0.5065	0.7216	0.885	0.99	1.0255	0.994	0.8897	0.722	0.5067	0.2619	0.0221	0.0142
800	0.0136	0.0195	0.2534	0.4949	0.7062	0.8667	0.9693	1.0041	0.9737	0.8711	0.7066	0.4958	0.2556	0.0202	0.0137
810	0.0116	0.0163	0.2295	0.4547	0.6564	0.8111	0.9046	0.9371	0.9128	0.8126	0.6572	0.4609	0.2347	0.0172	0.0118
820	0.0094	0.0133	0.2063	0.4156	0.607	0.7552	0.8405	0.8708	0.8516	0.7544	0.6081	0.4258	0.2138	0.0143	0.0096
830	0.0101	0.0128	0.2119	0.4222	0.6106	0.7553	0.8426	0.873	0.8504	0.7566	0.6114	0.4282	0.2168	0.0137	0.0103
840	0.0107	0.0123	0.2191	0.4333	0.6219	0.7657	0.8559	0.8868	0.8611	0.7687	0.6224	0.4358	0.2219	0.0131	0.0108
850	0.0105	0.0113	0.2189	0.4325	0.6193	0.7613	0.8518	0.8827	0.856	0.765	0.6197	0.4335	0.2208	0.0119	0.0105
860	0.0104	0.0102	0.2184	0.4309	0.6155	0.7554	0.8459	0.8766	0.849	0.7597	0.6157	0.4306	0.2194	0.0108	0.0104

870	0.01	0.009	0.2136	0.4224	0.6036	0.741	0.8299	0.8601	0.833	0.7453	0.6039	0.4221	0.2147	0.0096	0.0099
880	0.0098	0.0079	0.2101	0.4159	0.5944	0.7298	0.8173	0.8469	0.8203	0.7339	0.5947	0.4157	0.2112	0.0085	0.0098
890	0.0083	0.0063	0.1895	0.3827	0.5562	0.6896	0.7692	0.7972	0.7771	0.6903	0.5569	0.389	0.1943	0.007	0.0083
900	0.0062	0.0045	0.1628	0.3376	0.5009	0.6285	0.698	0.7235	0.7106	0.6258	0.5021	0.3502	0.1712	0.0051	0.0063
910	0.0057	0.0034	0.1519	0.3174	0.4738	0.5965	0.6611	0.6852	0.6749	0.5928	0.4751	0.3318	0.1613	0.004	0.0059
920	0.0062	0.0028	0.1493	0.3091	0.4583	0.5748	0.6372	0.6603	0.6495	0.5719	0.4595	0.3218	0.1579	0.0034	0.0064
930	0.0031	0.0012	0.1023	0.2278	0.3585	0.4654	0.5085	0.527	0.5307	0.4556	0.3606	0.2523	0.1167	0.0017	0.0033
940	0.0016	0.0005	0.0716	0.1689	0.278	0.3704	0.4007	0.4153	0.4253	0.3584	0.2803	0.1956	0.0863	0.0008	0.0018
950	0.0021	0.0003	0.0759	0.1729	0.2771	0.3637	0.3958	0.4102	0.4159	0.3542	0.2789	0.1948	0.0883	0.0006	0.0022
960	0.0037	0	0.1018	0.2157	0.3258	0.4134	0.4563	0.4729	0.4684	0.409	0.327	0.2286	0.1098	0.0004	0.0039
970	0.0048	0	0.1257	0.2594	0.382	0.4772	0.5305	0.5498	0.5385	0.4757	0.3828	0.2674	0.1312	0.0001	0.0048
980	0.005	0	0.1375	0.2823	0.4128	0.5135	0.5724	0.5934	0.5788	0.5131	0.4134	0.2882	0.1418	0	0.005
990	0.0056	0	0.1509	0.3063	0.4431	0.5477	0.6124	0.6349	0.6164	0.549	0.4435	0.309	0.1534	0	0.0056
1000	0.0056	0	0.1534	0.3104	0.4474	0.5519	0.6178	0.6405	0.6206	0.5538	0.4477	0.3117	0.155	0	0.0055
1010	0.0053	0	0.1508	0.3055	0.4402	0.5428	0.6078	0.6302	0.6104	0.5448	0.4405	0.3065	0.1522	0	0.0052
1020	0.0051	0	0.1478	0.2996	0.4315	0.5318	0.5958	0.6178	0.5981	0.5339	0.4317	0.3002	0.149	0	0.005
1030	0.0048	0	0.1446	0.2933	0.4223	0.5203	0.5831	0.6046	0.5851	0.5225	0.4225	0.2936	0.1455	0	0.0047
1040	0.0044	0	0.1411	0.2867	0.4126	0.5082	0.5699	0.591	0.5717	0.5106	0.4128	0.2866	0.1418	0	0.0043
1050	0.0042	0	0.1376	0.2799	0.403	0.4964	0.5567	0.5773	0.5584	0.4988	0.4031	0.2799	0.1383	0	0.0041
1060	0.004	0	0.1341	0.2731	0.3933	0.4846	0.5435	0.5636	0.5451	0.4869	0.3935	0.2731	0.1347	0	0.0039
1070	0.0038	0	0.1306	0.2663	0.3837	0.4728	0.5302	0.5499	0.5319	0.475	0.3839	0.2663	0.1312	0	0.0037
1080	0.0032	0	0.1213	0.2506	0.3647	0.4521	0.506	0.5248	0.5094	0.453	0.3651	0.253	0.1232	0	0.0032
1090	0.0027	0	0.1119	0.2349	0.3457	0.4313	0.4817	0.4997	0.4869	0.4311	0.3463	0.2397	0.1152	0	0.0026
1100	0.0022	0	0.1026	0.2192	0.3268	0.4106	0.4574	0.4746	0.4645	0.4091	0.3275	0.2263	0.1072	0	0.0021
1110	0.0011	0	0.0675	0.1547	0.2459	0.322	0.3535	0.367	0.3687	0.315	0.2473	0.1698	0.0752	0	0.0011
1120	0.0001	0	0.0324	0.0902	0.1651	0.2334	0.2496	0.2594	0.2729	0.221	0.1671	0.1132	0.0431	0	0.0002
1130	0.0003	0	0.0429	0.1111	0.1922	0.263	0.2845	0.2955	0.3047	0.2525	0.194	0.1321	0.0533	0	0.0003
1140	0.0003	0	0.0414	0.1082	0.188	0.258	0.2788	0.2896	0.2991	0.2474	0.1898	0.1292	0.0518	0	0.0003
1150	0.0005	0	0.0523	0.1277	0.2113	0.2823	0.3079	0.3198	0.325	0.2739	0.2128	0.1455	0.0614	0	0.0005
1160	0.001	0	0.0755	0.1696	0.262	0.336	0.3718	0.3859	0.3823	0.3319	0.263	0.1809	0.0821	0	0.001
1170	0.0013	0	0.0849	0.1849	0.2786	0.3521	0.3917	0.4065	0.399	0.35	0.2793	0.1926	0.0897	0	0.0013
1180	0.0013	0	0.0856	0.1853	0.2778	0.35	0.3898	0.4045	0.3963	0.3484	0.2784	0.192	0.0898	0	0.0013
1190	0.0014	0	0.0863	0.1858	0.277	0.3479	0.3879	0.4025	0.3936	0.3468	0.2775	0.1915	0.09	0	0.0013
1200	0.0014	0	0.0871	0.1862	0.2761	0.3458	0.386	0.4005	0.3908	0.3451	0.2766	0.1909	0.0902	0	0.0013
1210	0.0014	0	0.0878	0.1869	0.2758	0.3443	0.385	0.3996	0.389	0.3443	0.2762	0.1905	0.0903	0	0.0012
1220	0.0013	0	0.0886	0.1876	0.2755	0.3429	0.3841	0.3986	0.3871	0.3434	0.2758	0.19	0.0904	0	0.0012
1230	0.0013	0	0.0894	0.1883	0.2751	0.3415	0.3832	0.3977	0.3853	0.3425	0.2753	0.1895	0.0905	0	0.0012
1240	0.0013	0	0.0901	0.189	0.2748	0.34	0.3822	0.3968	0.3834	0.3416	0.2749	0.1891	0.0906	0	0.0012
1250	0.0012	0	0.0855	0.1804	0.2629	0.3259	0.3666	0.3806	0.3677	0.3274	0.2631	0.1804	0.086	0	0.001
1260	0.001	0	0.081	0.1718	0.2511	0.3117	0.3509	0.3645	0.3521	0.3132	0.2512	0.1718	0.0814	0	0.0009
1270	0.0008	0	0.0764	0.1631	0.2392	0.2975	0.3353	0.3484	0.3364	0.2989	0.2394	0.1632	0.0768	0	0.0007
1280	0.0009	0	0.0793	0.1684	0.2464	0.306	0.3441	0.3574	0.3455	0.3072	0.2466	0.1689	0.08	0	0.0007
1290	0.0009	0	0.0822	0.1738	0.2536	0.3145	0.353	0.3664	0.3547	0.3156	0.2538	0.1746	0.0831	0	0.0007
1300	0.0008	0	0.077	0.1646	0.2424	0.3022	0.3385	0.3513	0.3414	0.3025	0.2427	0.167	0.0788	0	0.0006
1310	0.0006	0	0.0718	0.1555	0.2313	0.29	0.324	0.3363	0.3281	0.2895	0.2317	0.1594	0.0744	0	0.0005
1320	0.0005	0	0.0666	0.1464	0.2202	0.2778	0.3095	0.3212	0.3147	0.2765	0.2207	0.1518	0.07	0	0.0004
1330	0.0003	0	0.0488	0.1116	0.1748	0.2268	0.2501	0.2597	0.2592	0.2229	0.1756	0.1202	0.0532	0	0.0003
1340	0.0002	0	0.031	0.0768	0.1294	0.1759	0.1908	0.1982	0.2037	0.1693	0.1305	0.0887	0.0363	0	0.0001
1350	0	0	0.0132	0.042	0.084	0.1249	0.1315	0.1368	0.1481	0.1158	0.0854	0.0571	0.0195	0	0
1360	0	0	0.0105	0.0339	0.0694	0.105	0.1097	0.1142	0.1252	0.0965	0.0706	0.0471	0.0157	0	0
1370	0	0	0.0078	0.0259	0.0547	0.085	0.088	0.0916	0.1022	0.0772	0.0559	0.0371	0.0119	0	0
1380	0	0	0.0051	0.0178	0.0401	0.0651	0.0663	0.0691	0.0793	0.058	0.0411	0.0271	0.0082	0	0
1390	0	0	0.0024	0.0098	0.0255	0.0451	0.0446	0.0465	0.0564	0.0387	0.0263	0.0171	0.0044	0	0
1400	0	0	0.0021	0.0089	0.0237	0.0425	0.0419	0.0437	0.0532	0.0363	0.0245	0.0159	0.004	0	0

Table 2-12 Spectral Data for the Cold-Sunny Reference Day

	8	9	10	11	12	13	14	15	16	17	18
300	0	0	0	0.0004	0.0008	0.001	0.0007	0.0002	0	0	0
310	0	0.003	0.0185	0.0408	0.0587	0.062	0.0526	0.0317	0.0103	0.0005	0
320	0	0.0345	0.0987	0.1608	0.2036	0.21	0.1895	0.1374	0.0692	0.0134	0
330	0	0.0984	0.2169	0.3203	0.3889	0.3984	0.3667	0.2825	0.1639	0.0499	0
340	0.0008	0.1142	0.2376	0.343	0.4124	0.4221	0.3902	0.3049	0.1824	0.0632	0
350	0.0119	0.1395	0.2802	0.3988	0.4765	0.4875	0.452	0.3564	0.2171	0.082	0.0008
360	0.0251	0.1566	0.3061	0.4302	0.5111	0.5227	0.4858	0.3864	0.2392	0.0964	0.0067
370	0.0467	0.1995	0.3783	0.5239	0.6184	0.6321	0.5892	0.473	0.2985	0.1277	0.0165
380	0.0601	0.215	0.3984	0.5443	0.6388	0.6526	0.6099	0.4939	0.3169	0.1408	0.0236
390	0.0672	0.2209	0.402	0.5428	0.6338	0.6472	0.6063	0.4948	0.3221	0.1464	0.0276
400	0.1063	0.3372	0.6048	0.8084	0.9397	0.9591	0.9004	0.7397	0.4877	0.2247	0.0447
410	0.1359	0.4156	0.733	0.9695	1.1219	1.1446	1.0767	0.8905	0.595	0.2792	0.0579
420	0.1525	0.4512	0.7809	1.0219	1.1771	1.2004	1.1315	0.9422	0.6384	0.3061	0.0654
430	0.1521	0.44	0.7475	0.9683	1.1107	1.1321	1.0693	0.896	0.6153	0.3014	0.0651
440	0.1883	0.5367	0.8962	1.1501	1.3141	1.3389	1.2668	1.0677	0.7424	0.371	0.0802
450	0.2137	0.6145	1.0141	1.2925	1.4724	1.4999	1.4209	1.2028	0.844	0.4266	0.0902
460	0.2171	0.6432	1.0553	1.3396	1.5234	1.552	1.471	1.2484	0.881	0.4462	0.0907
470	0.2114	0.6456	1.0537	1.3327	1.5132	1.5418	1.462	1.2435	0.8819	0.4476	0.0871
480	0.2185	0.6778	1.0977	1.3826	1.567	1.5967	1.5149	1.2919	0.9218	0.4712	0.0889
490	0.2094	0.655	1.0517	1.3188	1.4921	1.5205	1.4435	1.2341	0.886	0.4573	0.0839
500	0.2138	0.6732	1.0728	1.3403	1.5143	1.5432	1.4657	1.2558	0.9065	0.472	0.0839
510	0.215	0.687	1.0895	1.3577	1.5323	1.5619	1.4837	1.2733	0.9226	0.4827	0.0827
520	0.2038	0.6621	1.0462	1.301	1.4673	1.4959	1.4212	1.221	0.8873	0.4656	0.0767
530	0.2067	0.6871	1.085	1.3484	1.5203	1.5504	1.4728	1.2657	0.9209	0.4827	0.076
540	0.2063	0.6935	1.0922	1.3554	1.5276	1.5581	1.4801	1.2729	0.9282	0.4877	0.0743
550	0.204	0.6923	1.088	1.349	1.5197	1.5505	1.4727	1.2673	0.9256	0.4874	0.0718
560	0.1961	0.6765	1.0645	1.3204	1.4879	1.5185	1.4418	1.2402	0.9055	0.4756	0.0673
570	0.1882	0.6629	1.046	1.2989	1.4644	1.4951	1.4188	1.2195	0.8893	0.4647	0.0623
580	0.1894	0.6613	1.0387	1.2878	1.4507	1.4815	1.4056	1.21	0.8838	0.4648	0.0615
590	0.1923	0.6586	1.0272	1.2704	1.4295	1.4599	1.3851	1.1949	0.8753	0.4653	0.0614
600	0.1941	0.66	1.0239	1.2634	1.4205	1.4508	1.3771	1.189	0.8747	0.4688	0.0625
610	0.1945	0.6585	1.0173	1.2526	1.4077	1.4377	1.3654	1.1793	0.8714	0.4704	0.0635
620	0.1991	0.6581	1.0079	1.2369	1.3882	1.4177	1.3471	1.1657	0.8658	0.4739	0.0655
630	0.2057	0.6593	1.0001	1.2231	1.3707	1.3998	1.3307	1.1539	0.8617	0.4793	0.0675
640	0.2164	0.6612	0.9908	1.2062	1.3494	1.3778	1.3107	1.1395	0.8569	0.4867	0.0719
650	0.2261	0.6613	0.9792	1.1869	1.3255	1.3532	1.2883	1.1229	0.8499	0.4925	0.076
660	0.2383	0.675	0.9891	1.1938	1.3309	1.3585	1.2942	1.1309	0.8614	0.5075	0.0823
670	0.2481	0.6894	1.0041	1.2091	1.3467	1.3747	1.3099	1.1462	0.8762	0.5213	0.0873
680	0.2362	0.6564	0.9575	1.1547	1.287	1.3142	1.2514	1.0941	0.8349	0.4959	0.0824
690	0.2149	0.6039	0.8864	1.0729	1.1977	1.2238	1.1638	1.0153	0.7712	0.4546	0.0718
700	0.2447	0.6349	0.9138	1.0979	1.2216	1.2476	1.1882	1.0413	0.7997	0.4876	0.083
710	0.2642	0.6564	0.9329	1.1153	1.2382	1.2641	1.2051	1.0593	0.8197	0.5102	0.0895
720	0.2253	0.5831	0.8383	1.0089	1.1199	1.145	1.0859	0.959	0.7262	0.4387	0.0679
730	0.2235	0.5866	0.844	1.0156	1.1279	1.1531	1.0944	0.9646	0.7332	0.443	0.0696
740	0.2293	0.6112	0.877	1.0522	1.1691	1.1945	1.137	0.9983	0.7684	0.4679	0.0788
750	0.2228	0.6086	0.874	1.0481	1.1646	1.1898	1.1331	0.9941	0.7671	0.4655	0.0808
760	0.145	0.4518	0.6809	0.8353	0.9377	0.9603	0.9096	0.7861	0.5888	0.3329	0.0507
770	0.1668	0.5066	0.7483	0.9085	1.0149	1.0384	0.9859	0.858	0.6517	0.3781	0.0595
780	0.2022	0.5756	0.8282	0.9937	1.1042	1.1286	1.0744	0.9421	0.7273	0.4386	0.0748
790	0.2021	0.5677	0.8157	0.9786	1.0873	1.1116	1.0578	0.9279	0.7161	0.4332	0.0726
800	0.207	0.5596	0.8003	0.9591	1.0652	1.0891	1.0362	0.9099	0.703	0.4296	0.0724
810	0.2001	0.5208	0.7431	0.8914	0.9891	1.0118	0.9606	0.8465	0.6496	0.3978	0.0661
820	0.1847	0.4786	0.6845	0.8231	0.913	0.9346	0.8853	0.7821	0.5949	0.3617	0.057
830	0.1894	0.4867	0.6928	0.8307	0.9215	0.9429	0.8949	0.789	0.606	0.3728	0.0622
840	0.1878	0.4976	0.7082	0.8478	0.9407	0.9623	0.9149	0.8048	0.6223	0.3829	0.0668
850	0.1793	0.4949	0.7059	0.8449	0.9378	0.9592	0.9124	0.8019	0.6211	0.3797	0.0677
860	0.1752	0.4929	0.7029	0.8408	0.9332	0.9545	0.9084	0.7978	0.6196	0.3786	0.0689
870	0.1726	0.4844	0.6902	0.8253	0.9159	0.9369	0.8916	0.7831	0.6086	0.3724	0.0686
880	0.1788	0.481	0.6819	0.8143	0.9032	0.9239	0.8793	0.7729	0.602	0.3724	0.0704
890	0.1742	0.4486	0.6356	0.7608	0.843	0.863	0.8187	0.7231	0.5568	0.3438	0.0635
900	0.1631	0.4012	0.569	0.6833	0.7565	0.7753	0.7325	0.6504	0.4933	0.3033	0.0516
910	0.1694	0.3856	0.5412	0.6484	0.7167	0.7346	0.6934	0.6182	0.4688	0.2935	0.0522

920	0.1833	0.3839	0.5303	0.6316	0.6967	0.7137	0.6749	0.6029	0.4623	0.2988	0.0599
930	0.1346	0.2922	0.4084	0.4909	0.5396	0.5544	0.5182	0.471	0.3447	0.2119	0.0369
940	0.0976	0.22	0.3115	0.3777	0.4147	0.427	0.3956	0.3635	0.2565	0.1513	0.022
950	0.1104	0.226	0.3145	0.3787	0.416	0.4277	0.3985	0.3639	0.2635	0.1636	0.027
960	0.1514	0.2775	0.3776	0.4497	0.4951	0.5077	0.4784	0.4301	0.3277	0.2188	0.0429
970	0.179	0.3273	0.4448	0.5285	0.5829	0.5972	0.5654	0.5038	0.3911	0.2645	0.0526
980	0.185	0.35	0.479	0.5703	0.6299	0.6452	0.6116	0.5424	0.4225	0.2832	0.0544
990	0.1959	0.3762	0.5153	0.613	0.6777	0.6938	0.6589	0.5821	0.4571	0.307	0.0608
1000	0.1951	0.3794	0.5205	0.6193	0.6848	0.7011	0.6663	0.5876	0.4627	0.3103	0.0616
1010	0.1905	0.373	0.512	0.6094	0.674	0.69	0.6558	0.5781	0.4554	0.3049	0.0605
1020	0.1859	0.3658	0.5023	0.5977	0.661	0.6768	0.6433	0.5669	0.447	0.2991	0.0597
1030	0.1793	0.3579	0.4918	0.5852	0.6473	0.6627	0.63	0.555	0.4379	0.2923	0.0584
1040	0.1699	0.3486	0.4803	0.5717	0.6326	0.6478	0.6158	0.5422	0.4276	0.2836	0.0557
1050	0.1674	0.3412	0.4696	0.5587	0.6182	0.633	0.6018	0.53	0.4183	0.278	0.0552
1060	0.1649	0.3339	0.4589	0.5458	0.6038	0.6183	0.5878	0.5177	0.4089	0.2724	0.0547
1070	0.1624	0.3265	0.4482	0.5329	0.5894	0.6036	0.5738	0.5055	0.3995	0.2669	0.0542
1080	0.151	0.3078	0.4242	0.5055	0.5591	0.5728	0.5435	0.4798	0.3761	0.2484	0.0488
1090	0.1397	0.289	0.4002	0.4782	0.5288	0.5421	0.5132	0.454	0.3526	0.23	0.0433
1100	0.1283	0.2703	0.3761	0.4508	0.4985	0.5114	0.4829	0.4283	0.3291	0.2116	0.0378
1110	0.0818	0.1902	0.2732	0.3333	0.3686	0.3795	0.3535	0.3174	0.2304	0.1381	0.0211
1120	0.0352	0.1101	0.1702	0.2159	0.2388	0.2476	0.2242	0.2065	0.1318	0.0646	0.0043
1130	0.0492	0.1365	0.2047	0.2554	0.2824	0.292	0.2675	0.2439	0.1641	0.087	0.0077
1140	0.0478	0.1332	0.1999	0.2496	0.276	0.2855	0.2613	0.2384	0.1598	0.0844	0.0074
1150	0.0639	0.1582	0.2309	0.2844	0.3144	0.3243	0.2998	0.2712	0.1904	0.1085	0.0135
1160	0.0975	0.2116	0.2978	0.3596	0.3973	0.4084	0.383	0.3422	0.2558	0.1593	0.0259
1170	0.1124	0.2315	0.3213	0.3852	0.4255	0.4369	0.4117	0.3663	0.2803	0.1805	0.0332
1180	0.1149	0.2327	0.3216	0.3848	0.4251	0.4363	0.4117	0.3659	0.2816	0.1831	0.035
1190	0.1174	0.2338	0.322	0.3845	0.4247	0.4358	0.4117	0.3656	0.2829	0.1857	0.0369
1200	0.1199	0.235	0.3223	0.3842	0.4243	0.4352	0.4116	0.3652	0.2842	0.1883	0.0387
1210	0.1211	0.2354	0.3226	0.3843	0.4246	0.4355	0.4123	0.3651	0.2854	0.1902	0.0402
1220	0.1222	0.2359	0.3229	0.3844	0.4249	0.4358	0.413	0.365	0.2866	0.192	0.0417
1230	0.1234	0.2364	0.3232	0.3845	0.4253	0.436	0.4137	0.3649	0.2877	0.1938	0.0432
1240	0.1246	0.2369	0.3235	0.3846	0.4256	0.4363	0.4143	0.3648	0.2889	0.1956	0.0447
1250	0.1164	0.2247	0.3085	0.3677	0.4073	0.4177	0.3964	0.3484	0.2751	0.1848	0.0414
1260	0.1082	0.2125	0.2935	0.3508	0.3891	0.3991	0.3785	0.3321	0.2612	0.1739	0.0382
1270	0.0999	0.2003	0.2785	0.3339	0.3708	0.3805	0.3606	0.3157	0.2473	0.163	0.0349
1280	0.1099	0.2107	0.2892	0.3448	0.382	0.3918	0.3716	0.3268	0.2576	0.173	0.0392
1290	0.1198	0.221	0.2999	0.3558	0.3931	0.4031	0.3826	0.3379	0.2678	0.183	0.0435
1300	0.113	0.2102	0.2858	0.3396	0.3751	0.3847	0.3645	0.3227	0.254	0.1721	0.0398
1310	0.1062	0.1994	0.2717	0.3234	0.357	0.3664	0.3464	0.3076	0.2402	0.1613	0.036
1320	0.0994	0.1886	0.2577	0.3072	0.3389	0.348	0.3283	0.2924	0.2264	0.1505	0.0322
1330	0.0716	0.1435	0.1999	0.241	0.2659	0.2737	0.256	0.2297	0.1717	0.1098	0.022
1340	0.0439	0.0983	0.1421	0.1749	0.193	0.1994	0.1836	0.1671	0.1171	0.0691	0.0118
1350	0.0161	0.0532	0.0842	0.1087	0.12	0.1251	0.1113	0.1044	0.0624	0.0284	0.0015
1360	0.0127	0.0429	0.0687	0.0891	0.0984	0.1027	0.091	0.0857	0.0503	0.0225	0.0012
1370	0.0093	0.0327	0.0531	0.0696	0.0769	0.0804	0.0707	0.067	0.0382	0.0166	0.0008
1380	0.006	0.0224	0.0375	0.0501	0.0553	0.058	0.0503	0.0483	0.0261	0.0108	0.0005
1390	0.0026	0.0122	0.022	0.0305	0.0338	0.0357	0.03	0.0296	0.014	0.0049	0.0002
1400	0.0023	0.011	0.0202	0.0283	0.0313	0.0331	0.0277	0.0274	0.0127	0.0043	0.0002

Table 2-13 Spectral Data for the Hot-Cloudy Reference Day

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
300	0	0	0	0.0005	0.0021	0.005	0.0062	0.0064	0.0066	0.004	0.0016	0.0004	0	0	0
310	0	0.0002	0.007	0.0253	0.0446	0.0682	0.0684	0.0663	0.0719	0.0523	0.0312	0.016	0.0055	0.0004	0
320	0.0005	0.0064	0.0352	0.0793	0.1135	0.1558	0.1479	0.1406	0.1547	0.1183	0.0781	0.0485	0.0255	0.0068	0.0003
330	0.004	0.0221	0.0731	0.1445	0.1943	0.2577	0.2401	0.2269	0.2508	0.1949	0.1328	0.0872	0.0516	0.0208	0.0031
340	0.0056	0.0259	0.0762	0.1494	0.198	0.2608	0.2409	0.2269	0.2517	0.1961	0.1343	0.089	0.0532	0.0228	0.0042
350	0.0074	0.0309	0.0856	0.1688	0.2215	0.2905	0.2661	0.2498	0.2781	0.2168	0.1488	0.0989	0.0589	0.0254	0.005
360	0.0089	0.0338	0.0894	0.1776	0.2305	0.3011	0.2734	0.2558	0.2858	0.2229	0.1532	0.1022	0.0606	0.0258	0.0053
370	0.0124	0.0421	0.1065	0.2119	0.2716	0.3532	0.318	0.2967	0.3326	0.2596	0.179	0.1201	0.0713	0.03	0.0064
380	0.0136	0.044	0.1084	0.2159	0.2736	0.3542	0.3167	0.2947	0.3313	0.2587	0.1788	0.1205	0.0716	0.0294	0.0064
390	0.0136	0.0435	0.1059	0.2115	0.2653	0.3421	0.3042	0.2826	0.3183	0.2487	0.1721	0.1163	0.0689	0.0272	0.0058
400	0.0197	0.0637	0.1552	0.3105	0.3858	0.496	0.4389	0.4071	0.4594	0.359	0.2488	0.1685	0.0996	0.0379	0.0078
410	0.0235	0.0757	0.1845	0.3682	0.4534	0.5808	0.5117	0.4741	0.5357	0.419	0.291	0.1978	0.1171	0.0433	0.0088
420	0.0245	0.0794	0.1929	0.3838	0.4683	0.598	0.5248	0.4855	0.5494	0.43	0.2992	0.2041	0.1211	0.0436	0.0086
430	0.0225	0.0747	0.1813	0.3597	0.4352	0.5542	0.4846	0.4478	0.5074	0.3973	0.2767	0.1892	0.1124	0.0392	0.0074
440	0.026	0.0884	0.2143	0.4236	0.5085	0.6458	0.5628	0.5197	0.5894	0.4617	0.3219	0.2206	0.1313	0.0446	0.0079
450	0.0281	0.0986	0.2405	0.4736	0.565	0.7159	0.6223	0.5741	0.6517	0.5108	0.3565	0.2448	0.146	0.0485	0.0082
460	0.0276	0.1006	0.2488	0.4896	0.5816	0.736	0.6386	0.5888	0.6688	0.5242	0.366	0.2517	0.1501	0.0488	0.0078
470	0.0259	0.0986	0.247	0.4856	0.5746	0.7264	0.6291	0.5797	0.659	0.5165	0.3607	0.2482	0.1481	0.0472	0.007
480	0.0257	0.1015	0.2558	0.5019	0.5915	0.7469	0.6456	0.5946	0.6764	0.5301	0.3703	0.255	0.1522	0.0476	0.0066
490	0.0232	0.0963	0.2434	0.4768	0.5599	0.7063	0.6097	0.5612	0.6387	0.5006	0.3497	0.2409	0.1438	0.0441	0.0056
500	0.0223	0.0973	0.2469	0.4831	0.5654	0.7128	0.6144	0.5654	0.6438	0.5045	0.3524	0.2429	0.1449	0.0437	0.0051
510	0.021	0.0978	0.2496	0.4884	0.5704	0.7189	0.6192	0.5697	0.6488	0.5084	0.355	0.2445	0.1456	0.0431	0.0046
520	0.0185	0.0928	0.2386	0.4673	0.5451	0.6868	0.5915	0.5443	0.6198	0.4856	0.339	0.2333	0.1386	0.0401	0.0038
530	0.0175	0.0949	0.2468	0.4843	0.5645	0.7114	0.6127	0.5639	0.642	0.5029	0.3509	0.2412	0.1427	0.0404	0.0034
540	0.0163	0.0947	0.2478	0.4866	0.5666	0.7141	0.6148	0.5658	0.6442	0.5046	0.352	0.2417	0.1428	0.0398	0.003
550	0.015	0.0935	0.2463	0.4841	0.5631	0.7096	0.6105	0.5616	0.6397	0.5009	0.3492	0.2397	0.1414	0.0389	0.0027
560	0.0134	0.0901	0.2403	0.4739	0.5509	0.6948	0.597	0.5489	0.6257	0.4894	0.3407	0.2335	0.1373	0.0372	0.0023
570	0.0118	0.087	0.2353	0.4661	0.5411	0.6831	0.5852	0.5373	0.6136	0.479	0.3327	0.2277	0.1336	0.0357	0.0021
580	0.0105	0.0834	0.2281	0.454	0.5269	0.6662	0.5696	0.5224	0.5976	0.4659	0.3227	0.2202	0.1287	0.034	0.0019
590	0.0094	0.0799	0.22	0.4396	0.51	0.6456	0.5513	0.5052	0.5786	0.4508	0.3115	0.212	0.1236	0.0324	0.0017
600	0.0095	0.0819	0.222	0.441	0.5101	0.6447	0.5504	0.5045	0.5775	0.4502	0.3117	0.2127	0.1244	0.0327	0.0016
610	0.0099	0.0855	0.2268	0.4462	0.514	0.6478	0.5527	0.5068	0.5798	0.4523	0.314	0.2152	0.1267	0.0336	0.0015
620	0.0096	0.0857	0.2243	0.4397	0.5053	0.6362	0.5424	0.4973	0.569	0.444	0.3084	0.2116	0.1249	0.0332	0.0014
630	0.0093	0.0859	0.222	0.4337	0.4968	0.625	0.5316	0.4869	0.5578	0.435	0.3021	0.2076	0.123	0.0329	0.0013
640	0.0095	0.0867	0.2195	0.4265	0.4869	0.6118	0.5196	0.4757	0.5453	0.4253	0.2955	0.2034	0.1211	0.0328	0.0013
650	0.0096	0.0871	0.2164	0.4185	0.4761	0.5976	0.5067	0.4636	0.5318	0.4147	0.2884	0.1989	0.1189	0.0326	0.0013
660	0.0101	0.0898	0.2185	0.4199	0.4765	0.5972	0.5066	0.4635	0.5315	0.415	0.289	0.1997	0.1199	0.0331	0.0012
670	0.0103	0.0917	0.221	0.4235	0.4799	0.6013	0.5098	0.4665	0.5349	0.4177	0.2909	0.2011	0.1209	0.0335	0.0012
680	0.009	0.0847	0.2074	0.4002	0.4546	0.571	0.4839	0.4425	0.5079	0.3959	0.2749	0.1894	0.1133	0.0311	0.0011
690	0.0068	0.0744	0.1883	0.368	0.4198	0.5292	0.4478	0.409	0.4703	0.3655	0.2525	0.1729	0.1025	0.0276	0.0009
700	0.0078	0.0804	0.1963	0.3789	0.4292	0.5392	0.4548	0.4148	0.4777	0.3715	0.2573	0.1773	0.1065	0.0297	0.0012
710	0.0081	0.0848	0.2028	0.3878	0.4374	0.5481	0.4616	0.4207	0.4848	0.3775	0.262	0.1814	0.1099	0.0312	0.0012
720	0.0025	0.0474	0.1395	0.2894	0.339	0.4354	0.372	0.3394	0.391	0.3042	0.2058	0.1362	0.0764	0.0181	0.0004
730	0.0029	0.0548	0.1525	0.3097	0.3616	0.4614	0.3962	0.3629	0.4159	0.3247	0.2216	0.148	0.0839	0.02	0.0002
740	0.0038	0.0751	0.1893	0.3668	0.4227	0.5314	0.458	0.4215	0.4797	0.3766	0.2622	0.1793	0.1049	0.0259	0
750	0.0035	0.0796	0.1968	0.3773	0.4355	0.5457	0.4735	0.4374	0.4954	0.3903	0.2734	0.1876	0.1099	0.0265	0
760	0.002	0.0549	0.1496	0.2987	0.3531	0.4481	0.3919	0.363	0.4102	0.3212	0.2223	0.1494	0.0843	0.0187	0
770	0.0018	0.0635	0.1676	0.3284	0.3846	0.485	0.4238	0.3926	0.4433	0.3486	0.243	0.1649	0.0943	0.021	0
780	0.0013	0.0758	0.1891	0.3625	0.4204	0.5265	0.4597	0.4259	0.4806	0.3796	0.2665	0.1826	0.1061	0.0242	0
790	0.0009	0.0724	0.183	0.3527	0.4096	0.5139	0.4483	0.415	0.4688	0.3699	0.2591	0.177	0.1025	0.0231	0
800	0.0011	0.0692	0.176	0.3407	0.3948	0.496	0.4307	0.3978	0.4507	0.3549	0.2477	0.1691	0.098	0.0225	0
810	0.0012	0.0525	0.1436	0.2874	0.3364	0.4272	0.3704	0.3409	0.3881	0.3045	0.2096	0.1406	0.0796	0.0179	0
820	0.0007	0.0381	0.1156	0.2409	0.2857	0.3673	0.3185	0.2926	0.3342	0.2614	0.1773	0.1165	0.0639	0.0135	0
830	0.0009	0.0479	0.1324	0.2659	0.3111	0.3954	0.3422	0.3147	0.3587	0.2811	0.1931	0.1293	0.073	0.0163	0
840	0.0006	0.0576	0.1497	0.2926	0.3402	0.4287	0.3726	0.344	0.39	0.3069	0.2134	0.1448	0.0832	0.0186	0
850	0.0001	0.0612	0.1557	0.3009	0.3502	0.4399	0.3847	0.3564	0.4022	0.3177	0.2223	0.1514	0.0871	0.019	0
860	0	0.0647	0.161	0.3082	0.358	0.4482	0.3929	0.3647	0.4105	0.3248	0.2284	0.1563	0.0904	0.0195	0
870	0	0.0633	0.1578	0.3021	0.3511	0.4397	0.3856	0.3579	0.4029	0.3188	0.224	0.1533	0.0885	0.019	0
880	0	0.0626	0.155	0.2967	0.3435	0.4302	0.3754	0.3476	0.3924	0.3099	0.2174	0.1489	0.0864	0.0191	0
890	0.0008	0.0464	0.1225	0.2434	0.2848	0.3616	0.3145	0.2899	0.3295	0.2589	0.1783	0.1195	0.0677	0.0151	0
900	0.0007	0.0279	0.0855	0.182	0.2168	0.2813	0.2429	0.2222	0.2553	0.1988	0.133	0.0862	0.0466	0.0099	0
910	0.0006	0.0211	0.0717	0.1578	0.1884	0.2467	0.2105	0.191	0.2218	0.1715	0.1129	0.0722	0.0385	0.0081	0.0001

920	0.0009	0.0231	0.073	0.1572	0.1838	0.2393	0.2004	0.1804	0.2115	0.1626	0.1071	0.0695	0.0384	0.0091	0.0003
930	0.0001	0.0054	0.0272	0.0714	0.09	0.1245	0.1056	0.0943	0.1121	0.0853	0.0524	0.0306	0.0144	0.0025	0
940	0	0.0017	0.0122	0.037	0.049	0.0709	0.06	0.0529	0.064	0.048	0.0278	0.0151	0.0063	0.0008	0
950	0.0002	0.0043	0.0187	0.0491	0.061	0.0852	0.07	0.0613	0.0747	0.0558	0.0333	0.0193	0.0094	0.0019	0.0001
960	0.0007	0.0145	0.0451	0.0994	0.1147	0.1511	0.1222	0.1078	0.1298	0.0976	0.0623	0.04	0.0224	0.0058	0.0003
970	0.0008	0.0232	0.0686	0.1446	0.166	0.2146	0.1762	0.1573	0.1864	0.1418	0.0932	0.0612	0.0348	0.0088	0.0003
980	0.0005	0.0295	0.0838	0.1726	0.1983	0.2542	0.2115	0.1905	0.2232	0.1711	0.1142	0.0758	0.0433	0.0105	0.0002
990	0.0001	0.0406	0.1056	0.2087	0.238	0.3014	0.2526	0.2289	0.2659	0.2051	0.1394	0.0943	0.0551	0.0135	0
1000	0	0.0444	0.113	0.2207	0.2517	0.3173	0.2673	0.243	0.2811	0.2175	0.1488	0.1012	0.0593	0.0142	0
1010	0	0.0445	0.1128	0.22	0.2513	0.3165	0.2676	0.2437	0.2812	0.218	0.1495	0.1016	0.0593	0.0138	0
1020	0	0.0445	0.1121	0.2179	0.2491	0.3135	0.2656	0.2422	0.279	0.2165	0.1487	0.1012	0.059	0.0135	0
1030	0	0.0444	0.1111	0.2154	0.2462	0.3095	0.2628	0.24	0.276	0.2144	0.1476	0.1006	0.0586	0.0132	0
1040	0	0.044	0.1099	0.2123	0.2427	0.3048	0.2594	0.2372	0.2723	0.2118	0.1462	0.0997	0.0582	0.0129	0
1050	0	0.043	0.1073	0.2074	0.2371	0.2978	0.2534	0.2317	0.266	0.207	0.1428	0.0974	0.0568	0.0126	0
1060	0	0.042	0.1048	0.2025	0.2315	0.2907	0.2474	0.2263	0.2597	0.2021	0.1395	0.0951	0.0555	0.0123	0
1070	0	0.041	0.1023	0.1976	0.2259	0.2836	0.2414	0.2208	0.2534	0.1972	0.1361	0.0928	0.0542	0.012	0
1080	0	0.0334	0.088	0.1744	0.202	0.2558	0.2188	0.2002	0.2297	0.1787	0.1223	0.0822	0.0468	0.0099	0
1090	0	0.0257	0.0738	0.1513	0.1781	0.228	0.1962	0.1796	0.2061	0.1603	0.1085	0.0715	0.0394	0.0078	0
1100	0	0.0181	0.0595	0.1282	0.1542	0.2001	0.1736	0.159	0.1825	0.1419	0.0946	0.0608	0.032	0.0056	0
1110	0	0.0091	0.0312	0.0701	0.087	0.1158	0.1022	0.0938	0.1075	0.0836	0.0541	0.0334	0.0168	0.0028	0
1120	0	0.0001	0.0028	0.012	0.0197	0.0315	0.0308	0.0285	0.0326	0.0252	0.0136	0.006	0.0017	0.0001	0
1130	0	0.0005	0.0063	0.0223	0.0337	0.0507	0.048	0.0443	0.0507	0.0393	0.0225	0.011	0.0036	0.0002	0
1140	0	0.0005	0.0059	0.021	0.0319	0.0484	0.0459	0.0424	0.0485	0.0376	0.0214	0.0104	0.0034	0.0002	0
1150	0	0.0029	0.0148	0.0399	0.0539	0.0759	0.0692	0.0636	0.0729	0.0566	0.0346	0.0193	0.0082	0.001	0
1160	0	0.0079	0.0332	0.079	0.0995	0.1333	0.1179	0.1081	0.124	0.0963	0.0622	0.0378	0.0181	0.0026	0
1170	0	0.013	0.0459	0.1018	0.124	0.1624	0.1417	0.1298	0.1489	0.1158	0.0765	0.0484	0.0248	0.0041	0
1180	0	0.0148	0.0491	0.1066	0.1286	0.1674	0.1455	0.1333	0.1529	0.1189	0.0791	0.0506	0.0265	0.0046	0
1190	0	0.0165	0.0523	0.1114	0.1332	0.1724	0.1494	0.1368	0.1569	0.1221	0.0817	0.0528	0.0281	0.0051	0
1200	0	0.0182	0.0555	0.1161	0.1378	0.1774	0.1532	0.1403	0.161	0.1252	0.0842	0.055	0.0297	0.0056	0
1210	0	0.0209	0.0599	0.1226	0.1441	0.1843	0.1586	0.1452	0.1666	0.1295	0.0877	0.0579	0.032	0.0063	0
1220	0	0.0235	0.0643	0.129	0.1503	0.1912	0.164	0.1501	0.1722	0.1339	0.0912	0.0608	0.0342	0.007	0
1230	0	0.0262	0.0686	0.1354	0.1566	0.1981	0.1693	0.1549	0.1778	0.1382	0.0947	0.0638	0.0365	0.0078	0
1240	0	0.0288	0.073	0.1418	0.1628	0.205	0.1747	0.1598	0.1834	0.1425	0.0982	0.0667	0.0387	0.0085	0
1250	0	0.027	0.0693	0.1353	0.1558	0.1964	0.1676	0.1533	0.1759	0.1366	0.094	0.0637	0.0368	0.008	0
1260	0	0.0251	0.0655	0.1288	0.1488	0.1879	0.1604	0.1468	0.1684	0.1307	0.0897	0.0607	0.0348	0.0075	0
1270	0	0.0233	0.0618	0.1223	0.1417	0.1793	0.1532	0.1403	0.1609	0.1248	0.0855	0.0576	0.0329	0.0069	0
1280	0	0.0241	0.0632	0.1244	0.1438	0.1817	0.1553	0.1421	0.163	0.1266	0.0868	0.0586	0.0336	0.0072	0
1290	0	0.025	0.0645	0.1265	0.1459	0.1842	0.1573	0.1439	0.1651	0.1284	0.0882	0.0596	0.0343	0.0074	0
1300	0	0.0205	0.056	0.1125	0.1312	0.1671	0.1433	0.1312	0.1505	0.1171	0.0797	0.0531	0.0298	0.0062	0
1310	0	0.0161	0.0475	0.0985	0.1166	0.1499	0.1294	0.1185	0.1359	0.1057	0.0712	0.0466	0.0254	0.0049	0
1320	0	0.0117	0.0389	0.0845	0.102	0.1328	0.1154	0.1057	0.1213	0.0944	0.0628	0.0401	0.021	0.0037	0
1330	0	0.0078	0.0261	0.0573	0.0699	0.0918	0.0804	0.0737	0.0845	0.0657	0.0432	0.0273	0.0141	0.0024	0
1340	0	0.0039	0.0133	0.0302	0.0378	0.0509	0.0453	0.0416	0.0477	0.0371	0.0237	0.0144	0.0072	0.0012	0
1350	0	0	0.0005	0.0031	0.0058	0.01	0.0103	0.0095	0.0109	0.0084	0.0042	0.0016	0.0003	0	0
1360	0	0	0.0004	0.0024	0.0045	0.0078	0.008	0.0075	0.0085	0.0066	0.0032	0.0012	0.0003	0	0
1370	0	0	0.0003	0.0017	0.0032	0.0056	0.0058	0.0054	0.0062	0.0048	0.0023	0.0009	0.0002	0	0
1380	0	0	0.0002	0.001	0.002	0.0034	0.0036	0.0033	0.0038	0.0029	0.0014	0.0005	0.0001	0	0
1390	0	0	0.0001	0.0004	0.0007	0.0013	0.0013	0.0012	0.0014	0.0011	0.0005	0.0002	0	0	0
1400	0	0	0.0001	0.0003	0.0006	0.0011	0.0012	0.0011	0.0012	0.001	0.0005	0.0002	0	0	0

Table 2-14 Spectral Data for the Cold-Cloudy Reference Day

	8	9	10	11	12	13	14	15	16	17
300	0	0	0	0	0	0	0	0	0	0
310	0	0.0001	0.0022	0.0061	0.0093	0.01	0.0069	0.0029	0.0003	0
320	0	0.0057	0.0235	0.0387	0.0484	0.0516	0.0412	0.0268	0.0095	0
330	0	0.0248	0.0617	0.0866	0.1025	0.1089	0.0907	0.067	0.0351	0
340	0	0.0308	0.0668	0.0916	0.1078	0.1146	0.0957	0.0719	0.0415	0
350	0	0.0381	0.0755	0.1032	0.1215	0.1295	0.1078	0.0811	0.0495	0
360	0.0013	0.0429	0.0789	0.1079	0.1274	0.1359	0.1128	0.0847	0.0539	0.0017
370	0.0052	0.0548	0.0941	0.1288	0.152	0.1625	0.1346	0.1009	0.0669	0.0077
380	0.0082	0.0584	0.0955	0.1311	0.1549	0.1658	0.1371	0.1025	0.0697	0.0125
390	0.0099	0.0584	0.0929	0.1281	0.1515	0.1626	0.134	0.0998	0.0689	0.0154
400	0.0163	0.0863	0.1355	0.1879	0.2223	0.2389	0.1965	0.1458	0.1011	0.0256
410	0.0215	0.1032	0.1607	0.2234	0.2643	0.2843	0.2336	0.173	0.1203	0.034
420	0.0247	0.1089	0.1681	0.2338	0.2763	0.2975	0.2444	0.181	0.1264	0.0393
430	0.0248	0.1029	0.1579	0.2198	0.2595	0.2798	0.2297	0.1701	0.1193	0.0398
440	0.0307	0.1223	0.1869	0.2599	0.3065	0.3307	0.2715	0.2013	0.1416	0.0496
450	0.0347	0.1364	0.2097	0.2916	0.3436	0.371	0.3046	0.226	0.1585	0.0562
460	0.0348	0.1388	0.2167	0.3018	0.3555	0.3841	0.3152	0.2336	0.1624	0.0564
470	0.0333	0.1357	0.2149	0.2997	0.3529	0.3814	0.3129	0.2318	0.1598	0.054
480	0.0338	0.1395	0.2225	0.3103	0.3651	0.3949	0.3239	0.2401	0.165	0.0549
490	0.0317	0.1321	0.2117	0.2951	0.347	0.3756	0.308	0.2285	0.1569	0.0515
500	0.0313	0.1332	0.2147	0.2992	0.3516	0.3807	0.3121	0.2316	0.1589	0.0512
510	0.0303	0.1334	0.2167	0.3022	0.3551	0.3848	0.3153	0.2339	0.1599	0.0499
520	0.0275	0.1263	0.2068	0.2888	0.3395	0.3679	0.3013	0.2233	0.1521	0.0457
530	0.0265	0.1284	0.213	0.2982	0.3508	0.3804	0.3112	0.2302	0.1557	0.0445
540	0.0253	0.1277	0.2134	0.2991	0.352	0.3818	0.3121	0.2307	0.1554	0.0428
550	0.0237	0.1257	0.2117	0.2971	0.3496	0.3794	0.31	0.229	0.1537	0.0406
560	0.0215	0.1205	0.2055	0.2893	0.3408	0.3701	0.302	0.2225	0.1482	0.0374
570	0.0191	0.1155	0.2002	0.2828	0.3336	0.3624	0.2953	0.2169	0.143	0.0339
580	0.018	0.1137	0.1974	0.2788	0.3288	0.3574	0.2911	0.2139	0.1411	0.0325
590	0.0173	0.112	0.1941	0.2738	0.3228	0.351	0.2859	0.2103	0.1392	0.0316
600	0.0171	0.113	0.1943	0.2733	0.3218	0.35	0.2852	0.2104	0.1402	0.0315
610	0.0171	0.1141	0.1947	0.2728	0.3208	0.3488	0.2845	0.2105	0.1413	0.0314
620	0.0171	0.1151	0.1938	0.2704	0.3174	0.3451	0.2819	0.2093	0.142	0.0315
630	0.017	0.1161	0.1931	0.2682	0.3142	0.3418	0.2794	0.2082	0.1429	0.0318
640	0.0177	0.1179	0.1924	0.2655	0.3104	0.3377	0.2764	0.207	0.1443	0.0331
650	0.0182	0.1193	0.1911	0.2622	0.3059	0.3328	0.2728	0.2053	0.1452	0.0342
660	0.0193	0.1237	0.1945	0.2652	0.3086	0.3357	0.2757	0.2085	0.1498	0.0361
670	0.0199	0.1273	0.1981	0.2691	0.3128	0.3402	0.2796	0.2122	0.1537	0.0373
680	0.0179	0.1191	0.1869	0.2547	0.2964	0.3225	0.2647	0.2004	0.1443	0.0339
690	0.0143	0.1058	0.17	0.2334	0.2724	0.2966	0.2428	0.1827	0.1293	0.0284
700	0.0166	0.1152	0.1792	0.2433	0.2828	0.3078	0.2528	0.192	0.1393	0.0328
710	0.0177	0.1218	0.1863	0.2512	0.2912	0.3168	0.2608	0.1992	0.1465	0.0354
720	0.0111	0.0942	0.1551	0.2146	0.2519	0.2743	0.2241	0.1676	0.1174	0.0243
730	0.0113	0.0977	0.1594	0.2204	0.2585	0.2813	0.23	0.172	0.121	0.025
740	0.0135	0.111	0.1748	0.2394	0.2791	0.3032	0.249	0.1878	0.1349	0.0289
750	0.0137	0.1131	0.1771	0.2424	0.2824	0.3065	0.252	0.1901	0.1371	0.0291
760	0.008	0.0761	0.1291	0.1826	0.2157	0.2343	0.1906	0.1398	0.0943	0.0173
770	0.0089	0.0884	0.1465	0.2047	0.2405	0.2611	0.2134	0.1582	0.1091	0.0198
780	0.0113	0.1068	0.1685	0.2315	0.2701	0.293	0.2408	0.1811	0.1298	0.0254
790	0.0105	0.1037	0.1646	0.2267	0.2647	0.2873	0.2359	0.177	0.1264	0.0243
800	0.0101	0.1012	0.1606	0.2209	0.258	0.2801	0.2299	0.1728	0.1235	0.0238
810	0.0086	0.0889	0.1442	0.1994	0.2337	0.2539	0.2079	0.1555	0.1098	0.0207
820	0.0067	0.0764	0.1278	0.1784	0.21	0.2285	0.1864	0.1384	0.0959	0.017
830	0.0076	0.0824	0.1338	0.1852	0.217	0.2359	0.193	0.1444	0.102	0.0188
840	0.0084	0.0886	0.141	0.194	0.2267	0.2462	0.202	0.1517	0.1085	0.0203
850	0.0084	0.09	0.1423	0.1959	0.2288	0.2482	0.2038	0.1531	0.1098	0.0202
860	0.0085	0.0913	0.1434	0.197	0.2298	0.2493	0.2049	0.1541	0.111	0.0203
870	0.0083	0.0898	0.1409	0.1935	0.2258	0.2449	0.2013	0.1514	0.1092	0.0199
880	0.0085	0.0893	0.1393	0.1907	0.2222	0.2411	0.1983	0.1495	0.1084	0.0202
890	0.0072	0.077	0.1237	0.1707	0.1999	0.2171	0.1779	0.1333	0.095	0.0174
900	0.0051	0.0611	0.1031	0.1441	0.17	0.1852	0.1508	0.1119	0.0774	0.0131
910	0.0049	0.0567	0.096	0.1336	0.1575	0.1718	0.1398	0.1041	0.0723	0.0125

920	0.006	0.0591	0.096	0.1313	0.1537	0.1678	0.1371	0.1036	0.0743	0.0144
930	0.0026	0.0332	0.0616	0.0876	0.1049	0.1148	0.0925	0.0678	0.0449	0.0069
940	0.0012	0.0195	0.0403	0.0592	0.0722	0.0793	0.0631	0.045	0.0279	0.0035
950	0.0019	0.0235	0.0441	0.0631	0.0759	0.0835	0.0668	0.0487	0.032	0.005
960	0.0038	0.0389	0.0637	0.0876	0.1029	0.1129	0.0916	0.069	0.0493	0.0099
970	0.0048	0.0511	0.0818	0.1118	0.1307	0.1429	0.1166	0.0881	0.0636	0.013
980	0.0047	0.0567	0.091	0.1249	0.1461	0.1595	0.1302	0.098	0.0703	0.0139
990	0.0054	0.0652	0.1024	0.1401	0.1633	0.178	0.1457	0.1101	0.0797	0.0161
1000	0.0053	0.0672	0.1052	0.1439	0.1677	0.1828	0.1496	0.113	0.0819	0.0164
1010	0.0051	0.0663	0.1038	0.1423	0.166	0.1808	0.148	0.1115	0.0808	0.0161
1020	0.0049	0.0654	0.1021	0.14	0.1633	0.1779	0.1456	0.1097	0.0795	0.0157
1030	0.0047	0.0642	0.1002	0.1374	0.1603	0.1745	0.1429	0.1076	0.0781	0.0152
1040	0.0043	0.0627	0.098	0.1345	0.1568	0.1707	0.1398	0.1052	0.0762	0.0144
1050	0.0042	0.0614	0.0958	0.1315	0.1533	0.1669	0.1367	0.1029	0.0747	0.0141
1060	0.0041	0.0601	0.0937	0.1285	0.1498	0.1631	0.1336	0.1006	0.0731	0.0138
1070	0.004	0.0588	0.0916	0.1256	0.1463	0.1593	0.1305	0.0983	0.0715	0.0135
1080	0.0034	0.0528	0.0842	0.1164	0.1363	0.1484	0.1213	0.0907	0.0649	0.0117
1090	0.0028	0.0467	0.0768	0.1073	0.1263	0.1376	0.1121	0.0831	0.0583	0.01
1100	0.0022	0.0406	0.0694	0.0982	0.1164	0.1268	0.1028	0.0755	0.0517	0.0082
1110	0.0011	0.023	0.043	0.0635	0.0771	0.0841	0.0672	0.0475	0.0304	0.0043
1120	0.0001	0.0053	0.0165	0.0288	0.0378	0.0414	0.0316	0.0196	0.009	0.0005
1130	0.0002	0.0091	0.0238	0.039	0.0498	0.0545	0.0423	0.0275	0.0142	0.001
1140	0.0002	0.0086	0.0229	0.0378	0.0483	0.0529	0.0409	0.0265	0.0136	0.0009
1150	0.0005	0.0145	0.0315	0.0489	0.0608	0.0664	0.0523	0.0356	0.0207	0.0022
1160	0.0012	0.0267	0.0497	0.0725	0.0872	0.0951	0.0765	0.0547	0.0354	0.0048
1170	0.0017	0.0333	0.0578	0.0824	0.0979	0.1067	0.0864	0.0631	0.0427	0.0065
1180	0.0019	0.0345	0.059	0.0835	0.0989	0.1078	0.0874	0.0642	0.044	0.007
1190	0.002	0.0358	0.0601	0.0846	0.1	0.1089	0.0885	0.0653	0.0452	0.0074
1200	0.0022	0.0371	0.0612	0.0857	0.101	0.11	0.0895	0.0664	0.0465	0.0078
1210	0.0023	0.0383	0.0623	0.0867	0.102	0.111	0.0905	0.0673	0.0476	0.0082
1220	0.0025	0.0394	0.0633	0.0878	0.103	0.1121	0.0915	0.0683	0.0487	0.0086
1230	0.0026	0.0406	0.0643	0.0889	0.104	0.1132	0.0925	0.0693	0.0497	0.009
1240	0.0027	0.0418	0.0654	0.0899	0.1049	0.1142	0.0935	0.0703	0.0508	0.0094
1250	0.0025	0.039	0.0618	0.0853	0.0998	0.1086	0.0887	0.0665	0.0476	0.0086
1260	0.0022	0.0362	0.0581	0.0807	0.0946	0.103	0.084	0.0627	0.0444	0.0078
1270	0.002	0.0335	0.0545	0.0761	0.0894	0.0973	0.0793	0.0589	0.0412	0.007
1280	0.0023	0.036	0.0574	0.0795	0.0931	0.1013	0.0827	0.0618	0.0441	0.0079
1290	0.0025	0.0386	0.0603	0.0829	0.0968	0.1053	0.0862	0.0648	0.047	0.0087
1300	0.0022	0.0351	0.056	0.0776	0.0909	0.099	0.0808	0.0604	0.0432	0.0077
1310	0.0019	0.0316	0.0517	0.0722	0.085	0.0926	0.0754	0.056	0.0394	0.0067
1320	0.0015	0.0281	0.0474	0.0669	0.0792	0.0863	0.07	0.0516	0.0356	0.0057
1330	0.001	0.0193	0.0337	0.0486	0.0582	0.0635	0.0511	0.037	0.0248	0.0039
1340	0.0005	0.0105	0.02	0.0303	0.0373	0.0407	0.0322	0.0224	0.0139	0.002
1350	0	0.0016	0.0064	0.0119	0.0163	0.0179	0.0133	0.0078	0.0031	0.0001
1360	0	0.0013	0.005	0.0095	0.013	0.0143	0.0106	0.0061	0.0024	0.0001
1370	0	0.0009	0.0036	0.007	0.0096	0.0106	0.0078	0.0045	0.0018	0.0001
1380	0	0.0006	0.0023	0.0045	0.0063	0.0069	0.0051	0.0028	0.0011	0
1390	0	0.0002	0.0009	0.002	0.003	0.0033	0.0023	0.0012	0.0004	0
1400	0	0.0002	0.0008	0.0018	0.0026	0.0029	0.002	0.001	0.0003	0

Table 2-15 Spectral Data for the Nice Reference Day

	6	7	8	9	10	11	12	13	14	15	16	17	18	19
300	0	0	0	0.0005	0.002	0.004	0.0057	0.0055	0.0043	0.0023	0.0007	0.0001	0	0
310	0	0.0013	0.0115	0.0341	0.0653	0.0908	0.1091	0.1035	0.095	0.0712	0.0409	0.0152	0.0018	0
320	0.0003	0.0165	0.057	0.1165	0.1858	0.2349	0.2701	0.2559	0.2441	0.1995	0.1361	0.0713	0.0202	0.0001
330	0.002	0.0464	0.1198	0.2195	0.331	0.4061	0.4602	0.4354	0.4212	0.3531	0.2543	0.1478	0.0549	0.0006
340	0.0036	0.0515	0.1271	0.2293	0.3431	0.4184	0.4727	0.4456	0.434	0.365	0.2655	0.1564	0.061	0.0024
350	0.0066	0.0594	0.1452	0.261	0.3898	0.4735	0.5343	0.5014	0.4916	0.4137	0.3025	0.1788	0.0709	0.0061
360	0.0099	0.0632	0.1541	0.2762	0.4117	0.4984	0.5619	0.525	0.518	0.4361	0.3206	0.19	0.0758	0.0104
370	0.0159	0.0763	0.1856	0.3306	0.4908	0.5918	0.6662	0.6201	0.6155	0.5189	0.3838	0.2286	0.092	0.0176
380	0.0194	0.0784	0.191	0.338	0.5002	0.6007	0.6756	0.6264	0.6253	0.5279	0.3929	0.2352	0.095	0.0221
390	0.0211	0.0771	0.1889	0.3324	0.4905	0.587	0.6596	0.6093	0.6116	0.5169	0.3868	0.2325	0.0938	0.0244
400	0.0328	0.1132	0.2795	0.4894	0.7201	0.859	0.9647	0.8882	0.8958	0.7579	0.57	0.344	0.1383	0.0383
410	0.041	0.1347	0.3342	0.5812	0.8521	1.0135	1.137	1.0442	1.0574	0.8957	0.6771	0.4107	0.165	0.0483
420	0.0449	0.1414	0.3514	0.6068	0.8864	1.0509	1.1779	1.0792	1.097	0.9306	0.7071	0.4314	0.1736	0.0534
430	0.0437	0.1336	0.3323	0.5698	0.8297	0.9809	1.0986	1.0041	1.0244	0.8702	0.6645	0.4077	0.1644	0.0524
440	0.0529	0.1587	0.3945	0.6718	0.9748	1.1496	1.2864	1.1736	1.201	1.0214	0.7835	0.4835	0.1955	0.0637
450	0.059	0.178	0.4435	0.7512	1.0871	1.2795	1.4307	1.3035	1.3369	1.138	0.8759	0.5426	0.2193	0.0711
460	0.0591	0.183	0.4592	0.7759	1.1216	1.3189	1.4742	1.3417	1.3783	1.1726	0.9038	0.5602	0.2251	0.071
470	0.0566	0.1806	0.4563	0.7694	1.1112	1.3058	1.4592	1.3264	1.3648	1.1605	0.8956	0.5553	0.2218	0.0678
480	0.0572	0.1864	0.4729	0.7951	1.147	1.3469	1.5046	1.3661	1.408	1.1968	0.925	0.5742	0.2286	0.0684
490	0.0534	0.177	0.4504	0.7553	1.0886	1.2774	1.4266	1.2936	1.3355	1.1347	0.8783	0.5459	0.2169	0.0637
500	0.0528	0.179	0.4571	0.7649	1.1017	1.2921	1.4428	1.3068	1.3511	1.1474	0.8891	0.553	0.2191	0.063
510	0.0516	0.1801	0.4623	0.7728	1.1128	1.3047	1.4568	1.3183	1.3645	1.158	0.8978	0.5583	0.2202	0.0614
520	0.0476	0.1714	0.4423	0.739	1.0641	1.2475	1.3929	1.2595	1.3048	1.1065	0.8581	0.5332	0.2092	0.0563
530	0.0468	0.1758	0.4574	0.7649	1.1021	1.2925	1.4431	1.3041	1.3519	1.1452	0.8877	0.5506	0.2144	0.0552
540	0.0452	0.1754	0.4591	0.7677	1.1064	1.2977	1.4489	1.3087	1.3575	1.1489	0.8905	0.5517	0.2136	0.0532
550	0.0433	0.1733	0.4563	0.7632	1.1002	1.2907	1.4411	1.301	1.3501	1.1417	0.8847	0.5473	0.2107	0.0507
560	0.0402	0.1676	0.4455	0.7466	1.0777	1.2651	1.4128	1.2748	1.3234	1.1177	0.8652	0.5337	0.2037	0.047
570	0.0371	0.1625	0.437	0.7345	1.0619	1.2476	1.3937	1.2569	1.3051	1.1007	0.8508	0.5229	0.1974	0.0432
580	0.0355	0.159	0.4298	0.7227	1.0457	1.229	1.3729	1.2374	1.2856	1.0834	0.837	0.5135	0.1928	0.0411
590	0.0341	0.1551	0.4205	0.7069	1.0232	1.2028	1.3435	1.21	1.2581	1.0596	0.8185	0.5016	0.1877	0.0392
600	0.0342	0.1554	0.4201	0.7044	1.0184	1.1964	1.3362	1.2028	1.2517	1.054	0.8151	0.5003	0.1876	0.0388
610	0.0345	0.1563	0.4208	0.7031	1.015	1.1914	1.3303	1.1971	1.2466	1.0497	0.813	0.5004	0.1883	0.0388
620	0.0347	0.1554	0.4161	0.6931	0.999	1.1719	1.308	1.1767	1.2261	1.0326	0.8008	0.494	0.1867	0.0385
630	0.0349	0.1547	0.4122	0.6843	0.9848	1.1544	1.2878	1.1585	1.2076	1.0173	0.7899	0.4883	0.1853	0.0383
640	0.0358	0.154	0.4071	0.673	0.9668	1.1323	1.2624	1.1354	1.1842	0.9981	0.7764	0.4816	0.184	0.0388
650	0.0364	0.1529	0.4011	0.6605	0.9471	1.1082	1.235	1.1104	1.159	0.9772	0.7615	0.4738	0.1822	0.0391
660	0.038	0.1553	0.4041	0.6624	0.9479	1.1081	1.2344	1.1093	1.1589	0.9776	0.7632	0.4763	0.1844	0.04
670	0.0389	0.1577	0.4089	0.669	0.9566	1.1179	1.245	1.1186	1.1691	0.986	0.7704	0.4813	0.1867	0.0404
680	0.0355	0.1479	0.387	0.6356	0.9108	1.066	1.1878	1.0672	1.1147	0.9386	0.7315	0.4549	0.1748	0.0365
690	0.0303	0.1335	0.3557	0.5884	0.8462	0.9929	1.1068	0.9953	1.0378	0.8717	0.6766	0.4175	0.1578	0.031
700	0.0338	0.1407	0.3684	0.6039	0.8638	1.011	1.125	1.0127	1.056	0.8891	0.6931	0.4312	0.1657	0.0342
710	0.0361	0.1461	0.3782	0.6161	0.8775	1.0251	1.139	1.0264	1.0699	0.9024	0.7057	0.4416	0.1714	0.0362
720	0.0233	0.1131	0.3102	0.5179	0.7469	0.8794	0.9786	0.8818	0.9168	0.7692	0.5936	0.3608	0.1323	0.0231
730	0.0248	0.1179	0.3207	0.5331	0.7659	0.9007	1.0012	0.9042	0.9383	0.7879	0.6093	0.3723	0.1377	0.0241
740	0.0304	0.1344	0.3548	0.5814	0.8277	0.9693	1.0756	0.9741	1.0096	0.85	0.6621	0.411	0.1564	0.0289
750	0.0311	0.1365	0.3586	0.5859	0.8317	0.9733	1.0793	0.9791	1.0134	0.8535	0.6656	0.4144	0.1583	0.0287
760	0.0194	0.0985	0.2754	0.4642	0.6705	0.7929	0.8831	0.802	0.8257	0.6884	0.5275	0.3186	0.1148	0.0178
770	0.0223	0.1117	0.3054	0.5076	0.7267	0.8553	0.9501	0.8633	0.8901	0.7454	0.5757	0.3522	0.1295	0.02
780	0.028	0.129	0.3414	0.5581	0.7916	0.9269	1.0272	0.9333	0.9643	0.8113	0.6321	0.3926	0.1487	0.0245
790	0.0266	0.1254	0.334	0.5471	0.7769	0.9103	1.0088	0.9166	0.9469	0.7961	0.6196	0.3839	0.1445	0.0231
800	0.0256	0.1216	0.3252	0.5333	0.7579	0.8884	0.9846	0.8942	0.9241	0.7765	0.604	0.3736	0.1401	0.0222
810	0.021	0.1055	0.2883	0.4773	0.6823	0.8023	0.8898	0.8072	0.8342	0.6995	0.5411	0.3307	0.1213	0.0181
820	0.0165	0.0903	0.2539	0.4251	0.6118	0.7219	0.8015	0.7262	0.7505	0.6276	0.4826	0.2909	0.1038	0.014
830	0.0189	0.0973	0.2677	0.4435	0.6344	0.7464	0.8278	0.7507	0.776	0.6501	0.5026	0.3065	0.1117	0.0157
840	0.0211	0.1047	0.2831	0.4654	0.6624	0.7774	0.8616	0.7823	0.8084	0.6781	0.5263	0.3238	0.1198	0.017
850	0.0215	0.1062	0.286	0.4688	0.6659	0.781	0.8653	0.7862	0.8121	0.6814	0.5295	0.3266	0.1213	0.0168
860	0.022	0.1077	0.2884	0.4714	0.6682	0.7831	0.8673	0.7885	0.8142	0.6834	0.5318	0.329	0.1227	0.0167
870	0.0214	0.1055	0.2829	0.4625	0.6555	0.7683	0.8508	0.7737	0.7987	0.6702	0.5215	0.3224	0.12	0.0159
880	0.0212	0.104	0.2789	0.4556	0.6458	0.7568	0.838	0.7618	0.7867	0.6601	0.5137	0.3176	0.1182	0.0156
890	0.017	0.0884	0.2438	0.4035	0.5767	0.6789	0.7527	0.6828	0.7055	0.5902	0.4559	0.2774	0.1003	0.0125
900	0.0118	0.0694	0.2005	0.3385	0.4899	0.5802	0.6445	0.5828	0.6028	0.5021	0.3838	0.228	0.0788	0.0087
910	0.0102	0.0627	0.1835	0.3114	0.4527	0.537	0.597	0.5384	0.5581	0.4642	0.3538	0.2087	0.071	0.0073

920	0.0113	0.0635	0.1818	0.3057	0.4429	0.524	0.5824	0.524	0.5449	0.454	0.3476	0.2069	0.0718	0.0079
930	0.0042	0.0337	0.1088	0.193	0.2888	0.3475	0.3885	0.3466	0.3614	0.2977	0.2214	0.1234	0.0379	0.0028
940	0.0018	0.0194	0.069	0.1277	0.1963	0.2393	0.2689	0.2381	0.249	0.2032	0.1478	0.0783	0.0218	0.0012
950	0.003	0.0237	0.0785	0.141	0.2132	0.2577	0.2886	0.2564	0.268	0.22	0.1625	0.0892	0.0268	0.002
960	0.0072	0.0412	0.1213	0.2065	0.3017	0.3586	0.3987	0.3583	0.3725	0.3094	0.2352	0.1379	0.0467	0.0048
970	0.0101	0.0558	0.1594	0.2667	0.384	0.4538	0.5025	0.4556	0.4705	0.3925	0.3012	0.1805	0.0632	0.0068
980	0.0116	0.0636	0.18	0.2997	0.4286	0.5059	0.559	0.5096	0.5237	0.4375	0.3366	0.2031	0.0718	0.0076
990	0.0141	0.0739	0.2045	0.3369	0.478	0.5625	0.6203	0.5679	0.5816	0.4871	0.3766	0.2301	0.0832	0.0091
1000	0.0148	0.0766	0.211	0.3466	0.4901	0.5762	0.6348	0.5826	0.5954	0.499	0.3864	0.237	0.0862	0.0093
1010	0.0145	0.0758	0.2087	0.3427	0.4842	0.5692	0.6268	0.576	0.588	0.4928	0.3816	0.2342	0.0851	0.0089
1020	0.0142	0.0747	0.2056	0.3373	0.4762	0.5598	0.6163	0.5666	0.5782	0.4846	0.3754	0.2305	0.0838	0.0085
1030	0.0139	0.0734	0.202	0.3312	0.4675	0.5494	0.6049	0.5559	0.5676	0.4756	0.3686	0.2264	0.0822	0.008
1040	0.0134	0.0718	0.1979	0.3244	0.458	0.5381	0.5927	0.5444	0.5562	0.4659	0.3611	0.2218	0.0804	0.0075
1050	0.013	0.0701	0.1934	0.3169	0.4474	0.5257	0.579	0.5318	0.5433	0.455	0.3527	0.2166	0.0785	0.0071
1060	0.0127	0.0684	0.1888	0.3095	0.4368	0.5133	0.5653	0.5192	0.5304	0.4442	0.3442	0.2113	0.0765	0.0067
1070	0.0123	0.0668	0.1843	0.302	0.4262	0.5008	0.5516	0.5066	0.5176	0.4333	0.3358	0.2061	0.0745	0.0063
1080	0.0104	0.0598	0.1683	0.2782	0.3946	0.465	0.5125	0.4705	0.4804	0.4015	0.3096	0.188	0.0666	0.0052
1090	0.0085	0.0527	0.1523	0.2545	0.363	0.4292	0.4735	0.4345	0.4433	0.3696	0.2834	0.1699	0.0587	0.0042
1100	0.0066	0.0457	0.1363	0.2307	0.3314	0.3934	0.4344	0.3984	0.4062	0.3377	0.2571	0.1518	0.0508	0.0031
1110	0.0034	0.0259	0.0824	0.1451	0.2133	0.2569	0.2848	0.2606	0.2649	0.2182	0.1623	0.0916	0.0288	0.0016
1120	0.0002	0.006	0.0286	0.0594	0.0952	0.1204	0.1352	0.1228	0.1236	0.0986	0.0674	0.0314	0.0067	0.0001
1130	0.0005	0.0102	0.0425	0.0834	0.1297	0.1612	0.1801	0.164	0.1657	0.1337	0.0942	0.0468	0.0113	0.0002
1140	0.0005	0.0097	0.0408	0.0804	0.1253	0.1559	0.1743	0.1587	0.1603	0.1292	0.0908	0.0449	0.0107	0.0002
1150	0.0014	0.0161	0.0583	0.1079	0.163	0.1992	0.2217	0.2023	0.2051	0.1672	0.1212	0.0644	0.0178	0.0005
1160	0.0034	0.0296	0.095	0.166	0.2426	0.291	0.3221	0.2949	0.3	0.2476	0.1853	0.1053	0.0327	0.0013
1170	0.0049	0.0367	0.1121	0.1913	0.276	0.3287	0.3631	0.3329	0.3392	0.2812	0.2131	0.1243	0.0405	0.0018
1180	0.0053	0.038	0.1146	0.1945	0.2797	0.3324	0.367	0.3366	0.343	0.2847	0.2164	0.1271	0.042	0.0018
1190	0.0056	0.0393	0.1171	0.1976	0.2833	0.3362	0.3709	0.3403	0.3469	0.2882	0.2197	0.1299	0.0434	0.0018
1200	0.006	0.0407	0.1196	0.2007	0.2869	0.3399	0.3749	0.344	0.3508	0.2918	0.223	0.1326	0.0448	0.0019
1210	0.0064	0.0421	0.1225	0.2046	0.2918	0.3452	0.3806	0.3494	0.3564	0.2966	0.2272	0.1359	0.0463	0.0019
1220	0.0069	0.0435	0.1254	0.2086	0.2967	0.3505	0.3864	0.3548	0.3619	0.3014	0.2314	0.1391	0.0479	0.0019
1230	0.0073	0.0449	0.1283	0.2125	0.3016	0.3559	0.3922	0.3602	0.3675	0.3062	0.2357	0.1424	0.0495	0.002
1240	0.0077	0.0464	0.1313	0.2164	0.3065	0.3612	0.398	0.3656	0.3731	0.311	0.2399	0.1457	0.051	0.002
1250	0.0071	0.0437	0.1248	0.2066	0.2932	0.346	0.3814	0.3505	0.3574	0.2976	0.229	0.1385	0.0481	0.0017
1260	0.0064	0.041	0.1184	0.1968	0.28	0.3308	0.3649	0.3353	0.3417	0.2841	0.2182	0.1314	0.0452	0.0015
1270	0.0058	0.0384	0.112	0.187	0.2667	0.3156	0.3484	0.3201	0.3261	0.2707	0.2073	0.1243	0.0423	0.0012
1280	0.0063	0.0402	0.1157	0.1921	0.2731	0.3226	0.3557	0.3268	0.3331	0.2771	0.2129	0.1283	0.0441	0.0012
1290	0.0068	0.0419	0.1195	0.1972	0.2794	0.3295	0.363	0.3334	0.3402	0.2835	0.2184	0.1322	0.046	0.0012
1300	0.0058	0.038	0.11	0.183	0.2603	0.3077	0.3391	0.3114	0.3176	0.2642	0.2027	0.1216	0.0415	0.001
1310	0.0049	0.034	0.1005	0.1687	0.2411	0.2859	0.3153	0.2893	0.295	0.245	0.1871	0.111	0.0371	0.0008
1320	0.0039	0.03	0.091	0.1544	0.222	0.264	0.2914	0.2673	0.2723	0.2257	0.1714	0.1003	0.0327	0.0005
1330	0.0026	0.0206	0.0641	0.1106	0.1609	0.1927	0.2132	0.1953	0.1987	0.1639	0.123	0.0706	0.0224	0.0004
1340	0.0013	0.0112	0.0371	0.0668	0.0998	0.1214	0.1349	0.1233	0.125	0.102	0.0746	0.0408	0.0122	0.0002
1350	0	0.0018	0.0102	0.0231	0.0386	0.0501	0.0567	0.0513	0.0513	0.0402	0.0263	0.0111	0.0019	0
1360	0	0.0014	0.008	0.0182	0.0306	0.0398	0.045	0.0407	0.0407	0.0318	0.0207	0.0087	0.0015	0
1370	0	0.001	0.0058	0.0133	0.0225	0.0294	0.0333	0.0301	0.0301	0.0235	0.0152	0.0063	0.0011	0
1380	0	0.0006	0.0036	0.0084	0.0145	0.0191	0.0216	0.0195	0.0195	0.0151	0.0096	0.0039	0.0006	0
1390	0	0.0002	0.0014	0.0035	0.0064	0.0087	0.01	0.0089	0.0089	0.0067	0.0041	0.0015	0.0002	0
1400	0	0.0002	0.0012	0.0031	0.0057	0.0078	0.0089	0.008	0.0079	0.006	0.0036	0.0013	0.0002	0

3.0 Module Energy Ratings Methodology

3.1 Approach

The MER method uses indoor tests to characterize the electrical performance of a PV module and to determine factors to correct for non-linear performance when the irradiance and PV module temperature vary. Meteorological data from MER reference days are used to calculate PV module irradiances and temperatures, from which PV module I-V curves are generated, one for each hour of an MER reference day. The calculated PV module irradiances and temperatures account for the PV module's spectral response and thermal characteristics. Summing the appropriate values from the hourly I-V curves determines the MER reference day energy ratings.

Three technical areas address implementing the MER method: (1) determining PV module temperature and irradiance correction factors and functions, (2) determining the irradiance and PV module temperature for each reference day hour, and (3) translating a reference I-V curve to the irradiance and PV module temperature conditions. This section presents the procedural steps and supporting documentation for validating the technical approach and some methodology results as applied to various PV modules. An abbreviated version of this section with only procedural steps is given in Appendix A.

3.2 PV Module Temperature and Irradiance Correction Factors and Functions

The correction factors and functions are determined based on Annex A2 of ASTM E1036-96 [1], but with a different normalization method that improved results. The ASTM procedure determines the correction factors and functions from a matrix of Isc and Voc values resulting from I-V curve measurements over a range of six irradiances and six operating temperatures. Figure 3-1 shows that a temperature range of 5°C-60°C and an irradiance range of 100-1000 W/m^2 enclose most of the MER reference day PV module irradiances and temperatures.

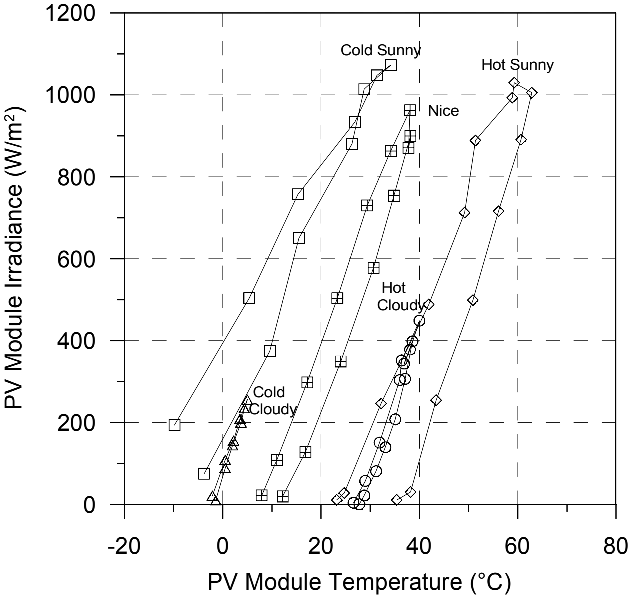

Figure 3-1. PV module irradiances and temperatures for the MER reference days for a PV module with an installed nominal operating cell temperature of 44°C.

One of the I-V curve measurements is performed at standard reporting conditions (SRC), which is 1000 W/m^2, 25°C, and AM1.5 spectrum. For lower irradiances, the PV module is covered with successive layers of screens or thin paper, while maintaining the solar simulator at the maximum irradiance value. The temperature may be varied by using a temperature-controlled chamber with a window for transmitting the radiation from the light source to the module.

The irradiance value for a filtered irradiance level is determined by multiplying the unfiltered irradiance by the ratio of Isc with filter to Isc without filter. This is done for each temperature level, and then an average irradiance is determined. These irradiances assume that the short-circuit current for a constant temperature is directly proportional to the irradiance. The temperature value for a temperature level is determined as the average of the measured values.

The matrix of Isc and Voc values resulting from I-V curve measurements is used to determine the Isc correction factor for temperature, α; the Voc correction function for temperature, $\beta(E)$; and the Voc correction function for irradiance, $\delta(T)$.

3.2.1 Determining α, the Isc Correction Factor for Temperature.

Figure 3-2 provides an example of how Isc varies with temperatures for different irradiance levels. Data such as these are used to find α.

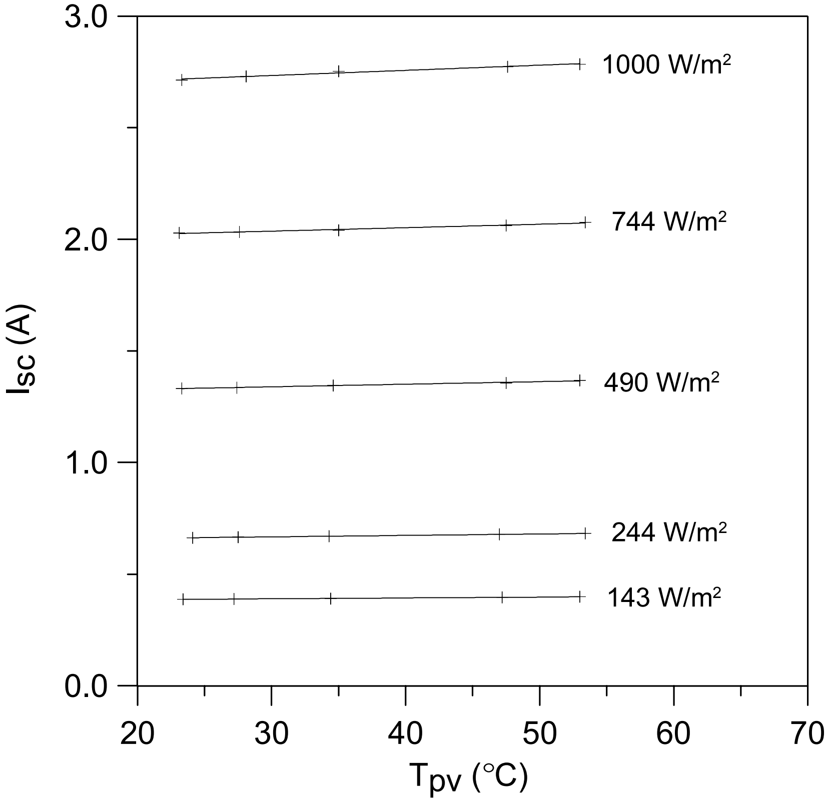

Figure 3-2. Example of Isc as a function of PV module temperature for various irradiance levels.

Step 1. Perform a least-squares fit to find the slope $\Delta Isc/\Delta T$ for the irradiance level of 1000 W/m^2.

Step 2. Normalize the slope by dividing by the Isc at the rated irradiance of 1000 W/m^2 and the rated temperature of 25°C. The normalized slope is α, the Isc correction factor for temperature. *(This is different than E1036. E1036 determines* α *as a function of the irradiance, which implies that Isc is not proportional to irradiance. Our assumption that Isc, for constant temperature, is directly proportional to irradiance requires that* α *be a constant for all irradiances.)*

3.2.2 Determining $\beta(E)$, the Voc Correction Function for Temperature.

Figure 3-3 provides an example of how Voc varies with temperatures for different irradiance levels. Data such as these are used to find $\beta(E)$.

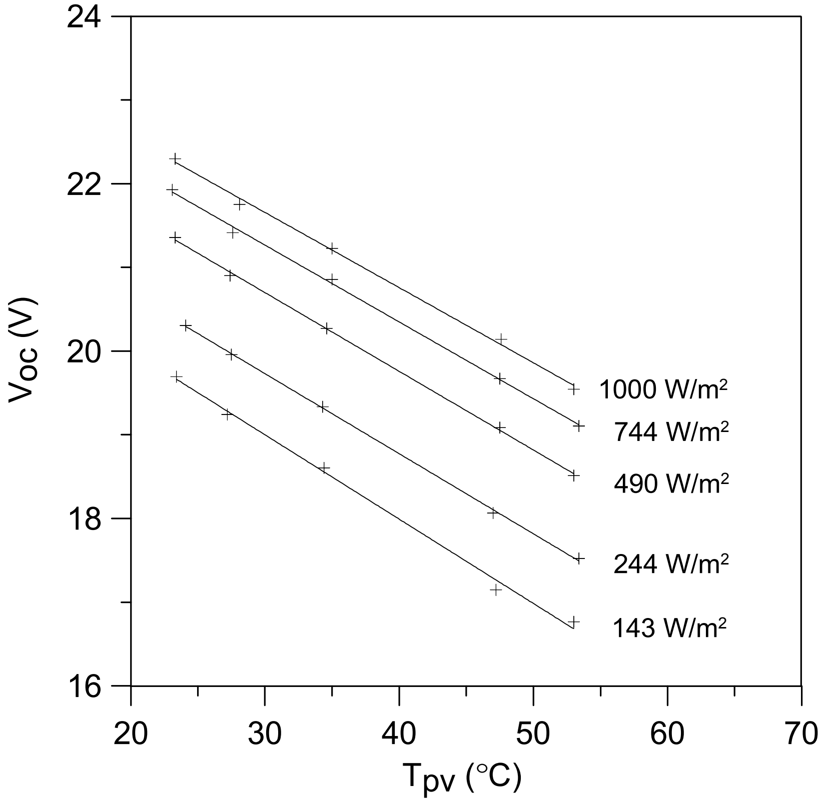

Figure 3-3. Example of Voc as a function of PV module temperature for various irradiance levels.

Step 1. Perform a least-squares fit to find the slope $\Delta Voc/\Delta T$ for each irradiance level E.

Step 2. Normalize each slope by dividing by the Voc at its irradiance level for the rated temperature of 25°C. *(This is a different normalization than used in E1036 and improved the accuracy. E1036 divides by the Voc for the rated irradiance of 1000 W/m^2 and the rated temperature of 25°C.)*

Step 3. Perform a least-squares fit of the normalized slopes versus irradiance to determine a function of the form:

$$\beta(E) = mE + b,$$

where

m = slope
b = y-intercept.

3.2.3 Determining δ(T), the Voc Correction Function for Irradiance.

Figure 3-4 provides an example of how Voc varies with the natural log of the irradiance for different temperature levels. Data such as these are used to find δ(T).

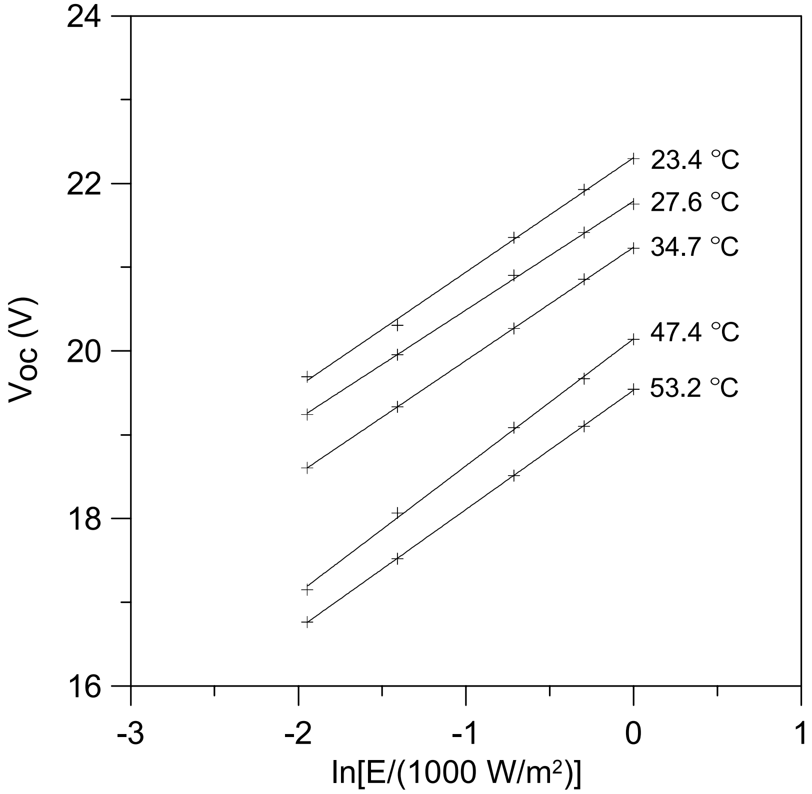

Figure 3-4. Example of Voc as a function of the natural log of the irradiance for various temperature levels.

Step 1. Perform a least-squares fit to find the slope ΔVoc/Δln(E) for each temperature level T.

Step 2. Normalize each slope by dividing by the Voc at its temperature level for the rated irradiance of 1000 W/m^2 . *(This is a different normalization than used in E1036 and improved the accuracy. E1036 divides by the Voc for the rated irradiance of 1000 W/m^2 and the rated temperature of 25°C.)*

Step 3. Perform a least-squares fit of the normalized slopes versus temperature to determine a function of the form:

δ(T) = mT + b,

where

m = slope

b = y-intercept.

3.3 Reference Day Module Irradiances and Temperatures

The solar radiation and meteorological data for the MER reference days are used to model hourly values of incident solar radiation and the PV module temperatures. These values are needed to model the PV module I-V curve so that both the maximum power and the current at a fixed voltage may be determined.

3.3.1 Determining Incident Irradiance

For use with the translation equations in the next section, the incident solar radiation must be directly proportional to the short-circuit current if the PV module temperature is held constant. Consequently, if the short-circuit current and the irradiance are known at SRC, the incident irradiance for another short-circuit current value may be determined by the following relationship:

$$E = E_0 \cdot \frac{Isc}{Isc_0} \,,$$

where:

Isc = short-circuit current
Isc_0 = short-circuit current at SRC
E_0 = irradiance at SRC,
where SRC equals 1000 W/m^2, AM1.5 spectral distribution, 25°C.

For the MER method we cannot directly determine the ratio of short-circuit currents because Isc is unknown. However, we can determine the ratio of the integral forms of the short-circuit currents because the module spectral responses and the spectral irradiances are available. Making these substitutions and replacing E_0 with its value of 1000 W/m^2 provides an equation for the incident irradiance:

$$E = \frac{\int_a^b E_{INC}(\lambda) SR(\lambda) d\lambda}{\int_a^b E_{REF}(\lambda) SR(\lambda) d\lambda} \cdot 1000\,\mathrm{W/m^2} \,, \tag{1}$$

where:

λ = wavelength
$E_{INC}(\lambda)$ = incident spectral irradiance
$E_{REF}(\lambda)$ = AM1.5 spectral irradiance, reference ASTM E892, normalized to 1000 W/m^2 [16]
$SR(\lambda)$ = absolute spectral response per ASTM E1021 [17].

Equation (1) assumes that the reference cell spectral response is equivalent at all test conditions and that the spectrum under the test conditions is equal to AM1.5.

For series-connected multijunction modules, the spectral response of the junction that gives the smallest numerator (current at actual conditions) is used to evaluate the numerator and the spectral response of the junction that gives the smallest denominator (current at reference conditions is used to evaluate the denominator. Spectral responses for two junctions are required to evaluate equation (1) if one junction is the current limiting factor at reference conditions and the other junction is the current limiting factor at actual conditions.

The integration limits for equation (1) are from 300 to 1400 nanometers. This matches the range of the incident spectral irradiance determined with the model SEDES2 [18]. SEDES2 is an adaptation of the model SEDES1 developed by Nann and Riordan [11]. Although SEDES1 provides spectral irradiances from 300 to 4000 nanometers, SEDES2 was computationally optimized for evaluating PV device performance by only providing spectral irradiances from 300 to 1400 nanometers, a range that encompasses the PV device's spectral responses.

Inputs to SEDES2 are reference day hourly solar radiation and meteorological data and the incident broadband radiation. The incident broadband radiation is calculated with a model developed by Perez et al. [19]. This model is an improved and refined version of their original model that was recommended by the International Energy Agency for calculating radiation for tilted surfaces [20].

The modeled incident spectral irradiance are included for each hour of the MER reference days; consequently, users are able to directly access a desired spectrum without the need to calculate it themselves.

3.3.2 Spectral Model Validation

Because the MER studies do not include measured spectra, the model SEDES2 was evaluated against spectra measured [21] at the Florida Solar Energy Center and Pacific Gas & Electric from 1986 to 1988. About 800 spectra were selected from this data base to compare the output (essentially the numerator of equation (1) of various types of PV devices by integrating their spectral responses with both the measured spectra and the corresponding modeled spectra. Modeled and measured spectra yielded PV device performance within about 5% and gave similar rankings of the relative performance of the various PV devices when the data were segregated into sunny and cloudy conditions.

3.3.3 Incident Angle Effects

King et al. (1998) [6] provides relative response as a function (a fourth-order polynomial) of incident angle for five commercial PV modules representing a variety of technologies. Because they are small and apply essentially equally to all PV modules, increased radiation transmittance losses and reflectance losses occurring at large incident angles are not included as part of the MER procedure. The functions give the response, based on short-circuit current, relative to the response for an incident angle of 0°. The four modules with glass front surfaces had essentially the same relative responses throughout a range of incident angles from 0° to 90°. The fifth module, with a front cover using a stippled sheet of Tefzel™ polymer, had a slightly better relative response. In general, relative responses were 100% for incident angles less than 50°. Relative responses decreased as the incident angle increased beyond this value. For an incident angle of 80°, the relative response was 60% to 65%.

Fortunately, the relative response is 100% during midday when the PV module is receiving most of its daily radiation. Also, because the relative response functions are applied only to the direct beam radiation component, the available incident radiation is not reduced for the *Cold Cloudy* and *Hot Cloudy* MER reference days. For the other reference days, applying the King et al. [6] relative response functions reduces the availability of the incident daily radiation by the following amounts: "nice" reference day – 1.1% for Tefzel™ front and 1.6% for glass front; *Cold Sunny* reference day – 0.5% for Tefzel™ front and 1.1% for glass front; and *Hot Sunny* reference day – 1.1% for Tefzel™ front and 1.9% for glass front.

3.3.4 Determining Module Temperatures.

A model developed by Fuentes [22] for use in the simulation program PVFORM, is used to determine PV module temperature. Inputs to the model are incident solar radiation, air temperature, wind speed, module height, and the module's installed-nominal-operating-cell temperature (INOCT). For rack-mounted PV modules, Menicucci and Fernandez [23] recommend using an INOCT that is 3°C less than the PV module's nominal operating cell temperature (NOCT). Whitaker and Newmiller [8] provide an alternative solution for INOCT based on NOCT and the PV module efficiency that gives similar results.

NOCT for a PV module may be determined using the procedure outlined in Annex A1 of ASTM E1036-96 [1]. NOCT is defined as the cell temperature of a PV module mounted with the back either open or closed (open for MER ratings) when the air temperature is 20°C, the wind speed is 1 m/s, the incident irradiance is 800 W/m^2, and the PV module is not connected to a load. INOCT is defined as the cell temperature for the installed configuration with the same meteorological conditions as for NOCT. The MER installed configuration is the same configuration as for NOCT, except that the PV module is operated under load, which lowers the cell temperature. Consequently, INOCT is determined by subtracting 3°C from NOCT.

Because the complexity of the Fuentes model makes it cumbersome to implement in the MER procedure, an empirical expression was derived from Fuentes modeled PV temperatures for each hour of the MER reference days.

For the same incident solar radiation, air temperature, and wind speed, the PV module's temperature rise above air temperature is essentially linearly dependent on the PV module INOCT. Consequently, for each reference day hour an equation can be used for the PV module temperature:

$$Tpv = f_1(E_{inc}, T_a, w) \times INOCT + f_2(E_{inc}, T_a, w), \qquad (2)$$

where f_1 equals the slope function and f_2 equals the y-intercept function. f_1 and f_2 were determined for each MER hour from a linear curve fit of several values of PV module temperatures modeled with the Fuentes model using different values of INOCT. Different hours have different values of f_1 and f_2 because they are functions of the hourly incident solar radiation, E_{inc}, air temperature, T_a, and wind speed, w.

The values of the functions f_1 and f_2 are included for each hour of the MER reference days. This permits the users to directly determine PV module temperature from the function values and their value of INOCT instead of a more involved process where he applies the Fuentes model. Figure 3-5 shows that using the reference hour functions f_1 and f_2 with equation (2) is equivalent to applying the Fuentes model directly. The MER method uses, via equation (2), the Fuentes model to model PV module temperatures.

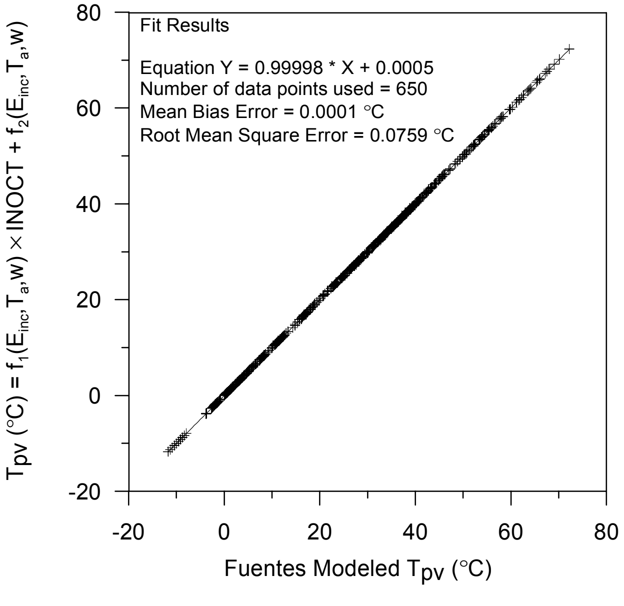

Figure 3-5. Comparison of PV module temperatures modeled directly with the Fuentes model and indirectly with equation (2) and reference hour functions f_1 and f_2. Data shown for 5 reference days and 10 PV modules with INOCT's from 35°C to 53°C at 2°C increments.

3.4 Translating a Reference I-V Curve

Using the incident radiation and the PV module temperature, Isc and Voc are calculated and a reference I-V curve is translated to determine maximum power and the current at a fixed voltage. These procedures are based on modifications to ASTM E1036-96.

3.4.1 Determining Isc.

The E1036 expression for Isc is of the form shown in equation (3) with SRC denoted by the zero subscripts. For clarity, the first term, used to correct for irradiance, is included. The E1036 method applies this irradiance correction with a separate equation,

$$Isc_0 = \frac{E_0}{E} \cdot \frac{Isc}{\left[1 + \alpha(E) \cdot T - \alpha(E_0) \cdot T_0\right]} . \tag{3}$$

As mentioned previously, the assumption that Isc, for constant temperature, is directly proportional to irradiance requires that α be a constant for all irradiances. Consequently, the MER method expresses the equation in the form:

$$Isc_0 = \frac{E_0}{E} \cdot \frac{Isc}{\left[1 + \alpha \cdot (T - T_0)\right]} . \tag{4}$$

Equation (4) translates Isc from actual conditions to SRC. For MER purposes, we need to translate from SRC to actual conditions. By rearranging the terms of equation (4), the Isc for actual conditions is given by equation (5).

$$Isc = \frac{E}{E_0} \cdot Isc_0 \cdot \left[1 + \alpha \cdot (T - T_0)\right] . \tag{5}$$

3.4.2 Determining Voc.

The E1036 expression for Voc is of the form shown in equation (6), with SRC denoted by the zero subscripts,

$$Voc_0 = \frac{Voc}{\left[1 + \beta(E) \cdot T - \beta(E_0) \cdot T_0\right]\left[1 + \delta(T) \cdot \ln(E) - \delta(T_0) \cdot \ln(E_0)\right]} . \tag{6}$$

Examination of equation (6) revealed that the function β should be evaluated for only one irradiance and the function δ should be evaluated for only one temperature. Furthermore, if β is evaluated for SRC, then δ should be evaluated for actual conditions, or vice versa.

Applying these corrections, the expression for Voc simplifies to:

$$Voc_0 = \frac{Voc}{\left[1 + \beta(E_0) \cdot (T - T_0)\right]\left[1 + \delta(T) \cdot \ln(E / E_0)\right]} . \tag{7}$$

Figure 3-6 illustrates the use of equation (7) to translate from conditions at point 1 to the SRC at point 0. Equation (7) follows path 1-A-0. If β is evaluated for actual conditions and δ is evaluated for SRC, the translation path is 1-B-0.

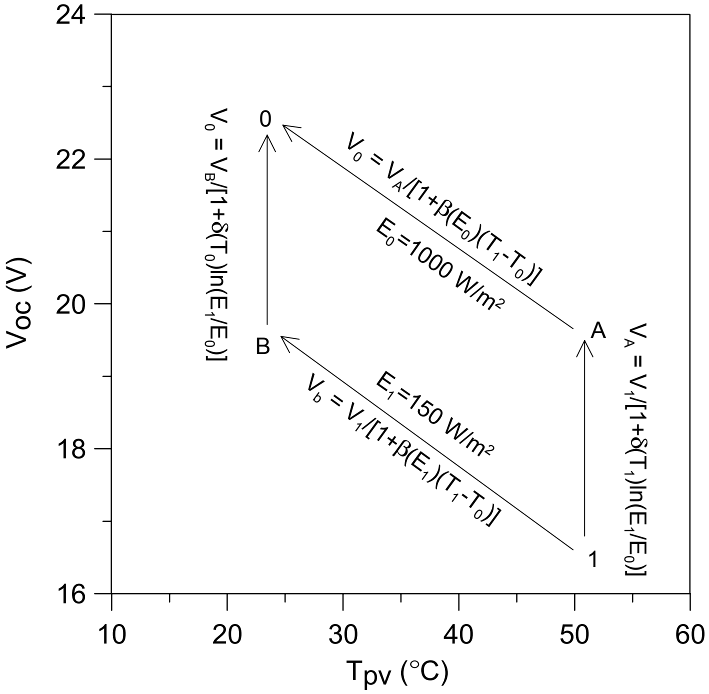

Figure 3-6. Translation paths to determine Voc at SRC.

Because β is evaluated in equation (7) at SRC, the procedure for deriving the function β may be simplified to finding the normalized slope ΔVoc/ΔT for the irradiance of 1000 W/m^2. This simplification is adopted in the procedural steps outlined in Appendix A.

By rearranging the terms of equation (7), the Voc at actual conditions, as required for the MER procedure, is given by equation (8),

$$Voc = Voc_0 \cdot [1 + \beta(E_0) \cdot (T - T_0)][1 + \delta(T) \cdot \ln(E / E_0)]. \tag{8}$$

3.4.3 Translating the I-V Curve.

ASTM E1036 translates each I-V data point by multiplying the currents by the ratio of short circuit currents and the voltages by the ratio of open circuit voltages. Consequently, the fill factor is not changed because both the numerator and denominator of the fill factor expression are effectively multiplied by the same Isc and Voc ratios. Because a PV module's fill factor changes with changes in temperature and irradiance, this creates an error when translating from SRC to actual conditions. The error will be larger for PV modules with a more widely varying fill factor and when translating to values further from SRC. Figures 3-7 through 3-9 show measured variations in fill factor for different temperatures and irradiances for three PV modules. Fill factors in the figures are normalized to the fill factor at the temperature and irradiance levels closest to SRC, to show the extent of the error introduced (up to 8% in Figure 3-8 and 11% in Figure 3-9) by not accounting for changes in fill factor.

The solution, for MER purposes is to not restrict the reference I-V curve to only the I-V curve measured at SRC. Rather, all the I-V curves measured for the I-V curve matrix used to determine the correction factors and functions are eligible reference curves. This permits a reference curve to be selected with a fill factor close to that of the desired conditions and mitigates translating from distant values.

A reference I-V curve is selected from the matrix of I-V curves by determining the irradiance level in the matrix of I-V curves that is closest to the desired irradiance and then selecting the I-V curve from that irradiance level with a temperature closest to the desired temperature.

Each I-V data pair of the reference I-V curve can be translated to the desired conditions using equations (9) and (10). The subscript R refers to the reference I-V curve, and Isc and Voc are determined with equations (5) and (8).

$$I = I_R \cdot \frac{Isc}{Isc_R} \text{, and} \tag{9}$$

$$V = V_R \cdot \frac{Voc}{Voc_R} \text{ .} \tag{10}$$

Because the translation procedure does not change the fill factor, the reference I-V curve data pair for maximum power becomes the translated I-V curve data pair for maximum power. To determine the current at a specified voltage, the current may be interpolated using the two adjacent I-V curve data pairs from the translated I-V curve with voltages above and below the specified voltage.

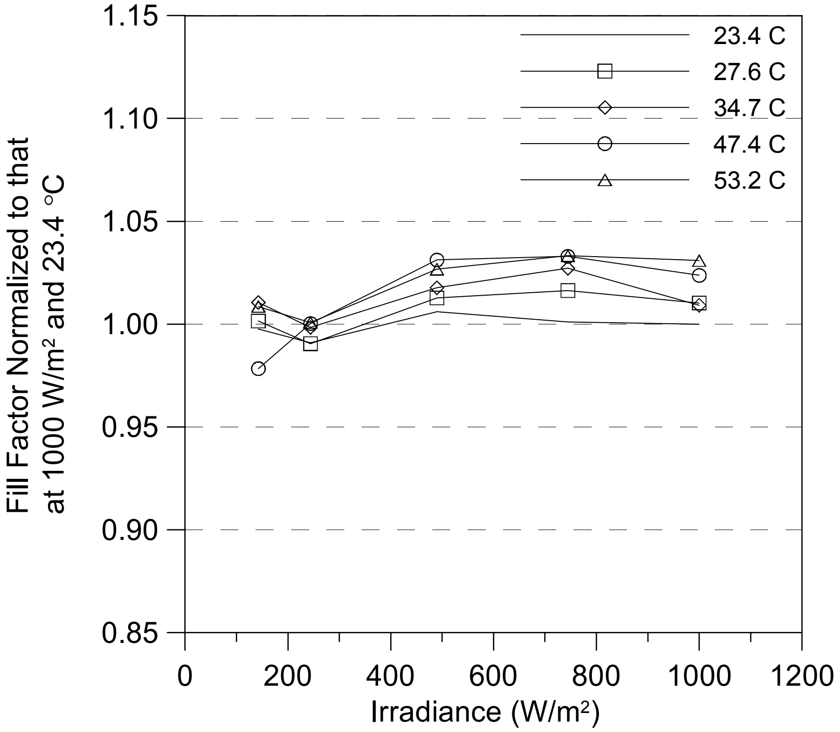

Figure 3-7. Variations in fill factor for an a-Si/a-Si/a-Si:Ge PV module.

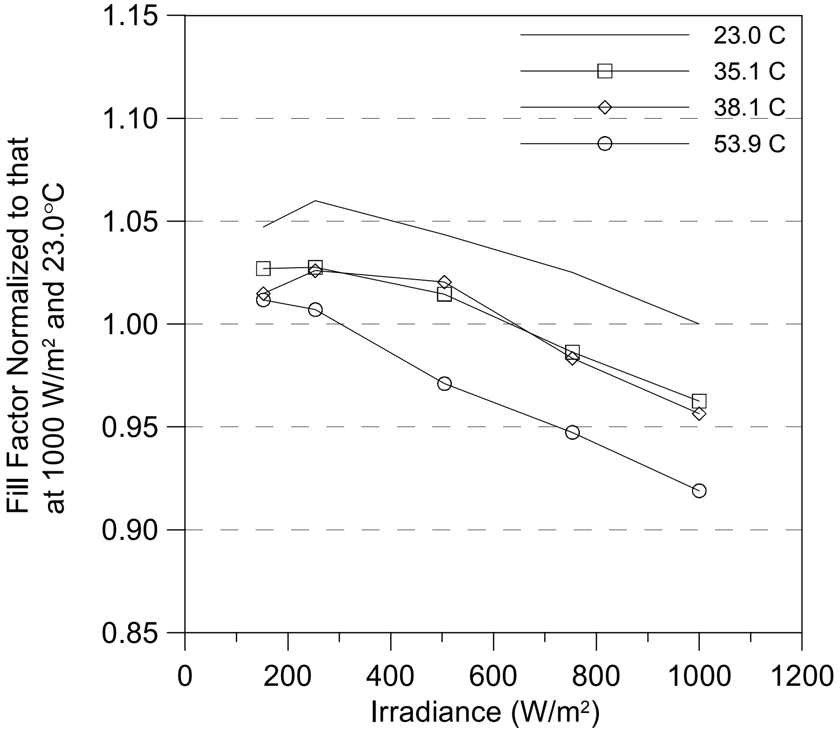

Figure 3-8. Variations in fill factor for a multi-crystalline Si PV module.

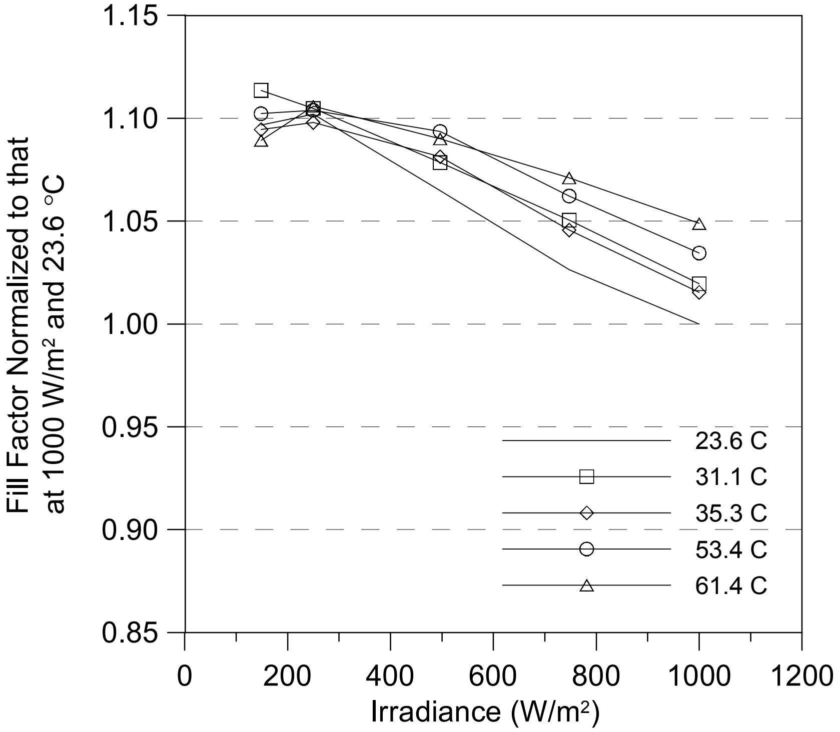

Figure 3-9. Variations in fill factor for a CdS/CdTe PV module.

4.0 Validation Results and Conclusions

4.1 General

The MER method was validated by comparing modeled and measured values of maximum power for seven PV modules representing various technologies. As shown in Figure 4-1, these PV modules are part of a group of PV modules located on the lower roof of NREL's Outdoor Test Facility (OTF). The PV modules face south with a tilt from horizontal of 40°. Two of the three data acquisition systems (DAS) on the Performance and Energy Ratings Testbed (PERT) recorded 1998 hourly or half-hourly values of PV module maximum power, as well as hourly PV module back-surface temperatures, wind speeds, and plane-of-array (POA) irradiances.

Modeled values of maximum power were determined using the equations and the irradiance and temperature correction factors and functions from Section 3. Necessary solar radiation and meteorological input for the model came from either the RMIS weather station or the Solar Radiation Research Laboratory (SRRL) weather station. The RMIS weather station is adjacent the OTF, and the SRRL weather station is on top of the mesa north of the OTF. Unless faulty, the RMIS data were used for model input. If the RMIS data were faulty, SRRL data were used.

Comparisons of modeled and measured maximum power were performed on an hourly, daily, monthly, and yearly basis. Models for determining intermediate values, such as the Perez model for incident irradiance and the Fuentes model for PV module temperature, were also evaluated. Because hourly values of current at a fixed voltage were not recorded, this data set was not used to compare modeled and measured operating currents that would be used to assign a PV module's amp-hour rating. However, independent tests using I-V curves measured on clear days showed that the MER method could estimate operating currents at a fixed voltage with comparable accuracy to that of estimating a PV module's maximum power.

Figure 4-1. PV Modules on the PERT Rack at NREL's Outdoor Test Facility.

4.2 PERT Modules and Data Acquisition

The PERT comprises of an outdoor fixture (rack) located on the roof of the OTF plus three DAS. There are presently 45 PV modules deployed on the PERT. The fixture on the roof is assembled so that all of the PV modules are erected facing due south ± 2°, and at angle with respect to the horizontal of 40 ± 1°. This planar arrangement of the modules is referred to as the POA. Its tilt angle (40°) corresponds approximately to the latitude for the OTF site, whose coordinates are more precisely 39.74° North latitude and 105.18° West longitude. The PERT DAS perform I-V measurement of the PV modules connected to them, as well as individual module temperature. Other measurements performed concurrently include ambient air temperature, POA irradiance, and wind speed. POA irradiance is measured with Kipp & Zonen pyranometers that are mounted on the same structure and at the same POA as the modules. There are presently three DAS on the PERT each with its own pyranometer.

The three DAS are referred to as PERT I, PERT II, and PERT III, which are names that allude to their starting dates of service. PERT I was commenced on February of 1996; PERT II on September 30th 1997; and PERT III on March 20th 1998. Each DAS consists of a Multi-Tracer unit interfaced to an Intel-based personal computer (PC). The Multi-Tracer units perform all the measurements and controls, while the PCs serve as graphical and end-user interface to the data and module configuration. The Multi-Tracer units are electronic, rack-mounted enclosures with the capacity for module current, voltage, and temperature measurements, as well as meteorological measurements. There are currently, two types of Multi-Tracer models in service — RD-1200 and RD-2400. The RD-1200 and RD-2400 Multi-Tracers are manufactured by RAYDEC, Inc., which is a business situated in Albuquerque, New Mexico. The RD-1200 is described in detail below. The RD-2400 is similar to the RD-1200, except that it provides for substantially higher module voltage and power capability over the 1200 model. Data generated by the Multi-Tracers is sampled by and transferred to the PC, where it is displayed and stored onto electronic media (hard-disk drive) for retrieval and subsequent analysis. The PC maintains configuration files that store and describe the operating parameters for the PV modules connected to each of the Multi-tracers. These configuration files contain information specific to each PV module and channel on the Multi-Tracers, including calibration constants, test schedules, and individual module data, such as area and load specifications. The PC communicates with the Multi-tracers via an RS232 serial link and port. It uses an RS232-to-RS485 protocol converter box to interface to the Multi-Tracers.

Presently, the group of PV modules that have been investigated and used to validate the energy ratings methodology reside on either PERT I or PERT II systems. The Multi-Tracer units used for these two DAS are RAYDEC model number RD-1200. Each of the RD-1200 Multi-Tracers (as well as the RD-2400) can accommodate up to 15 PV modules, in one of 15 separate channels. Each module is electrically connected to one of the DAS channels using a four-wire electrical measurement scheme. Two wires are used for conducting the module power/current across a series-combination of MOSFET power transistor and metal shunt resistor housed inside the Multi-Tracer. The other two leads are used for sensing the voltage close to the module terminals. There is one MOSFET and metal shunt element associated for each channel on the Multi-Tracer. The measurement scheme uses the voltage-sense leads to accurately gauge the voltage at the terminals of the PV modules, while the current flowing through is picked up as a small voltage developed across the metal shunts. The metal shunts are typically 2 milliohm resistance values, and have negligible power dissipated across them. The module I-V characteristics are traced by stepping the conductance of each of the power MOSFETs. In effect, these behave as programmable resistors. Because there is no power supply connected to, nor biasing the modules, the I-V trace is contained entirely within the first quadrant of the I-V cartesian coordinate plane. Because of finite resistance associated with the power leads connecting to the PV modules, plus the minimum resistance across the MOSFET when it's in its highest conductance state, this scheme can only approximate the module short-circuit current (Isc), which has to be obtained by extrapolation to zero voltage. Note that this does not affect the accurate determination of the PV module's optimum power point current and voltage. The power leads for these modules are #12-gauge wire that exhibits ~ 1.65 milliohms resistance per linear foot length. The power leads are typically between 20 and 40 feet in length, or equivalently, ~ 0.10 – 0.13 ohms total electrical resistance in series with the power MOSFET. The RD-1200 Multi-Tracers can sense module voltages up to 100 volts, and currents up to 15 amps. High module voltages are measured by first passing them through precision voltage dividers before being quantified by analog-to-digital (ADC) converters. Additionally, there are separate thermocouple (TC) inputs, associated with each channel, used for sensing module temperatures. All of the TCs are type ‘T’, and are typically bonded to the back of the modules near their midsection. TC measurements are corrected to common-junction temperatures using internal compensation circuits inside the Multi-Tracers.

Each Multi-Tracer unit is comprised of three printed-circuit boards that house separate control and measurement electronic circuitry and components. Two of the boards are used to perform measurements and control of the PV modules. The third printed-circuit board is used to perform measurements on auxiliary analog-input channels, such as irradiance, ambient temperature and wind speed. Each of these three printed–circuit boards contains an on-board resident microcontroller chip, a Dallas Semiconductor DS5000. The DS5000 is essentially an 8-bit processor with a core that is a clone of the Intel 8051 microprocessor. Each DS5000 microcontroller situated on each printed-circuit board inside the Multi-Tracers has on-board resident software (firmware) that executes measurement and control functions independently of the PC-platform to which they interface. For example, when the PV modules are not having their I-V characteristics traced, they may be loaded at their optimum-power point or at fixed voltage, depending on user-input configuration. This entails having the microcontrollers perform a perturb-and-measure algorithm for channels configured with a PV module. This algorithm attempts to maintain the module load in compliance with the configuration. During the times of scheduled I-V traces, the microcontrollers perform the actual sweep of each of the modules’ I-V characteristics including all module analog voltage measurements. The DS5000 microcontrollers are the front-line elements responsible for all the appropriate bias voltage signals sent to the power MOSFETs. These bias signals are needed to bring about the conductance changes in each MOSFET, in such a way as to step the load resistance seen by the PV modules. The DS5000 also coordinate all of the appropriate ADC measurements. The ADC measurements are temporarily stored on board the DS5000 until the next set of measurements is executed. These are uploaded to the PC, where they are displayed and stored. In order to mitigate potential thermal drift of DAS components and measurements, signals from precision voltage-source elements are periodically routed through the channels to calibrate the ADC by the microcontroller firmware.

An executive program operates on the PCs interfaced to each PERT DAS, and monitors all aspects of module performance. It acts to instruct the microcontrollers in each Multi-Tracer when it is supposed to perform I-V traces, or when it should be maintaining the modules under their configured loads. All modules are configured to operate under peak-power tracking conditions at all times, when they are not being actively traced for I-V characteristics. The data from the I-V traces are stored as text files by the PC. An entire IV trace for one module typically occurs within 2-3 seconds. It consists of I-V pairs, numbering typically 100-250 pairs, as well as irradiance, and ambient and module temperatures measurements. The data generated when the modules are loaded under peak-power conditions is sampled, averaged and saved to disk by the PC — this is the so-called ‘hourly data’. The hourly data consist of module current, voltage, temperature, and irradiance values averaged out and generated on set schedule. The ‘hourly data’ is generated on the following set schedule: the PERT I PC samples the peak-power tracking data (plus temperature and irradiance) once every 5 seconds, then averages these data out to disk file every hour; the PERT II samples every 5 seconds, and writes to file every 30 minutes. These data are time-stamped at the time of writing to file, based on the PC clock.

Some of the electrical characteristics of DAS RD-1200 Multi-Tracer units are tabulated below. These values represent only the characteristics of the DAS. Systematic errors of the measurements may be different.

Table 4-1 Electrical Characteristics of the RD-1200 Multi-Tracer

Measurement	Range Full Scale	Resolution	Accuracy	Capacity
Module Voltage	100 V	12 mV	100 mV	15
Module Current	+15 A	1.8 mA	15 mA	15
Pyranometer	±30 mV	4 mV	30 mV	(same as aux. voltage inputs)
Minimum Programmable Load step		50 mV		
Auxiliary voltage inputs	±3 volts	4 □V	30 □V	2
Auxiliary current inputs	± 110 mA	14 □A	110 □A	4
Thermocouple			±1°C	4 auxiliary plus one for each module channel

Typically, and with a frequency of once every 12-18 months, the DAS are calibrated using a software program provided by the manufacturer, plus calibrated voltage and current sources. Calibrated voltage and current signals are supplied to each analog input channel and the numerical values of these signals are subsequently entered as data to the calibration program. The program saves these calibration constants to disk file and also downloads these to the microcontrollers. With the wiring employed to connect the DAS to the PV modules in the study group, it is estimated that the error associated in module voltage measurements is limited by the accuracy of the DAS (100 mV) and its calibration. Similarly, because of the calibration procedures used and the negligible temperature coefficient of the shunt resistors (~ ±0.0015% per degree C), the accuracy of module current values is estimated to be limited by the electrical accuracy of the DAS (15 mA). The PC clocks are known to drift by 2-3 minutes every several months, after which time they are reset to within 10 seconds of standard time. Time values are thus estimated to be accurate within ± 4 minutes of standard time. The pyranometers used were either calibrated by the manufacturer or by the metrology group at NREL. That group also calibrates the voltage and current sources employed in the calibration of the DAS. The use of a single calibration constant to convert pyranometer voltage readings to irradiance values is estimated to result in a bias error of 3% or less. The measurement accuracy of module or ambient temperatures is ±1°C, and is strictly limited by the characteristics of type 'T' thermocouples

4.3 Temperature Coefficient Measurements

The Spire 240A solar simulator was used to measure the current *versus* voltage characteristics as a function of temperature and irradiance. The first step is to determine the I-V characteristics with respect to standard reference conditions (25 °C, 1000 Wm^{-2}, and IEC 60904-3 spectral distribution). This is accomplished by using a reference cell or module with a 0%-3% correction for spectral error depending on the technology to set the light level of the solar simulator.

At each temperature, the I-V characteristics are measured as a function of irradiance measured by inserting mesh screens near the lamp and reducing the monitor cells calibration accordingly. This allows the intensity to be set with an uncertainty of less than ±1%. Using this method, the I-V characteristics at irradiance levels of 150, 250, 500, and 750 Wm^{-2} are measured.

The temperature dependence is measured by increasing the power to a heater blanket located several cm below the module. An I-V curve is measured after the temperature has changed less than ±0.5 °C over a 5 min. period. The I-V curve is measured near five specific temperatures of 25, 35 50,35, and then 25 °C. At each temperature the front surface and back surface temperature are recorded with the front surface temperature normally used for any computations. During this procedure V_{oc} *versus* temperature is plotted and any hystersis or nonlinear behavior is noted. If the sample does exhibit a significant hysterisis of >5°C apparent shift in V_{oc} at 35 °C then the module will be remeasured with more temperature points.

The I-V parameters V_{oc}, I_{sc}, FF, V_{max}, I_{max}, P_{max}, are then tabulated as a function of irradiance and temperature and linear least squares curve fits as are performed to arrive at the coefficients.

4.4 Data Quality Assessment

To ensure reasonable results, data were assessed for quality and only data meeting quality assessment thresholds were used to validate the MER method. For the data analysis, the solar radiation, meteorological, and PV module data were checked for out-of-range and missing values to eliminate hours with bad data. Simple checks for out-of-range values do not detect all bad data; consequently, additional checks were made.

Solar Radiation. Direct normal and diffuse horizontal radiation are model inputs to the Perez plane-of-array radiation model and the SEDES2 spectral model. Using established quality assessment procedures [24], these two elements, along with global horizontal radiation, are checked with the equation:

$$K_t = K_d + K_n,$$

where:

K_t = global horizontal radiation ÷ extraterrestrial horizontal radiation
K_d = diffuse horizontal radiation ÷ extraterrestrial horizontal radiation
K_n = direct normal radiation ÷ extraterrestrial radiation.

Acceptable solar radiation values will satisfy the equation within an arbitrary error limit. For this study, the error limit was set at 0.05 for sun elevations above 10°, and 0.10 for sun elevations of 10° and below, where instrument errors are greater.

If RMIS data were missing or not within the error limit, SRRL data were tested. If the SRRL data were within the error limit, the SRRL data were used for model inputs; otherwise, the hour's data were not used for data analysis.

An additional check ensured consistency between the direct normal and diffuse horizontal radiation values and the tilt radiation values measured by the pyranometer located in the plane of the modules. If Perez modeled values and measured tilt values were not within ±75 W/m^2 (about 3 or 4 times the RMSE of the Perez model), the hour's data were not used for data analysis.

Meteorological Data. If RMIS meteorological data were missing or out-of-range, SRRL data were used in their place. This applied to dry bulb temperature, relative humidity, and atmospheric pressure. Wind speeds from PERT I or PERT II were used for model input to the Fuentes temperature model. The calibration constants for the anemometers were taken from manufacturer supplied values.

Surface Albedo. Surface albedo values were determined from SRRL data as the ratio of measured radiation from the inverted pyranometer to the measured radiation from the global horizontal pyranometer. Albedos were restricted to values ranging from 0.2, a nominal value for green vegatation and some soil types, to 0.9, a value for dry new snow. Albedo is an input value for the Perez solar radiation model.

Snow Days. Thirty-one days for 1998 were excluded from data analysis because of the occurrence of new or recent snowfall. Snow reduces PV output by shading the PV module and also causes erroneous radiometer readings. Snow days were determined from local newspaper records. They include: January 6; February 16; March 7, 8, 9, 10, 11, 18, 19, 20, 30, and 31; April 3, 6, 8, 15, 16, 17, 18, and 19; November 7, 8, 9, 10, and 11; and December 9, 10, 19, 20, 21, and 22.

PV Module Shading. The output of the CdS/CdTe PV module was observed to be 25% lower than expected for early morning and late afternoon hours during the summer. Examination of the PV module revealed that the mounting structure, located north but slightly higher than the PV module, would cast a shadow on the uppermost cell for these times. Because the shadowed cell would limit the PV module output, the sun position and the PV module and mounting structure geometry were used to exclude any hours when the mounting structure would shade the PV module from direct normal radiation. The mounting structure also obscures the uppermost cell's view of the sky dome, with a corresponding reduction in sky diffuse radiation received by the cell. The data analysis did not account for this reduction in diffuse radiation. The effect is small for clear and partly sunny conditions; but for overcast skies where the PV module receives only diffuse radiation, the reduction of PV output was more noticeable.

4.5 Modeled Parameters

Various models and equations are used to determine a PV module's I-V curve for a given set of environmental conditions. Table 4-2 lists the principle models and equations and their necessary input data. Because the output of one model may be used for the input of another, the list is in sequential order.

In order to reduce complexity, the MER method outlined in the previous section does not include an angle-of-incidence factor. However, it is used in this validation section in order to minimize known sources of errors by accounting for increased transmittance and reflectance losses occurring at high incident angles. These losses were accounted for in MER Eqns. (5) and (8) by multiplying the incident irradiance by the angle-of-incidence factor. On an annual basis, the use of angle-of-incidence factors reduced modeled energy by 1.2%.

For PV module temperature modeling, manufacturer's NOCT values for calculating INOCT values were generally not available. Consequently, INOCT values were estimated by screening the 1998 hourly data for meteorological conditions meeting the ASTM E1036 conditions for determining NOCT, and then applying procedures similar to ASTM E1036. NOCT is defined as the cell temperature of a PV module mounted with the back either open or closed (open for MER ratings) when the air temperature is 20°C, the wind speed is 1 m/s, the incident irradiance is 800 W/m^2, and the PV module is not connected to a load. INOCT is defined as the cell temperature for the installed configuration with the same meteorological conditions as for NOCT. The MER installed configuration is the same configuration as for NOCT, except that the PV module is operated under load, which lowers the cell temperature about 3°C.

Only one data hour met the requirements of wind speed (0.25 to 1.75 m/s), air temperature (5°C to 35°C), and predominantly southerly wind direction. Hours with northerly winds were excluded because of wind disruption by the building. The hour meeting the condition requirements was 10 a.m. on May 27, 1998. It had an average incident irradiance of 808 W/m^2, an average air temperature of 24.9°C, an average wind speed of 1.3 m/s, and an average wind direction of 18° west of south.

Fortunately, the measured irradiance was close to the INOCT condition of 800 W/m^2, so only a small correction was needed to determine the difference between the PV module temperature and the air temperature for an irradiance of 800 W/m^2. This difference, along with a correction of 1°C from ASTM E1036 Figure A1.1 to account for the wind speed during the hour being greater than 1 m/s and the air temperature being greater than 20°C, was added to 20°C to determine a PV module's INOCT.

Table 4-2. Models and Equations to Determine a PV Module's I-V Curve

Model or Equation	Output	Input
Perez et al., 1990	Incident Broadband Irradiance	Direct Normal Irradiance Diffuse Horizontal Irradiance Solar Zenith Angle Solar Incident Angle PV Module Tilt Angle Ground Albedo
SEDES2 (Nann and Emery, 1992)	Incident Spectral Irradiance	Incident Broadband Irradiance Direct Normal Irradiance Diffuse Horizontal Irradiance Solar Zenith Angle Solar Incident Angle Atmospheric Pressure Dew Point or Relative Humidity Latitude Longitude Elevation Day of Year
MER Eqn. 1 (pg 27)	Incident Irradiance	Incident Spectral Irradiance AM1.5 Spectral Irradiance PV Module Spectral Response
King et al., 1998	Angle-of-Incidence Factor	PV Module Cover Type Incident Broadband Irradiance Direct Normal Irradiance Solar Incident Angle
Fuentes, 1985	PV Module Temperature	Incident Broadband Irradiance Wind Speed Air Temperature PV Module INOCT
MER Eqn. 5 (pg 30)	Short-Circuit Current	Short-Circuit Current at SRC Incident Irradiance Angle-of-Incidence Factor Correction Factor α PV Module Temperature
MER Eqn. 8 (pg 31)	Open-Circuit Voltage	Open-Circuit Voltage at SRC Incident Irradiance Angle-of-Incidence Factor Correction Function β Correction Function δ PV Module Temperature
MER Eqns. 9 and 10 (pg 32)	I-V Curve	Short-Circuit Current Open-Circuit Voltage Short-Circuit Current at SRC Open-Circuit Voltage at SRC Selected Reference I-V Curve

Table 4-3 lists the calculated values of INOCT, and if available, the manufacturer's values of NOCT. The calculated INOCTs are based on PV module back surface temperature, which may be 2°C to 3°C less than the cell temperature. NOCT is based on cell temperature.

Table 4-3. Experimentally Determined INOCTs and Manufacturer's NOCTs

PV Module	INOCT(°C)	NOCT(°C)
a-Si/a-Si/a-Si:Ge, S/N 1736	37.5	—
CdS/CuInGaSSe, S/N 5165	41.7	—
CIS, S/N 114	37.1	—
Mono-Crystal Si, S/N 0442	40.4	47
Multi-Crystal Si, S/N 581836	38.8	49
a-Si/a-Si:Ge, S/N SYS49	47.1	—
CdS/CdTe, S/N 14407	42.7	—

4.6 Experimental Results for Correction Factors and Functions

Irradiance and temperature correction factors and functions were determined for a group of 7 PV modules representing different PV technologies. For each PV module, a matrix of Isc and Voc values resulting from I-V curve measurements over a range of irradiances and operating temperatures were determined. The I-V curve measurement data for each of the PV modules is given in Appendix B. These data are also shown graphically in Appendix C, along with graphs for α, β, and δ. The assumption that α is constant is shown reasonable by plotting α as a function of irradiance in Appendix C.

The matrices of Isc and Voc values and the MER procedures yielded the correction factors and functions shown in Table 4-4. For use with Equation (8), Table 4-4 provides values of β evaluated for E_0.

Table 4-4. Irradiance and Temperature Correction Factors and Functions

PV Module	α ($°C^{-1}$)	β(E) = mE + b ($°C^{-1}$)			δ(T) = mT + b (dimensionless)	
		$\beta(E_0)$	m	b	m	b
a-Si/a-Si/a-Si:Ge, S/N 1736	8.50e-4	-3.97e-3	1.17e-6	-5.14e-3	5.20e-4	4.72e-2
CdS/CuInGaSSe, S/N 5165	-1.32e-4	-3.75e-3	1.34e-6	-5.09e-3	6.07e-4	4.97e-2
CIS, S/N 114	1.94e-4	-4.94e-3	2.22e-6	-7.16e-3	8.39e-4	7.39e-2
Mono-Crystal Si, S/N 0442	3.60e-4	-3.63e-3	0.98e-6	-4.61e-3	3.21e-4	4.15e-2
Multi-Crystal Si, S/N581836	2.58e-4	-3.57e-3	1.02e-6	-4.59e-3	4.80e-4	3.55e-2
a-Si/a-Si:Ge, S/N SYS49	8.36e-4	-3.52e-3	1.56e-6	-5.08e-3	5.36e-4	5.53e-2
CdS/CdTe, S/N 14407	0.60e-4	-2.38e-3	1.21e-6	-3.59e-3	6.00e-4	1.61e-2

To evaluate their suitability, the correction factors and functions and the translation Equations (5) and (8) were used to translate from SRC to the irradiance and temperature conditions for which the other I-V curves in the I-V curve matrices were measured. These translated values of Isc and Voc were then compared to the measured values for 20 to 30 non-SRC conditions. Approximate translation ranges were 150 to 1000 W/m^2 for irradiance and 25°C to 55°C for temperature.

Table 4-5 shows the results of this comparison. As indicated by the small root-mean-square-errors (RMSEs) and mean-bias-errors (MBEs) in Table 4-5, the MER method can accurately translate from one condition to another. Assumptions concerning linearity for deriving correction factors and functions are valid and the translation equations for Isc and Voc are correct.

Comparisons were made using MBE and RMSE statistics. MBE provides the average deviation of the modeled values from the measured values.

$$MBE = \frac{\sum_{i=1}^{N}(y_i - x_i)}{N} \quad ,$$

where:

y_i = the *i*th modeled value
x_i = the *i*th measured value
N = the number of hourly data.

RMSE provides information on the variation of the modeled values around the measured values,

$$RMSE = \left\{ \frac{\sum_{i=1}^{N}(y_i - x_i)^2}{N} \right\}^{1/2} \quad ,$$

Table 4-5. Errors Due to Translation Equations and Correction Factors and Functions when Translating from SRC to Non-SRC Conditions. Errors Expressed as a Percentage of the PV Module Average Isc or Voc.

PV Module	Isc		Voc	
	RMSE (%)	MBE (%)	RMSE (%)	MBE (%)
a-Si/a-Si/a-Si:Ge, S/N 1736	0.17	-0.01	0.31	0.14
CdS/CuInGaSSe , S/N 5165	0.21	0.02	0.35	0.09
CIS, S/N 114	0.47	-0.01	0.78	0.23
Mono-Crystal Si, S/N 0442	0.15	0.00	0.45	-0.17
Multi-Crystal Si, S/N581836	0.29	0.00	0.29	0.00
a-Si/a-Si:Ge, S/N SYS49	0.14	0.01	0.67	0.06
CdS/CdTe, S/N 14407	0.26	0.00	0.40	-0.17
Average	0.24	0.00	0.46	0.03

The results in Table 4-5 do not include bias errors associated with measurements, because the translated values are compared to values that were used to derive the correction factors and functions. Consequently, the results may be viewed as those obtained if there were no bias errors when measuring the I-V curves, PV module temperatures, and irradiances that constitute the I-V curve matrices. The results show the combined effects of precision measurement errors; translation equation and correction factor and function errors; and departures from assumed linearity of Isc and Voc characteristics.

4.7 Comparisons of Modeled and Measured Values

Comparisons of modeled and measured maximum power were performed on an hourly, daily, monthly, and yearly basis. Models for determining intermediate values, such as the Perez model for incident irradiance and the Fuentes model for PV module temperature, were also evaluated. The Perez model for irradiance and the Fuentes model for PV module temperature were then used in place of actual measured values in the comparison of measured *versus* modeled maximum power output. Modeled values of maximum power were determined using modeled, not measured, values of incident irradiance and PV module temperature. MER modeled values of maximum power were also compared with those obtained using simpler models.

Hourly, Monthly, and Annual Results. Table 4-6 presents statistics comparing modeled and measured values of incident irradiance, PV module temperature, and maximum power for each of the 7 PV modules. In the table, the number of test hours refers to the number of daylight hours in 1998 that met all quality assessment criteria. Test hours vary because quality assessment procedures were applied individually to each PV module. Test hours are lower for the CdS/CdTe PV module because it was removed for 10 days in December for testing and certain summer hours were excluded when the PV module was shaded.

Table 4-6. RMSEs and MBEs for Modeled Values of Hourly Incident Irradiance, PV Module Temperature, and Maximum Power for 1998

PV Module	Test Hours	Modeled Incident Irradiance		Modeled PV Module Temperature		Maximum Power	
		RMSE (%)	MBE (%)	RMSE (°C)	MBE (°C)	RMSE (%)	MBE (%)
a-Si/a-Si/a-Si:Ge, S/N 1736	3362	4.5	-0.4	1.9	-0.7	9.7	4.7
CdS/CuInGaSSe , S/N 5165	3350	4.5	-0.4	3.3	-1.8	4.9	-0.7
CIS, S/N 114	3623	4.4	-0.7	3.8	-2.0	6.3	2.3
Mono-Crystal Si, S/N 0442	3706	4.5	-0.7	3.5	-2.2	5.2	-0.2
Multi-Crystal Si, S/N581836	3693	4.5	-0.7	3.3	-2.2	5.3	-0.1
a-Si/a-Si:Ge, S/N SYS49	3336	4.3	-0.7	2.8	-0.9	5.6	-1.0
CdS/CdTe, S/N 14407	2867	4.4	-0.7	4.3	-2.8	5.6	2.0

RMSEs and MBEs for incident irradiance and maximum power were determined in units of irradiance and power and then presented in the table as a percent of the average incident irradiance or maximum power. This facilitates comparing model results for the different PV modules. Variations in the number of test hours contributed to small differences in RMSEs for modeled incident irradiance. Incident irradiance MBEs for the first two PV modules were slightly different than the others because they are connected to the PERT II data acquisition system, while the other PV modules are connected to the PERT I data acquisition system. Each data acquisition system has its own pyranometer for recording the incident irradiance. The RMSEs and MBEs for incident irradiance are consistent with other evaluations of the Perez model.

The RMSEs for modeled PV module temperature were typically less than 4°C and the MBEs ranged from -0.7°C to -2.8°C.

With the exception of the a-Si/a-Si/a-Si:Ge PV module, RMSEs for modeled maximum power were 6% or less and MBEs were within ±2%. MBE for the a-Si/a-Si/a-Si:Ge PV module was 4.7% and the RMSE was 9.7%. For a-Si PV modules, studies have shown that seasonal changes in operating temperatures may cause seasonal changes in temperature coefficients and reference efficiencies (del Cueto and von Roedern, 1999) [25]. These types of changes are not accounted for by the MER method and may explain why the modeled results for this PV module were not as favorable.

Figures 4-2, 4-3, and 4-4 compare hourly measured and modeled values of maximum power for the mono-crystal silicon PV module, the a-Si/a-Si/a-Si:Ge PV module, and the a-Si/a-Si:Ge PV module. In the figures, the diagonal has a slope of one and represents the ideal relationship between measured and modeled values. The crystal silicon and a-Si/a-Si:Ge PV module exhibit typical agreement between measured and modeled values. For the a-Si/a-Si/a-Si:Ge PV module, at higher irradiances the modeled values were consistently greater than measured values, resulting in a greater MBE and RMSE.

The RMSEs in Table 4-6 are indicative of modeling accuracy for hourly data. Twice, the RMSE gives a 95% confidence interval. The MBEs in Table 4-6 indicate the modeling accuracy for the year. For monthly comparisons, Appendix D provides RMSEs and MBEs by month for each PV module.

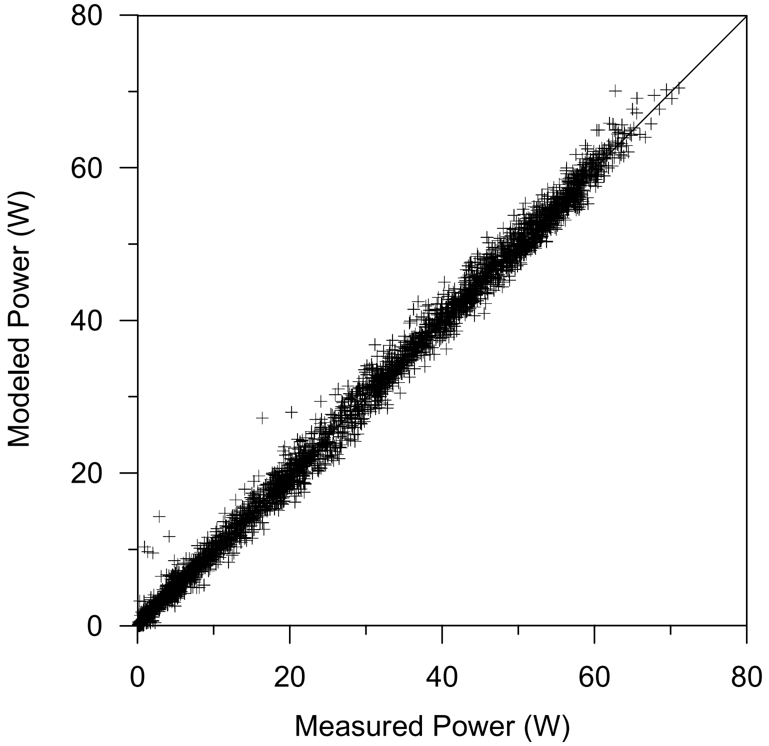

Figure 4-2. Comparison of hourly values of measured and modeled average maximum power for the mono-crystalline silicon PV module, S/N 0442.

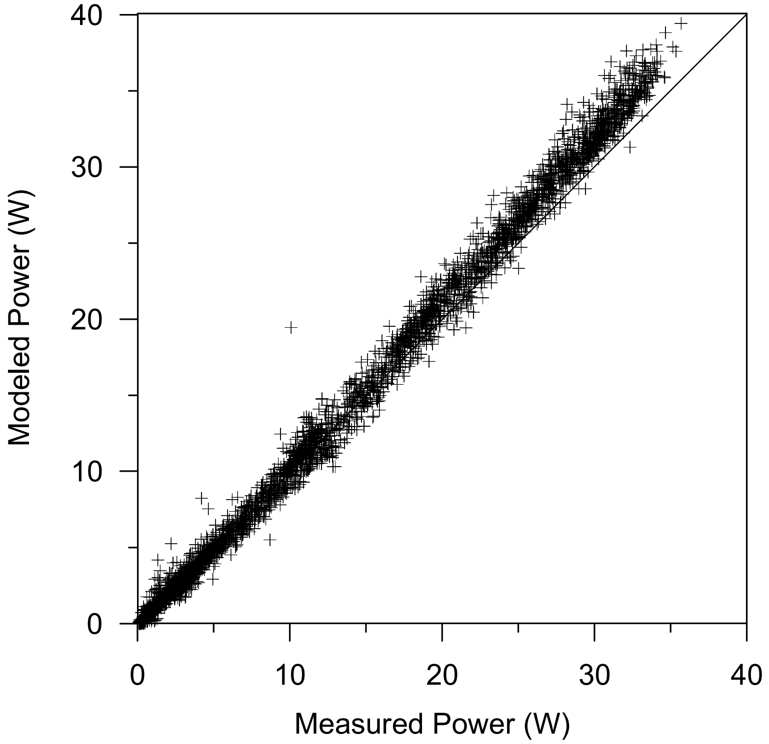

Figure 4-3. Comparison of hourly values of measured and modeled average maximum power for the a-Si/a-Si/a-Si:Ge PV module, S/N 1736.

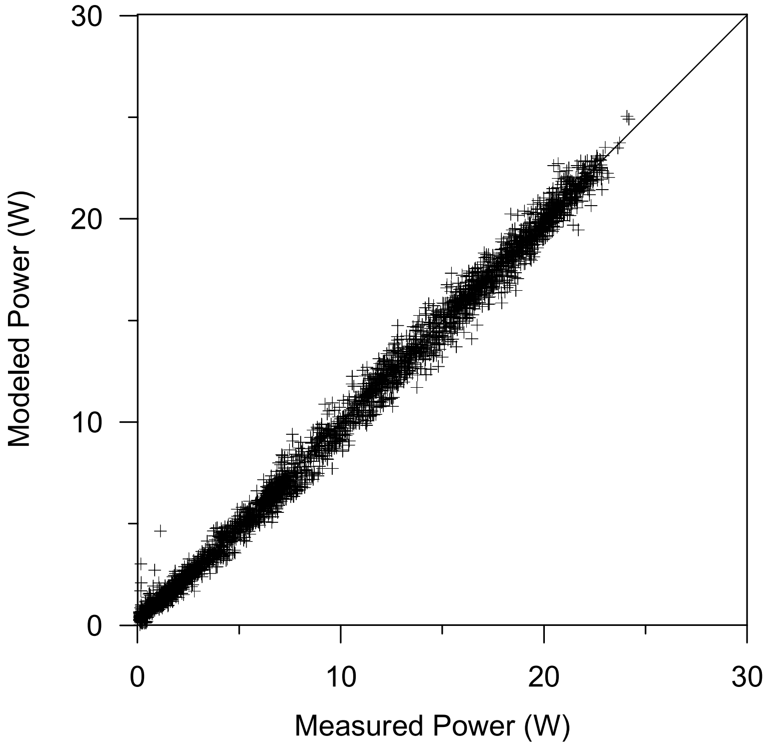

Figure 4-4. Comparison of hourly values of measured and modeled average maximum power for the a-Si/a-Si:Ge PV module, S/N SYS49.

MER Model Compared to Simpler Models. To show the benefit of the additional complexity of the MER model, its results were compared with two simpler models: (1) the MER model without spectral corrections (the incident irradiance is set equal to the incident broadband irradiance), and (2) a power model such as used in PVFORM [23]. The PVFORM model is of the form:

$$Pmp = \frac{E_{inc}}{1000} \cdot Pmp_0 \cdot \left[1 + \gamma \cdot \left(T - T_0\right)\right] \quad ,$$

where:

Pmp = maximum power, W
Pmp_0 = maximum power at SRC, W
E_{inc} = incident broadband irradiance, W/m^2
γ = maximum power correction factor for temperature, °C^{-1}
T = PV module temperature, °C
T_0 = 25 °C.

This equation is the same format as the MER equation (5) for short-circuit current, and γ is determined in the same manner as Equations (5)'s α. Table 4.7 lists Pmp_0 and γ values for the test PV modules.

Table 4-7. Maximum Power at SRC and Correction Factor for Temperature

PV Module	Pmp_0 (W)	γ(°C^{-1})
a-Si/a-Si/a-Si:Ge, S/N 1736	37.0	-0.002438
CdS/CuInGaSSe, S/N 5165	40.0	-0.004230
CIS, S/N 114	30.8	-0.005464
Mono-Crystal Si, S/N 0442	65.5	-0.005121
Multi-Crystal Si, S/N 581836	51.9	-0.005691
a-Si/a-Si:Ge, S/N SYS49	22.9	-0.002102
CdS/CdTe, S/N 14407	52.5	-0.001348

Figure 4-5 and 4-6 show how the MBEs and RMSEs respectively, of modeled power for the 1998 hourly data vary by modeling method and PV module. Of the three, the MER method yielded the lowest MBEs and RMSEs for each PV module. Not accounting for spectral characteristics, it shifted the MBE about +4%, except for the two a-Si PV modules where the MBE shift was greater (+6% to +8%). Compared to the MER method without spectral corrections, the PVFORM type model increased the MBE a few additional percent for most of the PV modules.

For the a-Si/a-Si/a-Si:Ge PV module, modeling errors were greater for all models, but the MER model achieved the best results by a factor of two or more. In addition to potential seasonal changes in temperature coefficients and reference efficiency, the multijunction construction of this PV module and the narrow range of wavelengths over which the cells respond to light require more accurate spectral irradiances and spectral response data to achieve the same level of model accuracy as the other PV modules. Figures 4-7 and 4-8 provide spectral response data for the PV modules.

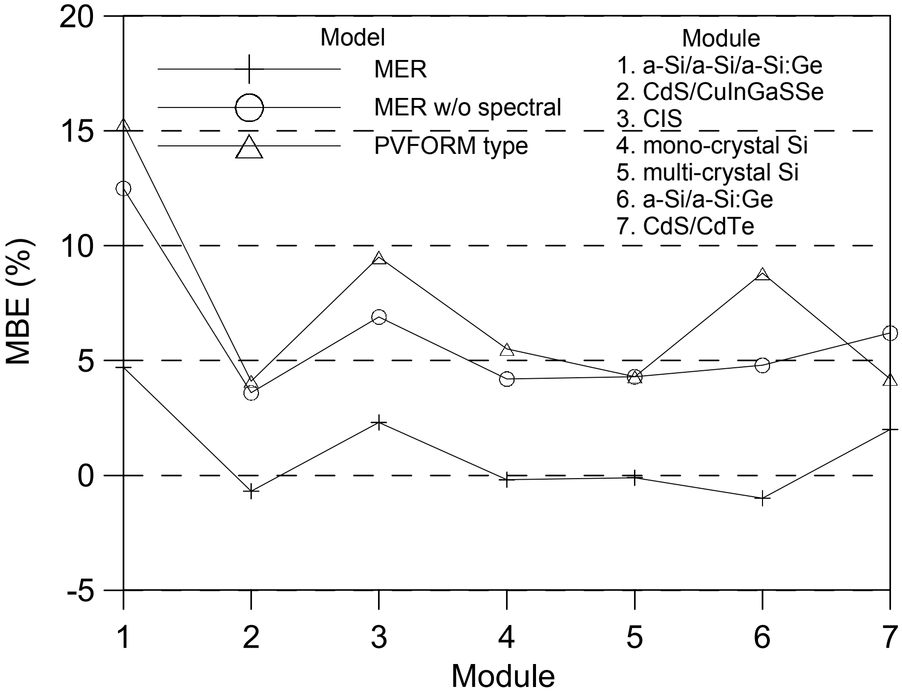

Figure 4-5. MBEs for 1998 hourly data for three modeling methods.

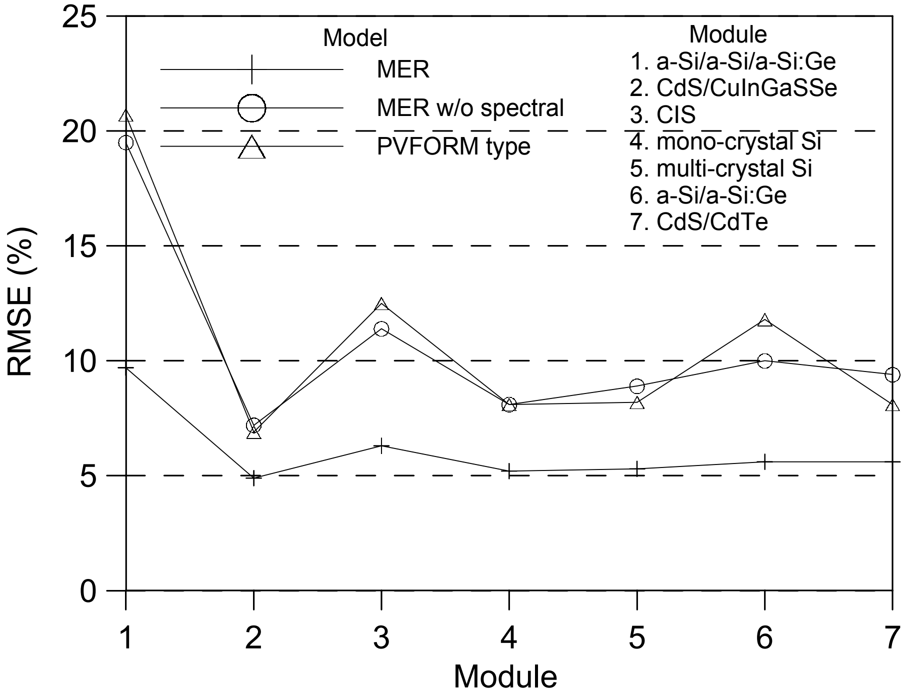

Figure 4-6. RMSEs for 1998 hourly data for three modeling methods.

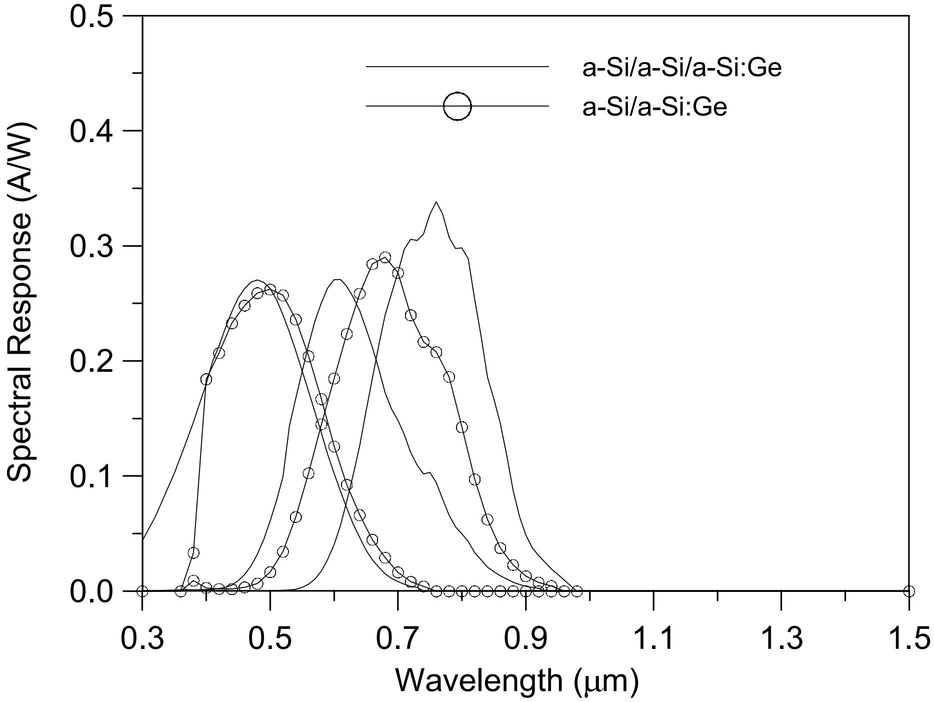

Figure 4-7. Spectral response of the junctions of a-Si PV modules.

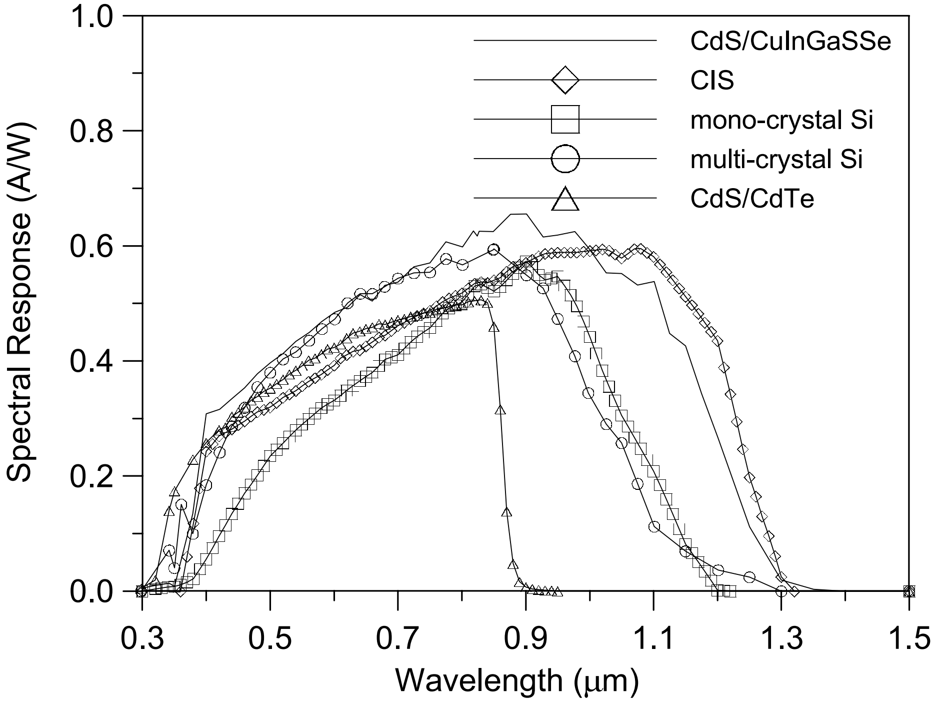

Figure 4-8. Spectral response of PV modules.

Daily Results. Comparisons of daily values of modeled and measured PV energy are the best indicators of the suitability of the MER method for rating PV modules for daily energy production. The comparisons were restricted to 208 days in 1998 where a minimum of 80% of daytime hours met the quality assessment criteria. (For the CdS/CdTe PV module, only 183 days met this requirement.) Figures 4-9 through 4-15 show MBEs for modeled daily PV energy as a function of the daily incident solar energy. The figures show good agreement between modeled and measured PV energy.

Further insight is given by comparing modeled and measured PV energy for days from 1998 that have similar PV module maximum temperatures (within 10°C) and incident solar radiation (within 1 kWh/m^2/day) to those of the MER days. The daily data were screened to find the average MBE for four similar days for each of the MER days. Table 4-8 shows the results of this comparison.

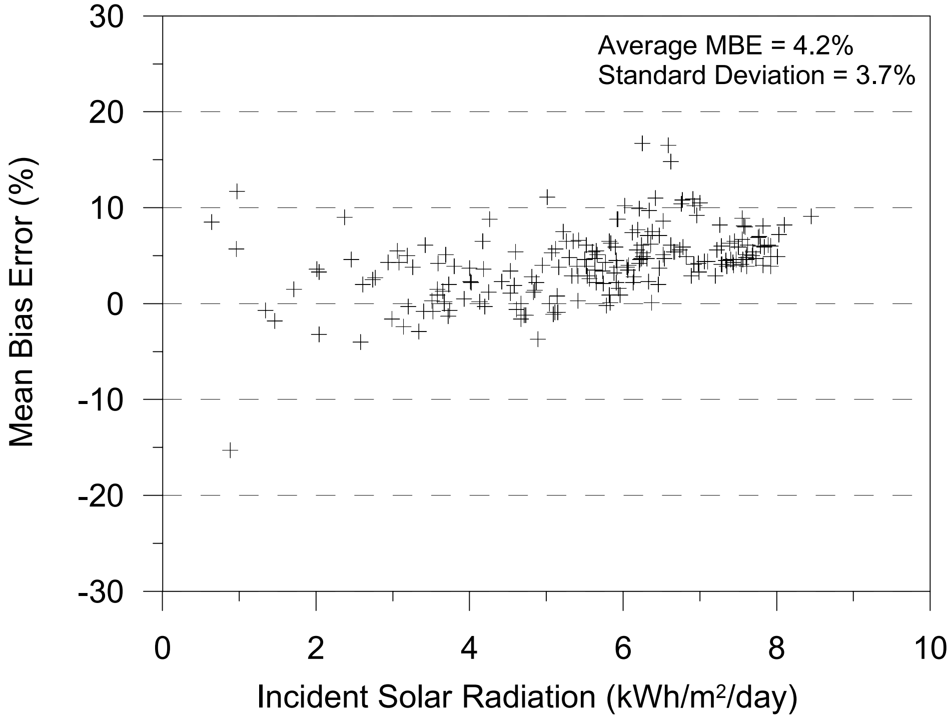

Figure 4-9. MBEs of modeled daily energy for the a-Si/a-Si/a-Si:Ge PV module.

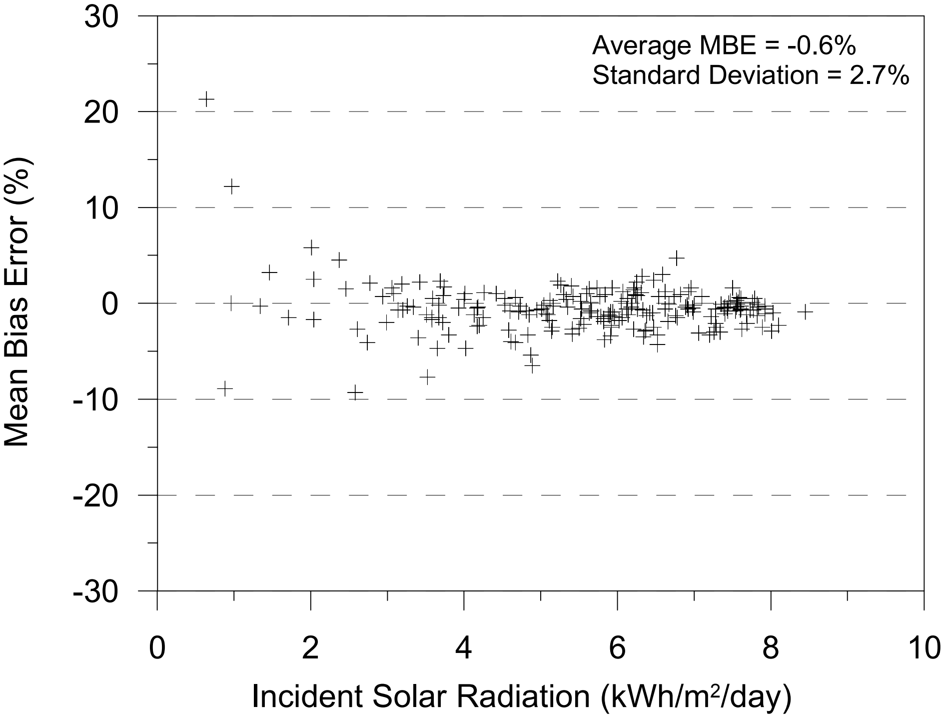

Figure 4-10. MBEs of modeled daily energy for the CdS/CuInGaSSe PV module.

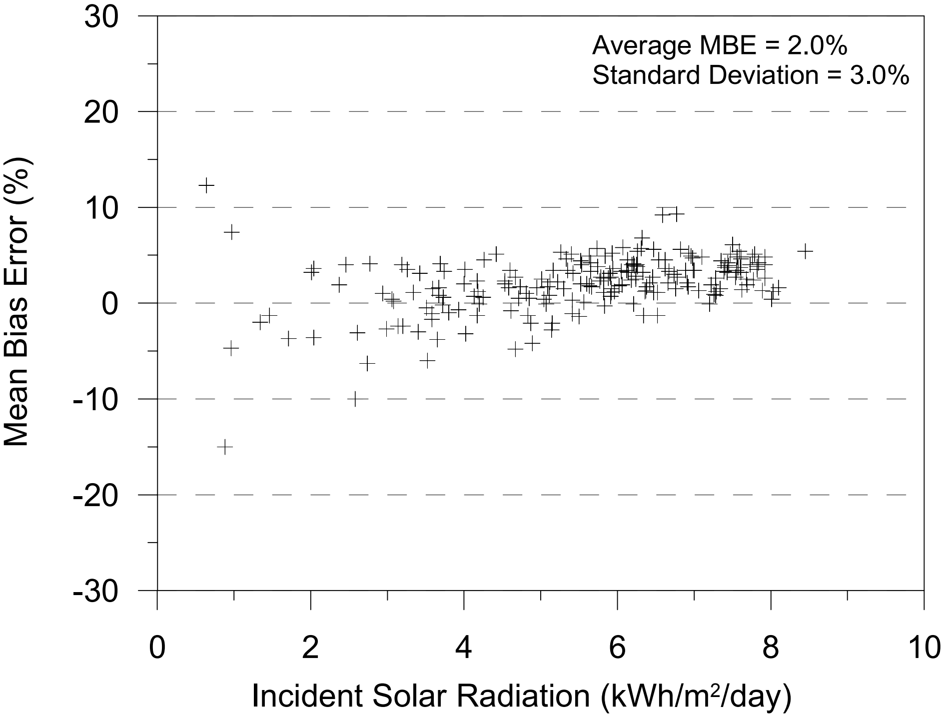

Figure 4-11. MBEs of modeled daily energy for the CIS PV module.

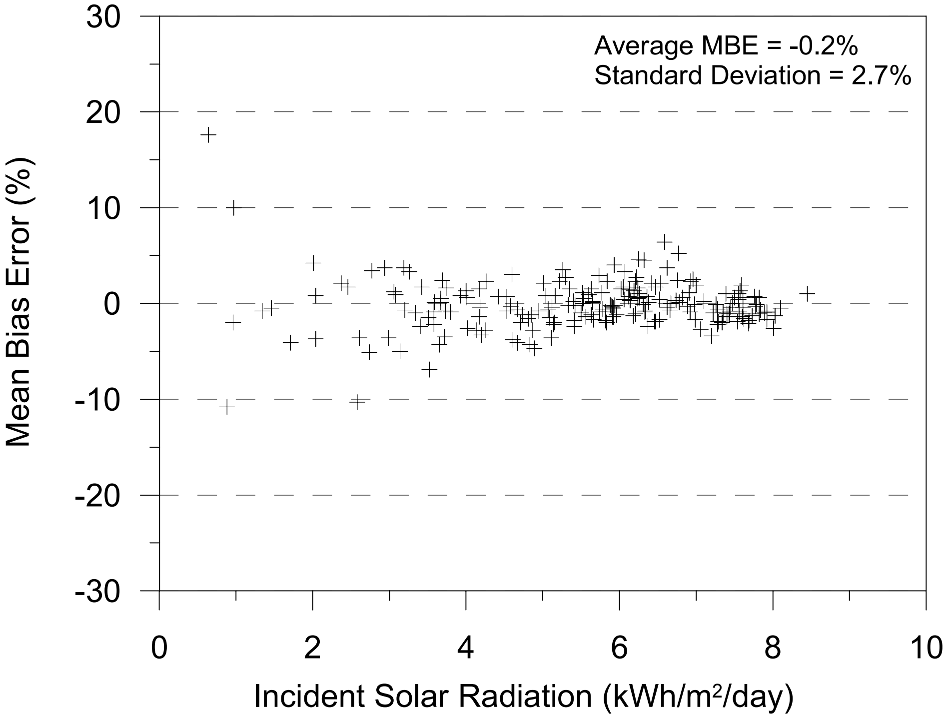

Figure 4-12. MBEs of modeled daily energy for the mono-crystalline silicon PV module.

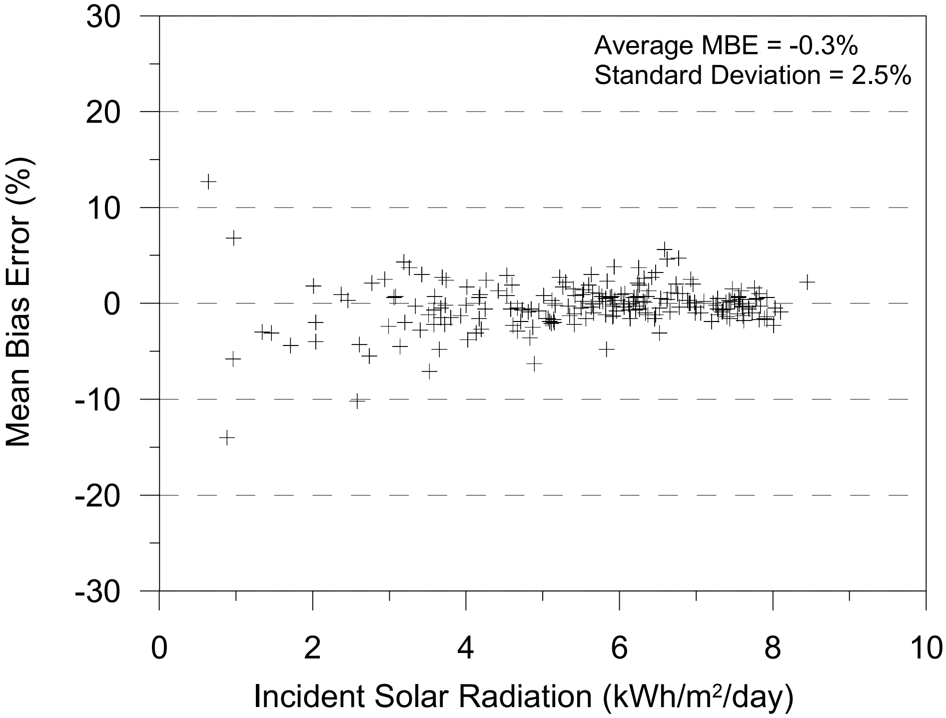

Figure 4-13. MBEs of modeled daily energy for the multi-crystalline silicon PV module.

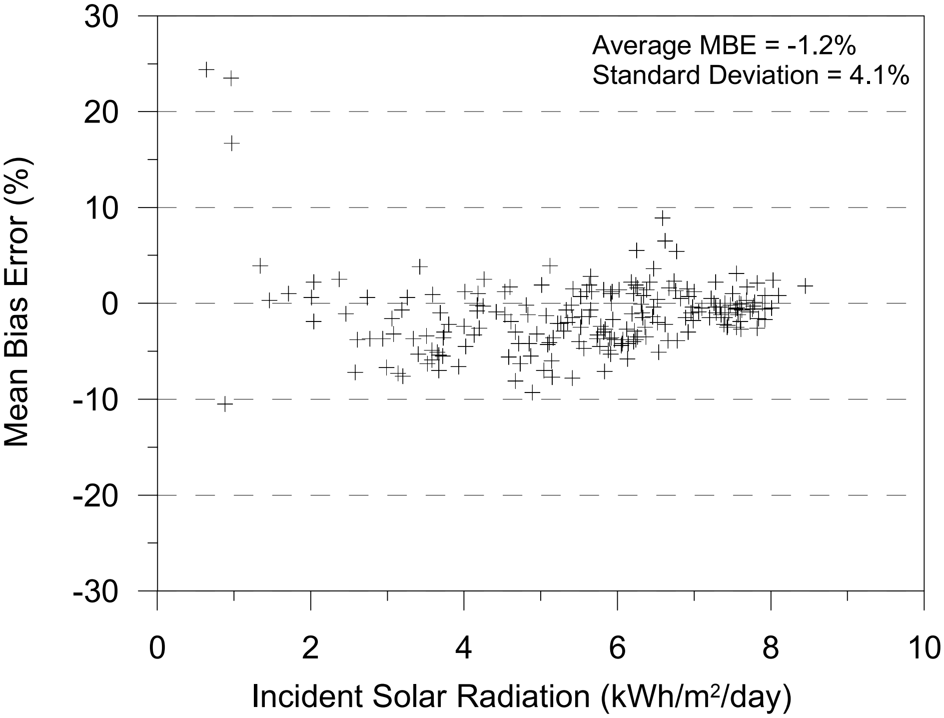

Figure 4-14. MBEs of modeled daily energy for the a-Si/a-Si:Ge PV module.

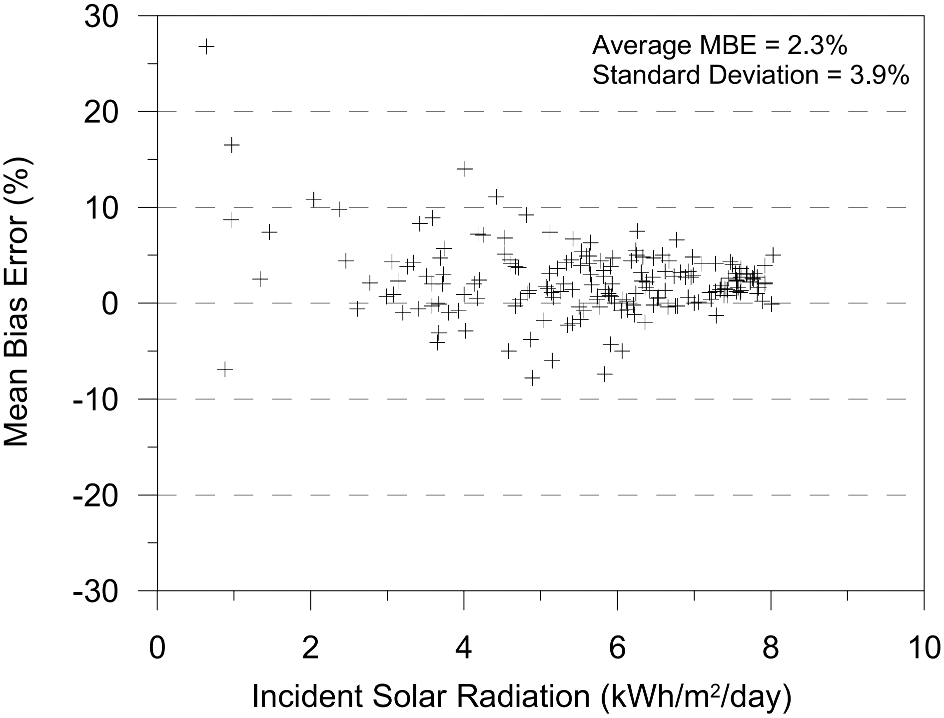

Figure 4-15. MBEs of modeled daily energy for the CdS/CdTe PV module.

Table 4-8. Percent MBEs of Modeled PV Daily Energy for Days Similar to MER Days

PV Module	Cold Cloudy	Cold Sunny	Nice	Hot Cloudy	Hot Sunny
	1/31/98 2/7/98 2/9/98 11/25/98	1/18/98 1/23/98 1/29/98 2/12/98	4/1/98 4/4/98 4/24/98 5/9/98	5/22/98 6/17/98 8/4/98 8/25/98	8/13/98 8/29/98 8/30/98 9/4/98
a-Si/a-Si/a-Si:Ge, S/N 1736	4 (-1 to 12)	9 (6 to 10)	7 (6 to 9)	2 (-2 to 6)	5 (5 to 6)
CdS/CuInGaSSe, S/N 5165	2 (-2 to 12)	-2 (-3 to 0)	-1 (-3 to 1)	1 (-1 to 2)	0 (-1 to 1)
CIS, S/N 114	-1 (-4 to 7)	2 (1 to 3)	2 (1 to 4)	1 (-2 to 3)	4 (4 to 5)
Mono-crystal Si, S/N 0442	0 (-4 to 10)	1 (0 to 2)	0 (-1 to 1)	0 (-5 to 2)	-1 (-1 to 0)
Multi-crystal Si, S/N 581836	-1 (-4 to 7)	0 (0 to 1)	0 (-2 to 1)	0 (-4 to 3)	0 (-1 to 0)
a-Si/a-Si:Ge, S/N SYS49	6 (1 to 17)	0 (-2 to 1)	1 (0 to 3)	-1 (-7 to 4)	-1 (-2 to 0)
CdS/CdTe, S/N 14407	8 (3 to 16)*	-1 (-2 to 0)	1 (0 to 3)	6 (2 to 9)*	2 (1 to 3)

*These values may be high because the model did not account for the uppermost PV cell's reduction in view of the sky by the module support structure.

The MBEs in Table 4-8 show how well the MER method estimates PV energy for each of the five MER days and how well it estimates the relative performance of different PV module technologies. MBEs greater than zero indicate that the MER method overestimates performance. MBEs less than one indicate that the performance is underestimated. In Table 4-8, the first value is the average MBE for the four selected days. The values in parenthesis are the range of MBEs for individual days. As expressed in Table 4-8 as a percentage, the ranges of MBEs are greatest for cloudy days. If expressed in units of Wh/day, the ranges of MBEs for cloudy days would have been more comparable to those for the sunny days. Energy produced for the cold cloudy days in Table 4-8 were 13% to 28% of that for the cold sunny days and the energy produced for the hot cloudy days in Table 4-8 were 40% to 48% of that for the hot sunny days.

The variation of the average MBEs (values not in parenthesis) for an MER day (vertical columns in Table 4-8) indicates the relative performance of the MER method for different PV module technologies. The smaller the variation of MBEs, the better the MER method estimates the relative performance of the PV modules. The variation of MBEs is an indication of the uncertainty of the MER method in predicting the relative performance of PV modules of different technologies. Table 4-9 shows these variations, as the percent uncertainty, for the group of PV modules and the group of PV modules excluding the a-Si PV modules. Uncertainties are higher when the a-Si PV modules are included because of the increased difficulty in modeling their spectral dependencies. Also, the MER method does not account for annealing effects and long-term degradation that may have occurred during the test period.

Table 4-9. Estimated Percent Uncertainty in Predicting Relative Performance

PV Module Group	Cold Cloudy*	Cold Sunny	Nice	Hot Cloudy*	Hot Sunny
All test PV modules	7	11	8	3	6
All test PV modules except a-Si	3	4	3	1	5

* CdS/CdTe PV module results not included because they were considered questionable.

The uncertainties in Table 4-9 are for PV modules whose indoor tests to characterize their electrical performance were performed using the same test equipment. Because it is likely that different facilities will be performing MER characterization tests and ratings, the overall uncertainty estimate should account for differences in the measurement of electrical performance by different facilities. ASTM E1036 lists a reproducibility limit of 6.7% for PV module performance measurements performed for a seven laboratory inter-comparison study.

By defining the overall uncertainty as the square root of the sum of the squares of the reproducibility limit and the maximum uncertainties from Table 4-9, a statement such as the following applies: "Because of errors in measurements and energy rating methodology, differences of 8% or less in the energy ratings of two PV modules are not significant. If one of the PV modules is amorphous silicon, differences of 13% or less in the energy ratings of two PV modules are not significant."

4.8 Limitations of the MER Method and Its Validation

To achieve a higher confidence in MER ratings requires reducing measurement errors and/or addressing limitations of the MER method. Based on NREL's experimental work, potential areas for lowering the measurement uncertainty of the results are:

- PV module temperature measurement – The indoor characterization tests used a temperature probe on the PV module front surface while the outdoor performance tests used a thermocouple fastened to the back surface. In addition, a post-evaluation test indicated that the use of a smaller thermocouple increased outdoor measured temperatures by 1°-3°C. Temperature measurement practices should provide accurate results using consistent methods for both indoor and outdoor tests. Accounting for the temperature gradients between PV cells and PV module back surfaces could also provide better estimates of PV module temperatures.
- POA irradiance – A more accurate POA irradiance measurement could be made by measuring the diffuse irradiance for the tilted PV modules and then adding the direct beam component determined from the absolute cavity radiometer measurement.
- Absolute spectral response – The absolute spectral responses assigned to the PV test modules were from previous measurements of similar PV cells and modules. A more accurate incident irradiance might be determined if the absolute spectral response was measured for each PV module being tested.
- Spectral irradiance measurements – Spectral irradiance measurements could be used to further evaluate the spectral irradiance model and to investigate departures between modeled and measured maximum power. For example, as shown in Figure 4-3, modeled values of maximum power were consistently higher than measured values for higher irradiances for the a-Si/a-Si/a-Si:Ge PV module. Among other reasons, were the overestimates due to the assigned absolute spectral responses, the modeled spectral irradiance, or the manner in which the incident irradiance is determined.
- Indoor characterization tests – Performing I-V curve measurements over a wider temperature range, such as 5°-60°C, would provide a better set of reference I-V curves for translating to desired conditions. This is more important for PV modules whose fill-factor varies significantly with temperature and irradiance.
- Climatic diversity – Outdoor measurements at more than one location would provide a wider range of climatic conditions for validating the MER method. This is primarily important for the assessment of the spectral irradiance modeling and of the incident irradiance calculations. The outdoor data collected at NREL supplied a sufficiently diverse set of PV module temperatures.
- Inter-laboratory measurements – The ability of different laboratories and test facilities to reproduce the same indoor test results is a large influence on the ability of the MER method to show relative differences between two modules tested at different facilities. Reducing the reproducibility limit for PV module measurements directly benefits the MER method.

MER simplifying assumptions also impose limitations on accuracy. Beside measurement errors, observed differences between modeled and measured maximum power may have resulted from a combination of effects not addressed by the MER method. These effects may include:

- Fill-factor varying with irradiance and temperature. The MER method varies fill-factor by setting it equal to that of the selected reference I-V curve.
- Non-linear behavior of temperature coefficients or their dependence on the spectral irradiance distribution.

- Changes in the relative spectral response of a PV module with changes in temperature, irradiance level, and PV module operating voltage.
- Non-linear relationships between short-circuit currents and irradiances.
- For multi-junction PV modules, the effect of spectral variations on fill-factor and voltage. The MER method accounts for spectral variations by determining the effect on short-circuit current.
- Seasonal changes in temperature coefficients and reference efficiencies for amorphous silicon PV modules.

4.9 Uncertainty Analysis of the NREL MER Validation

One way of deciding how accurate the method and validation are is to analyze the sources and magnitudes of uncertainties encountered in the measurements, modeling and validation results. Table 4-10 summarizes the results shown in tables 4-1, 4-5, 4-6, 4-8, and 4-9 to substantiate the conclusion that this method appears to reproduce actual energy production numbers at NREL under a wide variety of conditions with an overall accuracy of about 9% for all but amorphous silicon modules, where the method is probably accurate to 13%. For the selected reference days, the uncertainties are probably slightly lower, on the order of 5% and 11%, for crystalline and amorphous modules, respectively.

These conclusions are based on the following sources of uncertainty, and their magnitudes. Specifications of the equipment used and the comparisons of modeled and measured results for various parameters are the sources for the magnitudes. Note that elemental sources of uncertainty mentioned in the section on Limitations of the Method (section 4.8) are not included here, *but may already be included in the magnitudes of the model and translation bias and random errors.* All of the uncertainties are considered to be of unknown sign, even though some of the mean bias errors may have a sign. This approach is used to obtain the *most conservative* estimate of the validation uncertainty.

Table 4-10. Elemental Uncertainty Summary for Validation Method Models and Measurements

PERT Test Equipment COMBINED Bias and Random Errors (based on Table 4-1)		**Model/Translation BIAS** Error (See Table 4-5, 4-6)		**Model/Translation RANDOM** Errors (See table 4-5, 4-6)	
PARAMETER	% Uncertainty	Crystalline	Amorphous	Crystalline	Amorphous
Voltage	0.1%	0.2%	0.2%	0.8%	0.4%
Current	0.1%	[0.1%]	[0.1%]	0.3%	0.5%
Irradiance	4.0%	0.7%	0.4%	4.5%	4.5%
Module Temperature(*)	0.5%	1.1%	0.7%	2.0%	1.0%
Module Power	N/A	0.2%	4.7%	5.5%	9.7%
Column RSS	4.0%	3.0%	4.8%	7.4%	10.8%
RSS PERT+BIAS+RANDOM				**8.9%**	**12.5%**

RSS= Root-sum-square, the square root of the sum of the squares of the uncertainties.
[ ] Bias errors in the current with respect to PERT instrumentation are ~0.0; so PERT uncertainty used.
(*) Temperature percentages based on temperature coefficient effects at 0.5% per °C worst case.

Overall total RSS estimated uncertainty for the validation at NREL is 9% for crystalline modules and 13% for non-crystalline modules for approximately 3000 test hours, *covering a wide range of test conditions, including both similar and dissimilar to the selected reference day conditions.*

Table 4-8, shows that 100% of the MBEs for modeled PV Daily Energy with respect to similar days actual measured energy production with the PERT system are better than the estimated uncertainty. Eighty percent of all results differ by less than 1/2 of the estimated uncertainty in the crystalline case.

In conjunction with the reproducibility limit of 7% quoted for inter-laboratory measurements of module electrical performance (for crystalline modules), the above total overall uncertainty result is evidence that the conclusions of table 4-9, that energy production for all modules, except amorphous silicon modules can be predicted with *relative accuracy* of 11% and 5%, respectively, *for the selected reference days* is correct.

5.0 SUMMARY

The procedure determines the energy production of a PV module for five reference days. The reference days represent possible operating environments and are qualitatively described as *Hot Sunny*, *Cold Sunny*, *Hot Cloudy*, *Cold Cloudy*, and *Nice*. Based on statistical weather criteria, these days were selected from the NSRDB. Besides the hourly solar radiation and meteorological data from the NSRDB, the reference days include air mass, angle-of-incidence, POA and spectral irradiance for a south-facing PV module at latitude tilt, battery charging voltage, and parameters f_1 and f_2 for determining PV module temperature.

Indoor I-V curve measurements over a range of temperatures and irradiances characterize the electrical performance of a PV module and are used to determine factors to correct for non-linear performance when irradiance and temperature vary. They also serve as a matrix of reference I-V curves for translating to reference day conditions. The correction factors and functions are determined based on Annex A2 of ASTM E1036-96 (ASTM, 1996), but with modifications that improved translation accuracy.

The sensitivity of a PV module to variations in the spectral distribution of the incident radiation is accounted for by using an incident irradiance. The incident irradiance is determined for each hour using the PV module's spectral response, the MER hourly spectral irradiance, and the AM1.5 spectral irradiance. Multijunction PV modules are accommodated by using the junction spectral response(s) that are current limiting.

Differences in PV module thermal characteristics are accounted for by using a PV module's INOCT for input to the Fuentes temperature model. To simplify the MER procedure, an expression equivalent to directly using the Funetes model was determined for each MER hour. It is a linear relationship based on INOCT where parameter f_1 is the slope and f_2 is the y-intercept. Each MER hour has a different value of f_1 and f_2.

The procedure does not consider radiation and transmittance losses at large incident angles. These losses were judged too small, and not sufficiently different, for various PV modules to justify the complexity of their measurement and inclusion in the procedure.

When translating to the MER hourly conditions of incident irradiance and PV module temperature, the reference I-V curve measured under conditions closest to the desired hourly conditions is selected from the matrix of reference I-V curve. Because the translation does not change fill factor, this minimizes errors for PV modules with varying fill factors.

From the translated I-V curves, the peak power for each hour of an MER day is summed to determine the reference day energy in watt-hours for peak power operation. For battery charging applications, a rating is determined in amp-hours by summing the operating currents for the MER hour battery charging voltages. If needed, the operating current is interpolated using the I-V data points either side of the desired battery charging voltage.

PV performance measurements from NREL's Outdoor Test Facility during the calendar year 1998 were used to validate the procedure by comparing modeled and measured maximum power values for seven flat-plate PV modules representing different technologies. On an annual basis, modeled values compared within 5% of measured values. For days similar to the MER reference days, modeled values compared within 5% except for the a-Si/a-Si/a-Si:Ge PV module, whose modeled values compared within 9%. Modeling errors may have been greater for the a-Si/a-Si/a-Si:Ge PV module because the procedure does not account for potential seasonal changes in temperature coefficients and reference efficiency and its multijunction construction requires more accurate spectral irradiances and spectral response data to achieve the same level of model accuracy.

Taking into account reproducibility errors from ratings being performed by different facilities and the modeling errors, the following statement applies to the ability of this procedure to show relative differences in the energy production of two PV modules: “Because of errors in measurements and energy rating methodology, differences of 8% or less in the energy ratings of two PV modules are not significant. If one of the PV modules is amorphous silicon, differences of 13% or less in the energy ratings of two PV modules are not significant.”

This work was performed to develop and validate a PV module energy rating procedure for incorporation into IEEE PAR1479, “Recommended Practice for the Evaluation of Photovoltaic Module Energy Production.” Future work in this area would be to validate this procedure at various sites around the country. Also, this procedure could be modified to allow outdoors module characterization. NREL plans to spend sometime developing these areas with the goal of developing a standard procedure for conducting module energy ratings.

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Appendix A

Procedure for Determining the I-V Curves of a Nonconcentrator Terrestrial PV Module for the MER Reference Day Hours

Procedure for Determining the I-V Curves of a Nonconcentrator Terrestrial PV Module for the MER Reference Day Hours

A.1 The I-V curves of a PV module for the MER reference day hours are determined by: (a) measuring the I-V characteristics over a range of operating temperatures and irradiances to obtain matrices of open-circuit voltages, short-circuit currents, and reference I-V curves, (b) determining PV module temperature and irradiance correction factors and functions from the open-circuit voltage and short-circuit current matrices, (c) determining the irradiance and PV module temperature for each reference day hour, and (d) translating reference I-V curves to the hourly irradiance and PV module temperature conditions.

A.2 The following procedure is recommended for obtaining the Voc, Isc, and reference I-V curve matrices.

A.2.1 Select the range of temperatures and irradiances at which the measurements will be performed. The ranges should include most of the temperatures and irradiances determined in A.4 for the MER reference days and should also include the standard reporting conditions (SRC) of an irradiance of 1000 W/m^2, a module temperature of 25°C, and a spectral irradiance conforming to ASTM E 892. Suggested ranges are 5−60°C and 100−1000 W/m^2. A minimum of six temperature settings (suggested 5, 15, 25, 35, 45, and 60°C) and six irradiances settings (suggested 100, 200, 400, 600, 800, and 1000 W/m^2) should be selected, resulting in 36-element arrays for the Voc, Isc, and reference I-V curve matrices.

A.2.2 The I-V measurements are performed with equipment meeting the apparatus requirements of ASTM E 1036. A solar simulator is preferred for the light source to minimize spectral differences in the light source during the measurements.

A.2.3 The module temperature can be varied by the use of a temperature-controlled chamber with a window for transmitting the irradiance from the light source to the module. It is recommended that the temperature be increased and held to each setting in A.2.1 while I-V measurements are obtained for each irradiance setting, also selected in A.2.1.

A.2.4 For the maximum irradiance setting of 1000 W/m^2, the module irradiance should be measured with a calibrated reference cell. For irradiance settings below the maximum, the irradiance may be varied by using a filter of successive layers of screens or thin paper located between the light source and the module. When using the filter, the solar simulator is maintained at the maximum irradiance value.

A.2.5 At each temperature and irradiance setting, measure and record the I-V curve of the module.

A.2.6 For irradiance settings below the maximum, calculate the irradiance values from the module Isc data with:

$$E_f = E_u \cdot \frac{I_{scf}}{I_{scu}}$$

where:

E_f = the irradiance on the module while filtered.
E_u = the unfiltered maximum irradiance measured with a reference cell.
I_{scf} = the measured short-circuit current while filtered.
I_{scu} = the unfiltered measured short-circuit current for the maximum irradiance

The E_f values are calculated for each temperature of an irradiance setting and then averaged to obtain the matrix irradiance indices or levels. This procedure assumes that the filtering and the maximum irradiance at each temperature are identical and that the short-circuit current is proportional to the irradiance if the temperature is constant.

A.2.7 For each temperature setting, account for slight variations in temperature by averaging the temperatures to determine the matrix temperature indices or levels.

A.3 The following procedure is recommended for determining PV module temperature and irradiance correction factors from the open-circuit voltage and short-circuit current matrices.

A.3.1 Calculate the slope of Isc versus temperature, ΔIsc/ΔT, for the irradiance level of 1000 W/m^2 using a linear least-squares fit of the data obtained in A.2. Figure A.1 provides an example of how Isc might vary with temperature. Data such as these are used to find ΔIsc/ΔT.

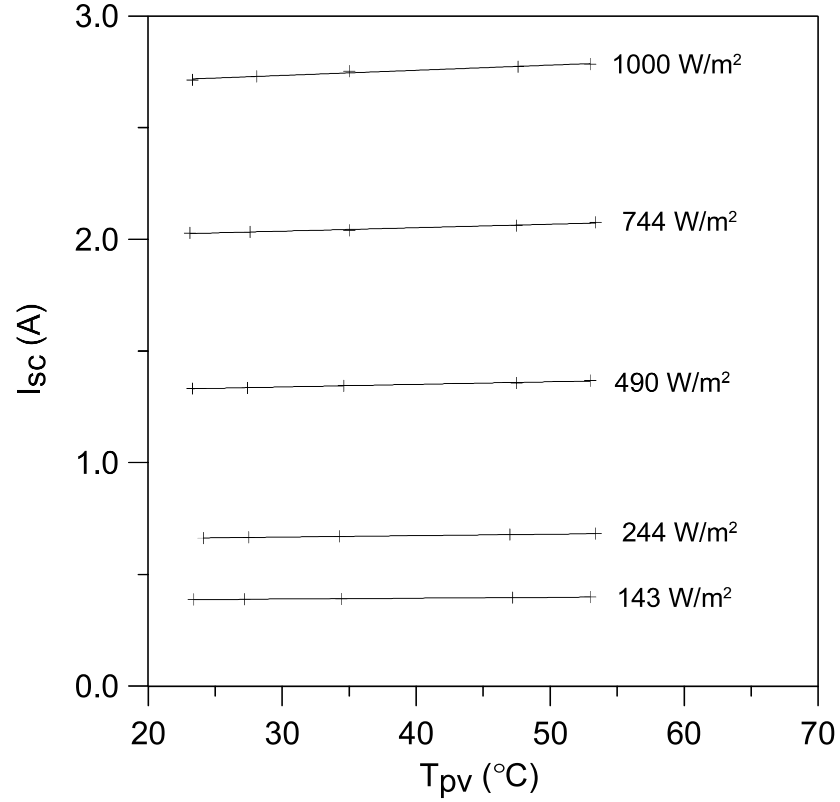


Figure A.1 Example of Isc as a function of PV module temperature for various irradiance levels

A.3.2 Using the linear fit obtained in A.3.1, calculate the short-circuit current at SRC, Isc_{src}. This value is used in A.5 for translating reference I-V curves to the hourly irradiance and module temperature conditions.

A.3.3 Normalize the slope obtained in A.3.1 by dividing by Isc_{src}. The normalized slope is the current correction factor for temperature, α.

A.3.4 Calculate the slope of Voc versus temperature, ΔVoc/ΔT, for the irradiance level of 1000 W/m^2 using a linear least-squares fit of the data obtained in A.2. Figure A.2 provides an example of how Voc varies with temperatures. Data such as these are used to find ΔVoc/ΔT.

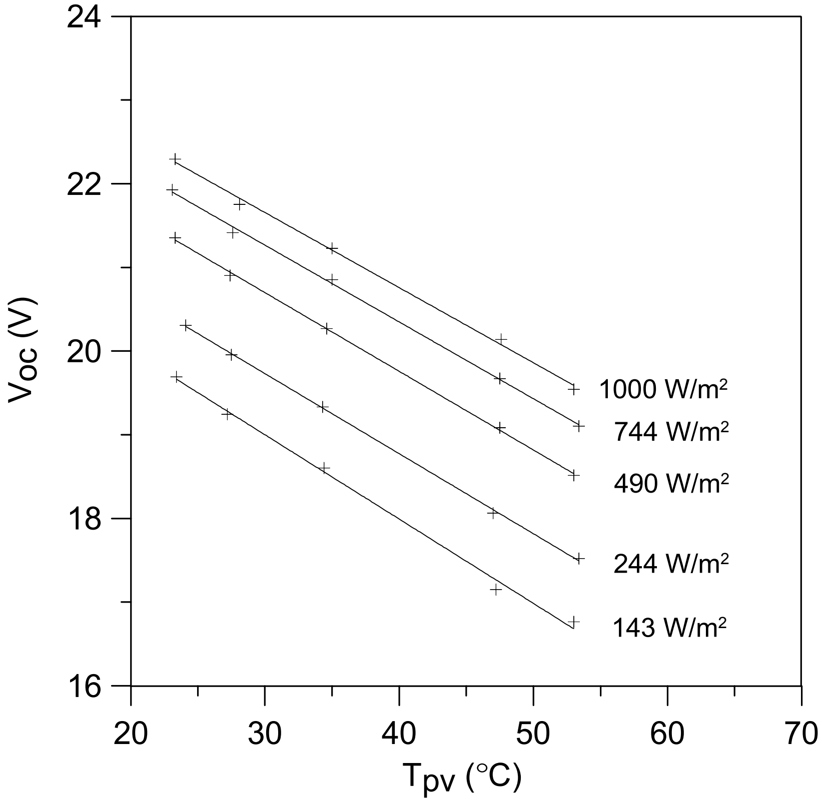


Figure A.2 Example of Voc as a function of PV module temperature for various irradiance levels

A.3.5 Using the linear fit obtained in A.3.4, calculate the open-circuit voltage at SRC, $\mathrm{Voc}_{\mathrm{src}}$. This value is used in A.5 for translating reference I-V curves to the hourly irradiance and module temperature conditions.

A.3.6 Normalize the slope obtained in A.3.4 by dividing by $\mathrm{Voc}_{\mathrm{src}}$. The normalized slope is the voltage correction factor for temperature, β.

A.3.7 Calculate the slope of Voc versus the natural logarithm of the irradiance, ΔVoc/ΔlnE, at each temperature level using a linear least-squares fit of the data obtained in A.2. Figure A.3 provides an example of how Voc varies with the natural log of the irradiance for different temperature levels. Data such as these are used to find ΔVoc/ΔlnE.

A.3.8 Calculate a normalization factor for each temperature level by evaluating each linear fit obtained in A.3.7 for Voc at an irradiance of 1000 W/m^2. Divide the slopes obtained in A.3.7 by the appropriate normalization factor.

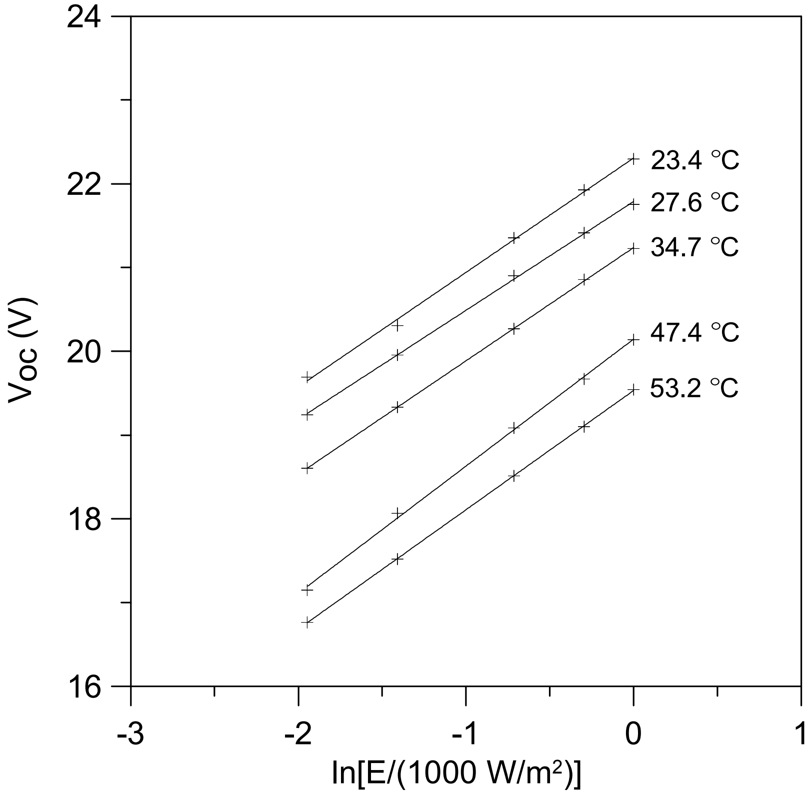


Figure A.3 Example of Voc as a function of the natural log of the irradiance for various temperature levels

A.3.9 Perform a linear least-squares fit of the normalized ΔVoc/ΔlnE slopes versus temperature. The resulting linear equation is the voltage correction function for irradiance, δ(T).

A.4 The following procedure is recommended for determining the irradiance and module temperatures for each MER reference day hour.

A.4.1 Calculate the irradiance for each hour of the MER reference days with:

$$E = \frac{\int_{300}^{1400} E_{INC}(\lambda) SR(\lambda) d\lambda}{\int_{300}^{1400} E_{REF}(\lambda) SR(\lambda) d\lambda} \cdot 1000\,\mathrm{W/m^2}$$

where:

λ = wavelength in nanometers

$E_{INC}(\lambda)$ = MER hour incident spectral irradiance

$E_{REF}(\lambda)$ = reference ASTM E 892 spectral irradiance, normalized to 1000 W/m^2

$SR(\lambda)$ = absolute spectral response per ASTM E1021

For series-connected multi-junction modules, the spectral response of the junction(s) that give the smallest numerator (current at MER hour conditions) and smallest denominator (current at reference conditions) are used to evaluate the equation. Spectral responses for two junctions are required to evaluate the equation if one junction is the current limiting factor at reference conditions and the other junction is the current limiting factor at the MER hour conditions.

A.4.2 Determine the module's nominal-operating-cell-temperature (NOCT) per Annex A1 of ASTM E 1036.

A.4.3 Determine the module's installed-nominal-operating-cell temperature (INOCT) in degrees centigrade with:

$$\text{INOCT} = \text{NOCT} - 3°\text{C}$$

A.4.4 Calculate the module temperature for each hour of the MER reference days with:

$$T = f_1 \times \text{INOCT} + f_2$$

where:

f_1 = slope function value for module temperature for the MER hour

f_2 = y-intercept function value for module temperature for the MER hour

A.5. The following procedure is recommended for translating reference I-V curves to the hourly irradiance and module temperature conditions and integrating the daily totals of energy for peak power and fixed-voltage operation.

A.5.1 Calculate the short-circuit current for the MER hour with:

$$Isc = \frac{E}{1000} \cdot Isc_{src} \cdot \left[1 + \alpha \cdot (T - 25)\right]$$

where:

E = irradiance from A.4.1

T = module temperature from A.4.4

Isc_{src} = short-circuit current at SRC from A.3.2

α = current correction factor for temperature from A.3.3

A.5.2 Calculate the open-circuit voltage for the MER hour with:

$$Voc = Voc_{src} \cdot \left[1 + \beta \cdot (T - 25)\right]\left[1 + \delta(T) \cdot \ln(E/1000)\right]$$

where:

E = irradiance from A.4.1

T = module temperature from A.4.4

Voc_{src} = open-circuit voltage at SRC from A.3.5

β = voltage correction factor for temperature from A.3.6

$\delta(T)$ = voltage correction function for irradiance from A.3.9

A.5.2 Select from the matrix of reference I-V curves the I-V curve with its irradiance level closest to E and its temperature level closest to T.

A.5.3 Translate each I-V data point of the selected reference I-V curve to the MER hour conditions of E and T with:

$$I = I_R \cdot \frac{Isc}{Isc_R}$$

and:

$$V = V_R \cdot \frac{Voc}{Voc_R}$$

where R is the subscript for the reference I-V curve currents and voltages.

A.5.4 Calculate the product of the current and voltage for each translated I-V data point and select the maximum product for the MER hour peak power. Sum the peak power for each hour of a MER reference day to determine the reference day energy in watt-hours (Wh) for peak power operation.

A.5.5 Select the two adjacent translated I-V data points whose voltages are directly above and below the voltage operation point for the MER hour. Calculate the module current, I_{op}, for the voltage operation point with:

$$I_{op} = I_1 + (V_{op} - V_1) \times \frac{I_2 - I_1}{V_2 - V_1}$$

where:

I_1 = current of translated I-V data point whose voltage is equal to or less than the voltage operation point for the MER hour
V_1 = voltage of translated I-V data point whose voltage is equal to or less than the voltage operation point for the MER hour
I_2 = current of translated I-V data point whose voltage is greater than the voltage operation point for the MER hour
V_2 = voltage of translated I-V data point whose voltage is greater than the voltage operation point for the MER hour
V_{op}= voltage operation point for the MER hour

Sum the currents, I_{op}s, for the hours of a MER reference day to determine the reference day energy in ampere-hours (Ah).

Appendix B

I-V Curve Matrix Data measured at NREL with SPIRE 240A Solar Simulator

a-Si/a-Si/a-Si:Ge PV Module, S/N 1736
August 20, 1997

IV#	E	Tpv	Isc	Voc	Pmax	Imp	Vmp	FF
9761	1000.0	23.3	2.7138	22.2955	37.0392	2.2385	16.5466	0.612
9762	744.4	23.1	2.0284	21.9272	27.2556	1.6023	17.0105	0.613
9763	489.9	23.3	1.3319	21.3546	17.5158	1.0539	16.6199	0.616
9764	142.7	23.4	0.3883	19.6920	4.6696	0.2866	16.2903	0.611
9765	1000.0	35.0	2.7527	21.2269	36.0990	2.3203	15.5579	0.618
9766	744.4	35.0	2.0401	20.8557	26.7530	1.6989	15.7471	0.629
9767	489.9	34.6	1.3456	20.2701	16.9922	1.0514	16.1621	0.623
9768	244.2	34.3	0.6703	19.3329	7.9209	0.5113	15.4907	0.611
9769	142.7	34.4	0.3899	18.6034	4.4870	0.2946	15.2283	0.619
9770	1000.0	53.0	2.7849	19.5433	34.3477	2.3487	14.6240	0.631
9771	744.4	53.4	2.0758	19.1025	25.0817	1.6684	15.0330	0.633
9772	489.9	53.0	1.3676	18.5142	15.9145	1.0928	14.5630	0.629
9773	244.2	53.4	0.6820	17.5208	7.3207	0.5183	14.1235	0.613
9774	142.7	53.0	0.3991	16.7664	4.1315	0.3000	13.7695	0.617
9775	1000.0	47.6	2.7736	20.1403	35.0056	2.3371	14.9780	0.627
9776	744.4	47.5	2.0622	19.6710	25.6505	1.6994	15.0940	0.632
9777	489.9	47.5	1.3574	19.0859	16.3534	1.0936	14.9536	0.631
9778	244.2	47.0	0.6782	18.0646	7.5021	0.5003	14.9963	0.612
9779	142.7	47.2	0.3960	17.1491	4.0673	0.2884	14.1052	0.599
9780	1000.0	28.1	2.7298	21.7529	36.7229	2.2408	16.3879	0.618
9781	744.4	27.6	2.0331	21.4156	27.0883	1.6462	16.4551	0.622
9782	489.9	27.4	1.3361	20.9032	17.3136	1.0526	16.4490	0.620
9783	244.2	27.5	0.6663	19.9559	8.0622	0.5067	15.9119	0.606
9784	142.7	27.2	0.3889	19.2428	4.5877	0.3022	15.1794	0.613
9785	244.2	24.1	0.6625	20.3070	8.1604	0.4965	16.4368	0.607

Legend
IV# = Identification number assigned to the IV curve
E = Incident irradiance (W/m^2), varied by adjusting lamp output and use of filter screens
Tpv = PV module temperature (°C), varied by use of heating pad below module and measured with a temperature probe on the top surface.
Isc = Short-circuit current (A)
Voc = Open-circuit voltage (V)
Pmax = Maximum power (W)
Imp = Current at maximum power (A)
Vmp = Voltage at maximum power (V)
FF = Fill factor

Note: These measurements were performed with available equipment. Recommended practice includes a wider temperature range (5-60°C) and the use of a temperature controlled chamber for adjusting PV module temperature.

CdS/CuInGaSSe PV Module, S/N 5165
August 21, 1997

IV#	E	Tpv	Isc	Voc	Pmax	Imp	Vmp	FF
9787	1000.0	23.2	2.4416	26.0138	40.2385	2.1433	18.7744	0.634
9788	752.2	23.0	1.8288	25.5984	30.7960	1.6008	19.2383	0.658
9789	503.9	23.1	1.2264	24.9410	20.4058	1.1027	18.5059	0.667
9790	254.1	23.2	0.6191	23.7069	9.9224	0.5433	18.2617	0.676
9791	152.1	23.2	0.3683	22.8377	5.6888	0.3232	17.6025	0.676
9792	1000.0	38.2	2.4265	24.5846	38.1693	2.1156	18.0420	0.640
9793	752.2	37.7	1.8311	24.1398	28.9629	1.6118	17.9688	0.655
9794	503.9	36.6	1.2257	23.5453	19.2169	1.0467	18.3594	0.666
9795	254.1	35.8	0.6198	22.4162	9.3108	0.5356	17.3828	0.670
9796	152.1	35.4	0.3727	21.4589	5.2632	0.3111	16.9189	0.658
9797	752.2	35.3	1.8298	24.3547	29.1614	1.6076	18.1397	0.654
9798	1000.0	57.2	2.4281	22.7352	34.6078	2.0785	16.6504	0.627
9799	752.2	56.4	1.8259	22.1606	25.9831	1.5808	16.4368	0.642
9800	503.9	56.9	1.2261	21.4270	17.0426	1.0497	16.2353	0.649
9801	254.1	56.0	0.6167	20.1199	8.0725	0.5299	15.2344	0.651
9802	152.1	55.5	0.3684	19.1083	4.5340	0.3093	14.6606	0.644
9803	152.1	49.1	0.3712	19.9603	4.8377	0.3209	15.0757	0.653
9804	254.1	47.5	0.6173	21.0478	8.5623	0.5419	15.8020	0.659
9805	503.9	47.3	1.2260	22.3095	17.9296	1.0816	16.5772	0.656
9806	752.2	47.0	1.8296	23.0281	27.2040	1.6308	16.6809	0.646
9807	1000.0	46.6	2.4358	23.5372	36.1604	2.0890	17.3096	0.631

Legend
IV# = Identification number assigned to the IV curve
E = Incident irradiance (W/m^2), varied by adjusting lamp output and use of filter screens
Tpv = PV module temperature (°C), varied by use of heating pad below module and measured with a temperature probe on the top surface.
Isc = Short-circuit current (A)
Voc = Open-circuit voltage (V)
Pmax = Maximum power (W)
Imp = Current at maximum power (A)
Vmp = Voltage at maximum power (V)
FF = Fill factor

Note: These measurements were performed with available equipment. Recommended practice includes a wider temperature range (5-60°C) and the use of a temperature controlled chamber for adjusting PV module temperature.

CIS PV Module, S/N 114
August 26, 1997

IV#	E	Tpv	Isc	Voc	Pmax	Imp	Vmp	FF
9831	1000.0	23.6	2.3892	23.1344	30.9353	1.9464	15.8935	0.560
9832	748.7	23.6	1.7915	22.5490	23.2986	1.4670	15.8813	0.577
9833	502.5	23.8	1.2072	21.7061	15.2774	0.9766	15.6433	0.583
9834	252.7	24.0	0.6066	20.1738	7.2961	0.4970	14.6790	0.596
9835	152.1	23.4	0.3654	19.0893	4.1532	0.2942	14.1174	0.595
9836	152.1	38.5	0.3648	17.1117	3.6457	0.2979	12.2375	0.584
9837	252.7	38.2	0.6070	18.3697	6.5004	0.5057	12.8540	0.583
9838	502.5	38.6	1.2054	19.8872	13.8853	0.9531	14.5691	0.579
9839	748.7	38.2	1.7970	20.8533	21.2655	1.5063	14.1174	0.567
9840	1000.0	38.0	2.3946	21.4389	28.7749	1.9227	14.9658	0.561
9841	1000.0	61.2	2.4012	18.8310	24.5842	1.8839	13.0493	0.544
9842	748.7	58.4	1.8017	18.1765	18.0411	1.4279	12.6343	0.551
9843	502.5	58.9	1.2050	17.2427	11.6945	0.9716	12.0361	0.563
9844	252.7	58.0	0.6111	15.6572	5.3348	0.4933	10.8154	0.558
9845	152.1	58.1	0.3655	14.4670	2.9154	0.2836	10.2783	0.551
9846	152.1	46.6	0.3658	16.3277	3.4045	0.2959	11.5051	0.570
9847	252.7	45.6	0.6040	17.4904	6.1170	0.5034	12.1521	0.579
9848	502.5	44.8	1.2115	19.0764	13.1663	1.0057	13.0920	0.570
9849	748.7	44.9	1.8052	19.9939	20.3721	1.4620	13.9343	0.564
9850	1000.0	46.0	2.4253	20.6940	27.5182	1.8960	14.5142	0.548

Legend
IV# = Identification number assigned to the IV curve
E = Incident irradiance (W/m^2), varied by adjusting lamp output and use of filter screens
Tpv = PV module temperature (°C), varied by use of heating pad below module and measured with a temperature probe on the top surface.
Isc = Short-circuit current (A)
Voc = Open-circuit voltage (V)
Pmax = Maximum power (W)
Imp = Current at maximum power (A)
Vmp = Voltage at maximum power (V)
FF = Fill factor

Note: These measurements were performed with available equipment. Recommended practice includes a wider temperature range (5-60°C) and the use of a temperature controlled chamber for adjusting PV module temperature.

Mono-Crystal Si PV Module, S/N 0442
August 27, 1997

IV#	E	Tpv	Isc	Voc	Pmax	Imp	Vmp	FF
9856	1000.0	22.0	4.3734	21.5058	66.5236	3.9333	16.9128	0.707
9857	752.4	22.7	3.2893	21.2475	50.2265	2.9527	17.0105	0.719
9858	503.3	23.2	2.1981	20.8572	33.2484	1.9358	17.1753	0.725
9859	252.3	23.4	1.1016	20.1314	15.9432	0.9621	16.5710	0.719
9860	151.4	23.5	0.6591	19.4854	9.0113	0.5532	16.2903	0.702
9861	151.4	34.7	0.6621	18.5177	8.6223	0.5660	15.2344	0.703
9862	252.3	35.1	1.1061	19.1499	15.0078	0.9871	15.2039	0.709
9863	503.3	35.1	2.2064	19.8635	31.4033	1.9904	15.7776	0.717
9864	752.4	35.1	3.2969	20.2407	47.2028	3.0010	15.7288	0.707
9865	1000.0	35.1	4.3868	20.5081	62.2246	4.0074	15.5273	0.692
9866	1000.0	55.6	4.4255	18.8986	55.2722	3.9981	13.8245	0.661
9867	752.4	55.0	3.3262	18.6215	42.2962	2.9665	14.2578	0.683
9868	503.3	54.7	2.2262	18.2124	27.9699	2.0250	13.8123	0.690
9869	252.3	54.4	1.1171	17.4225	13.4485	0.9656	13.9282	0.691
9870	151.4	54.8	0.6738	16.7794	7.6239	0.5840	13.0554	0.674
9871	151.4	38.6	0.6658	18.0966	8.3384	0.5831	14.3005	0.692
9872	252.3	38.1	1.1074	18.7084	14.6542	0.9828	14.9109	0.707
9873	503.3	38.1	2.2121	19.4978	30.5837	1.9845	15.4114	0.709
9874	752.4	38.0	3.3071	19.8869	46.0881	3.0084	15.3198	0.701
9875	1000.0	37.9	4.3833	20.2026	60.9539	3.9583	15.3992	0.688

Legend
IV# = Identification number assigned to the IV curve
E = Incident irradiance (W/m^2), varied by adjusting lamp output and use of filter screens
Tpv = PV module temperature (°C), varied by use of heating pad below module and measured with a temperature probe on the top surface.
Isc = Short-circuit current (A)
Voc = Open-circuit voltage (V)
Pmax = Maximum power (W)
Imp = Current at maximum power (A)
Vmp = Voltage at maximum power (V)
FF = Fill factor

Note: These measurements were performed with available equipment. Recommended practice includes a wider temperature range (5-60°C) and the use of a temperature controlled chamber for adjusting PV module temperature.

Multi-Crystal Si PV Module, S/N 581836
August 29, 1997

IV#	E	Tpv	Isc	Voc	Pmax	Imp	Vmp	FF
9880	1000.0	22.7	3.5467	21.3703	52.8580	3.1446	16.8091	0.697
9881	753.4	23.0	2.6704	21.0843	40.2515	2.3868	16.8640	0.715
9882	504.6	23.0	1.7927	20.7143	27.0217	1.6105	16.7786	0.728
9883	253.5	23.0	0.8953	20.0140	13.2455	0.7978	16.6016	0.739
9884	152.3	23.1	0.5368	19.3819	7.5988	0.4616	16.4612	0.730
9885	152.3	35.5	0.5401	18.4748	7.1460	0.4617	15.4785	0.716
9886	253.5	35.1	0.8995	19.0094	12.2530	0.8043	15.2344	0.717
9887	504.6	35.0	1.7842	19.7544	24.9370	1.5941	15.6433	0.708
9888	753.4	34.9	2.6682	20.1758	37.0282	2.3120	16.0156	0.688
9889	1000.0	34.9	3.5458	20.4575	48.6913	3.1470	15.4724	0.671
9890	1000.0	54.4	3.5741	18.9604	43.4317	3.1169	13.9343	0.641
9891	753.4	53.7	2.6974	18.6308	33.2018	2.3257	14.2761	0.661
9892	504.6	53.0	1.8128	18.2361	22.3869	1.5837	14.1357	0.677
9893	253.5	54.1	0.9055	17.4408	11.0909	0.8019	13.8306	0.702
9894	152.3	54.2	0.5425	16.6471	6.3719	0.4809	13.2507	0.706
9895	152.3	37.9	0.5457	18.1908	7.0251	0.4770	14.7278	0.708
9896	253.5	37.5	0.9046	18.7609	12.1422	0.7897	15.3748	0.715
9897	504.6	38.2	1.7858	19.4221	24.6828	1.5997	15.4297	0.712
9898	753.4	38.3	2.6775	19.8192	36.3908	2.3418	15.5395	0.686
9899	1000.0	38.6	3.5536	20.1086	47.6628	3.1731	15.0208	0.667

Legend
IV# = Identification number assigned to the IV curve
E = Incident irradiance (W/m^2), varied by adjusting lamp output and use of filter screens
Tpv = PV module temperature (°C), varied by use of heating pad below module and measured with a temperature probe on the top surface.
Isc = Short-circuit current (A)
Voc = Open-circuit voltage (V)
Pmax = Maximum power (W)
Imp = Current at maximum power (A)
Vmp = Voltage at maximum power (V)
FF = Fill factor

Note: These measurements were performed with available equipment. Recommended practice includes a wider temperature range (5-60°C) and the use of a temperature controlled chamber for adjusting PV module temperature.

a-Si/a-Si:Ge PV Module, S/N SYS49
September 5, 1997

IV#	E	Tpv	Isc	Voc	Pmax	Imp	Vmp	FF
9905	1000.0	23.3	0.6775	58.3346	22.9081	0.5471	41.8701	0.580
9906	739.5	23.2	0.5007	57.2059	16.7643	0.4011	41.7969	0.585
9907	482.1	23.4	0.3271	55.7931	10.6053	0.2494	42.5293	0.581
9908	242.8	23.5	0.1647	52.9047	4.9006	0.1219	40.2100	0.562
9909	141.3	23.5	0.0960	50.3541	2.5544	0.0684	37.3291	0.528
9910	141.3	37.0	0.0972	47.3243	2.4902	0.0716	34.7900	0.541
9911	242.8	37.7	0.1669	49.6186	4.7027	0.1229	38.2568	0.568
9912	482.1	37.4	0.3302	52.4093	10.2777	0.2573	39.9414	0.594
9913	739.5	37.6	0.5068	54.1859	16.2619	0.4052	40.1367	0.592
9914	1000.0	37.0	0.6857	55.3190	22.3949	0.5583	40.1123	0.590
9915	1000.0	54.5	0.6951	51.3509	21.3615	0.5634	37.9150	0.598
9916	739.5	55.1	0.5147	50.0109	15.4475	0.4174	37.0117	0.600
9917	482.1	54.7	0.3352	48.2581	9.7103	0.2687	36.1328	0.600
9918	242.8	52.3	0.1686	45.3640	4.4099	0.1322	33.3496	0.577
9919	141.3	53.0	0.0976	42.5919	2.2696	0.0679	33.4473	0.546
9920	141.3	48.1	0.0971	44.9094	2.3770	0.0717	33.1299	0.545
9921	242.8	46.8	0.1674	47.5349	4.5786	0.1250	36.6211	0.575
9922	482.1	46.5	0.3320	50.5226	10.0313	0.2609	38.4521	0.598
9923	739.5	47.3	0.5102	52.2042	15.9249	0.4113	38.7207	0.598
9924	1000.0	47.7	0.6913	53.4236	21.9258	0.5713	38.3789	0.594
9925	1000.0	42.0	0.6866	54.5418	22.2090	0.5497	40.4053	0.593
9926	739.5	42.7	0.5079	53.3324	16.1134	0.4000	40.2832	0.595
9927	482.1	42.3	0.3311	51.7924	10.2225	0.2624	38.9648	0.596
9928	242.8	41.3	0.1664	49.0579	4.6624	0.1242	37.5244	0.571
9929	141.3	40.6	0.0974	46.3759	2.4377	0.0688	35.4248	0.540
9930	141.3	26.5	0.0959	49.8234	2.5603	0.0668	38.3545	0.536
9931	242.8	26.2	0.1649	52.1184	4.8571	0.1230	39.5019	0.565
9932	482.1	26.0	0.3279	54.9675	10.5239	0.2537	41.4795	0.584
9933	739.5	25.9	0.5022	56.4787	16.6911	0.3982	41.9189	0.588
9934	1000.0	25.6	0.6782	57.6560	22.9278	0.5473	41.8945	0.586

Legend
IV# = Identification number assigned to the IV curve
E = Incident irradiance (W/m^2), varied by adjusting lamp output and use of filter screens
Tpv = PV module temperature (°C), varied by use of heating pad below module and measured with a temperature probe on the top surface.
Isc = Short-circuit current (A)
Voc = Open-circuit voltage (V)
Pmax = Maximum power (W)
Imp = Current at maximum power (A)
Vmp = Voltage at maximum power (V)
FF = Fill factor

Note: These measurements were performed with available equipment. Recommended practice includes a wider temperature range (5-60°C) and the use of a temperature controlled chamber for adjusting PV module temperature.

CdS/CdTe PV Module, S/N 14407
December 8, 1998

IV#	E	Tpv	Isc	Voc	Pmax	Imp	Vmp	FF
11471	1000.0	23.3	0.9686	91.5552	52.5184	0.7909	66.4063	0.592
11472	747.4	23.4	0.7264	90.8870	40.1309	0.5977	67.1387	0.608
11473	496.5	23.7	0.4813	89.9448	27.3002	0.3977	68.6523	0.631
11474	249.9	23.8	0.2423	87.9398	13.9050	0.2076	66.9678	0.653
11475	148.4	23.6	0.1439	86.2618	8.0619	0.1199	67.2119	0.649
11476	148.4	35.5	0.1446	82.5736	7.7392	0.1189	65.1123	0.648
11477	249.9	35.0	0.2429	84.3797	13.3270	0.2069	64.4043	0.650
11478	496.5	35.1	0.4795	86.5153	26.5658	0.4044	65.6982	0.640
11479	747.4	35.8	0.7226	87.5973	39.1964	0.6068	64.5996	0.619
11480	1000.0	35.2	0.9688	88.2025	51.3851	0.8092	63.5010	0.601
11481	1000.0	61.1	0.9698	83.1205	50.0703	0.8155	61.4014	0.621
11482	747.4	61.1	0.7260	81.7626	37.6485	0.6168	61.0352	0.634
11483	496.5	62.4	0.4826	80.1260	24.9606	0.3934	63.4521	0.645
11484	249.9	61.1	0.2420	77.2113	12.2373	0.2064	59.3018	0.655
11485	148.4	61.4	0.1441	74.9475	6.9664	0.1155	60.3271	0.645
11486	148.4	54.0	0.1437	76.6924	7.1937	0.1185	60.7178	0.653
11487	249.9	55.0	0.2423	79.3133	12.5629	0.1998	62.8662	0.654
11488	496.5	53.0	0.4818	82.3153	25.6849	0.4113	62.4512	0.648
11489	747.4	52.7	0.7253	83.9339	38.2944	0.6185	61.9141	0.629
11490	1000.0	52.2	0.9694	85.0685	50.5206	0.8271	61.0840	0.613
11496	148.4	31.8	0.1426	83.9270	7.8927	0.1207	65.3809	0.659
11497	249.9	31.4	0.2407	85.9031	13.5269	0.1949	69.4092	0.654
11498	496.5	31.0	0.4793	88.2800	27.0227	0.4003	67.5049	0.639
11499	747.4	31.1	0.7194	89.4876	40.0478	0.5911	67.7490	0.622
11500	1000.0	30.3	0.9662	90.3290	52.6973	0.8121	64.8926	0.604

Legend

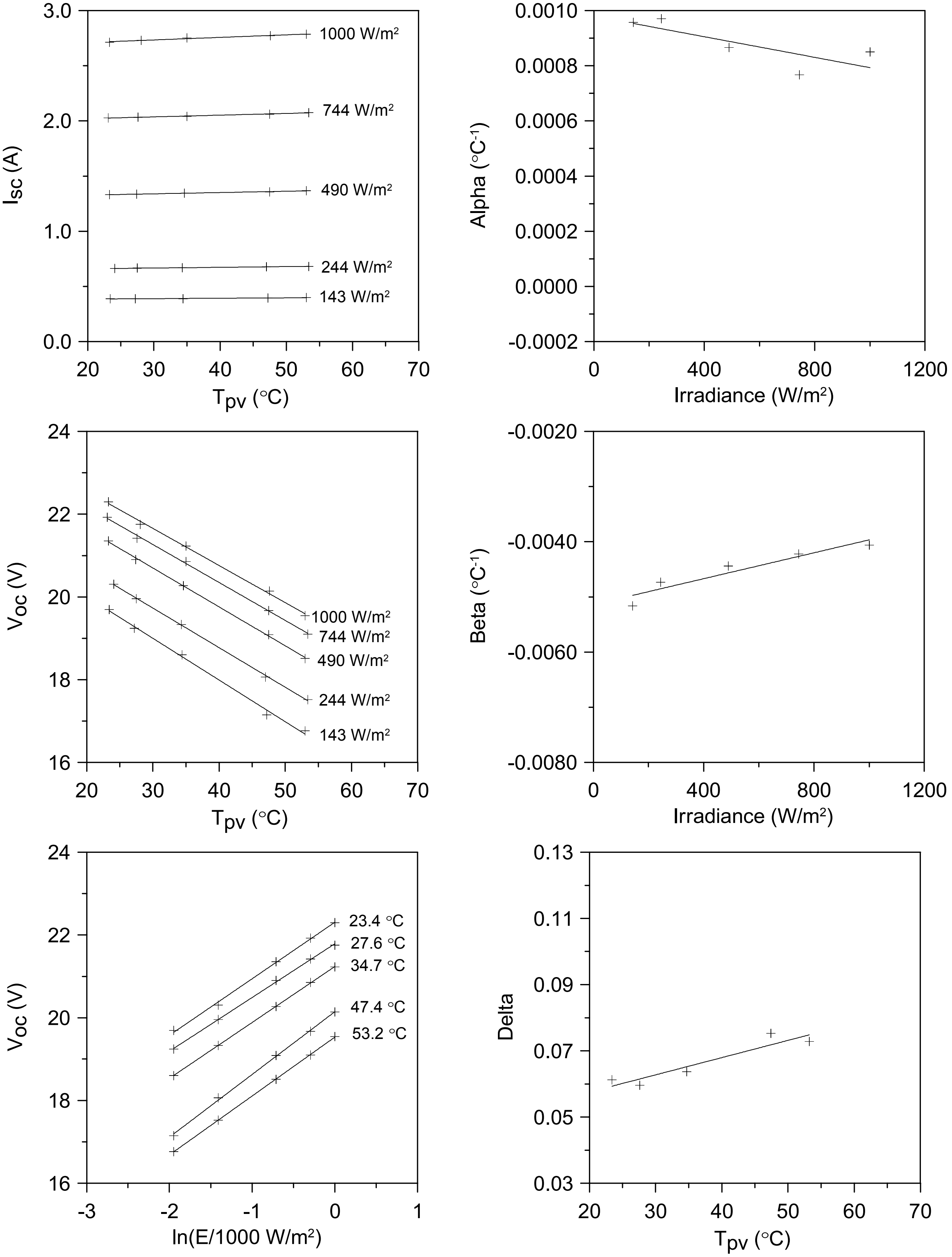
IV# = Identification number assigned to the IV curve
E = Incident irradiance (W/m^2), varied by adjusting lamp output and use of filter screens
Tpv = PV module temperature (°C), varied by use of heating pad below module and measured with a temperature probe on the top surface.
Isc = Short-circuit current (A)
Voc = Open-circuit voltage (V)
Pmax = Maximum power (W)
Imp = Current at maximum power (A)
Vmp = Voltage at maximum power (V)
FF = Fill factor

Note: These measurements were performed with available equipment. Recommended practice includes a wider temperature range (5-60°C) and the use of a temperature controlled chamber for adjusting PV module temperature.

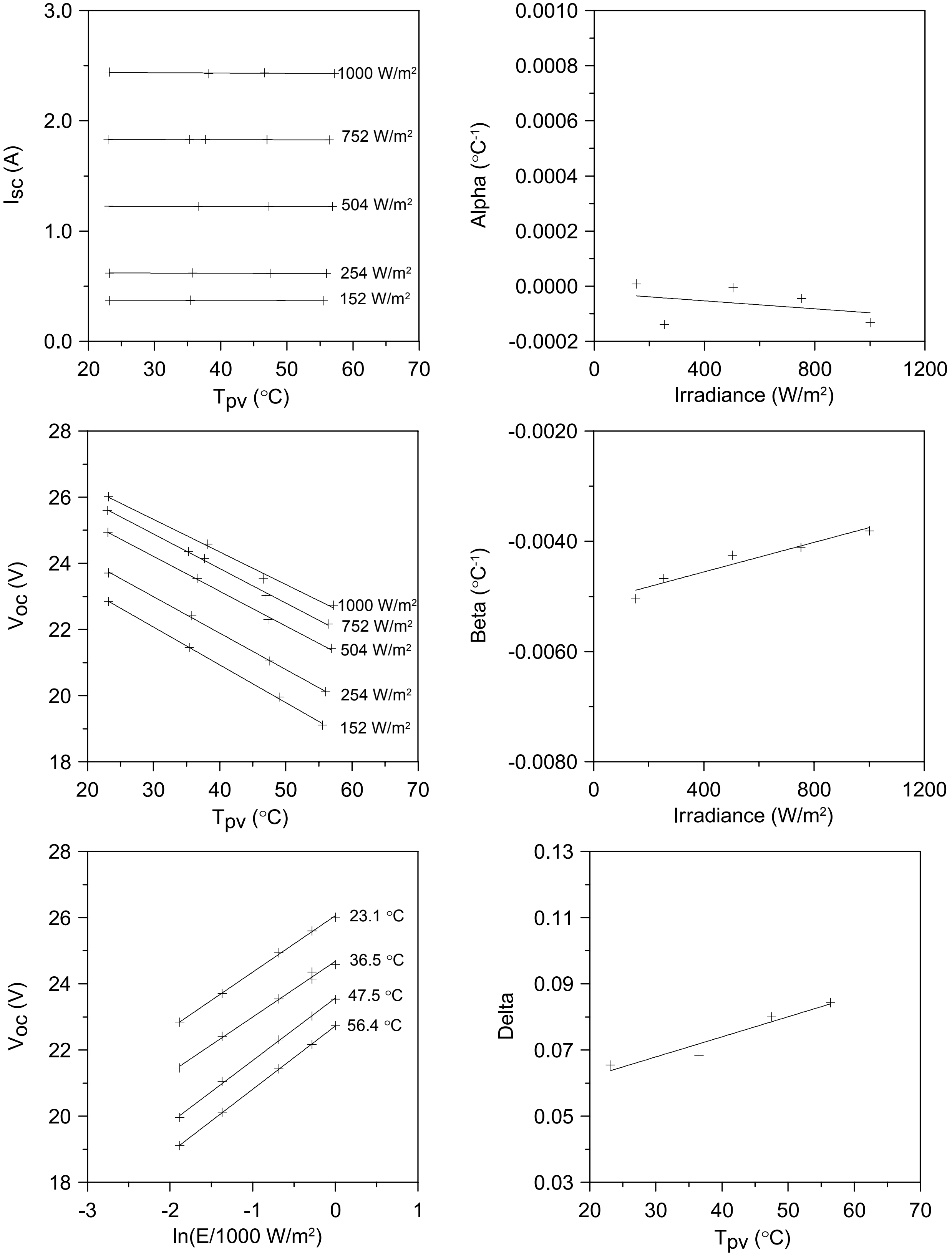
Appendix C

Graphs of I-V Curve Matrix Data and Temperature and Irradiance Correction Functions

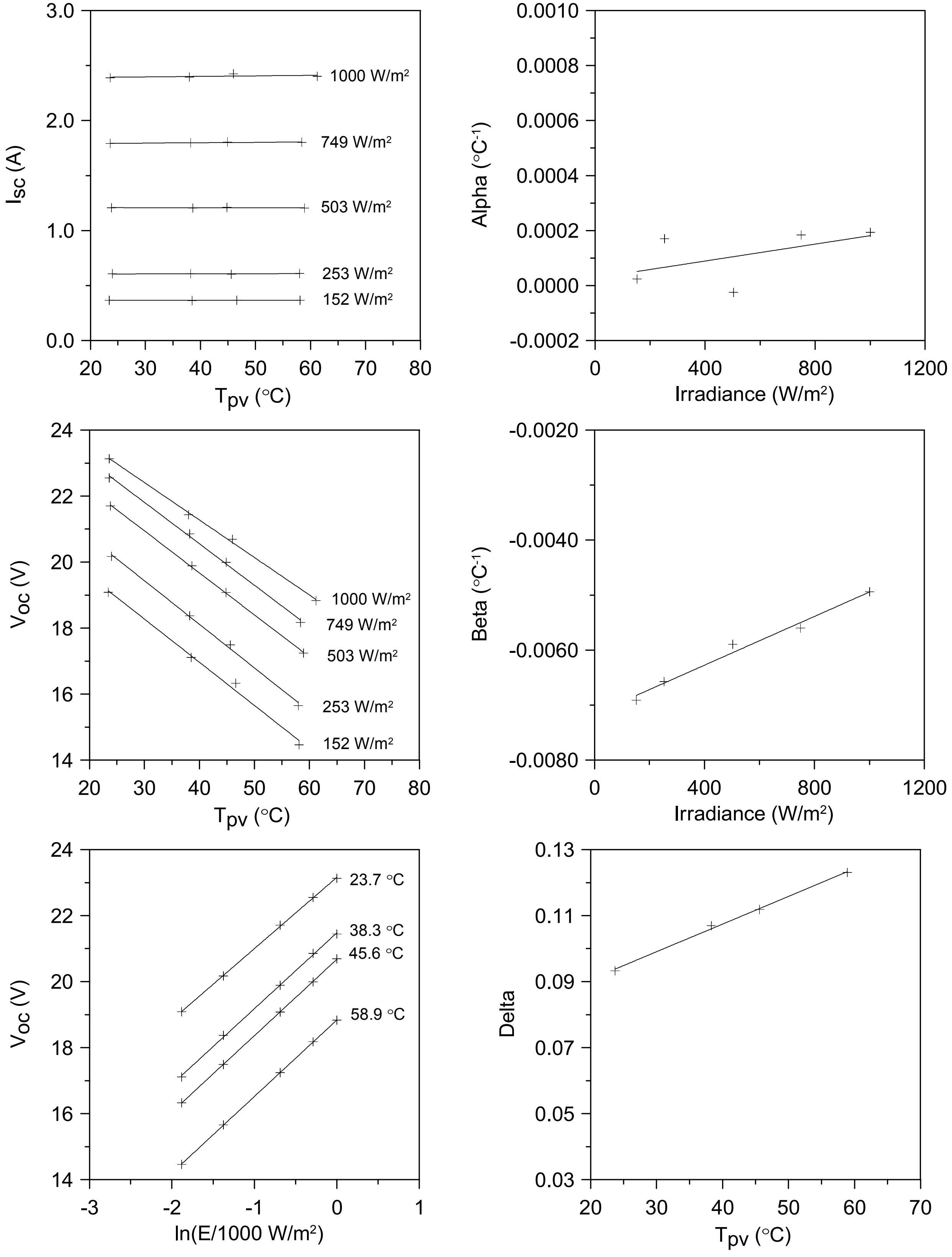
a-Si/a-Si/a-Si:Ge PV Module, S/N 1736



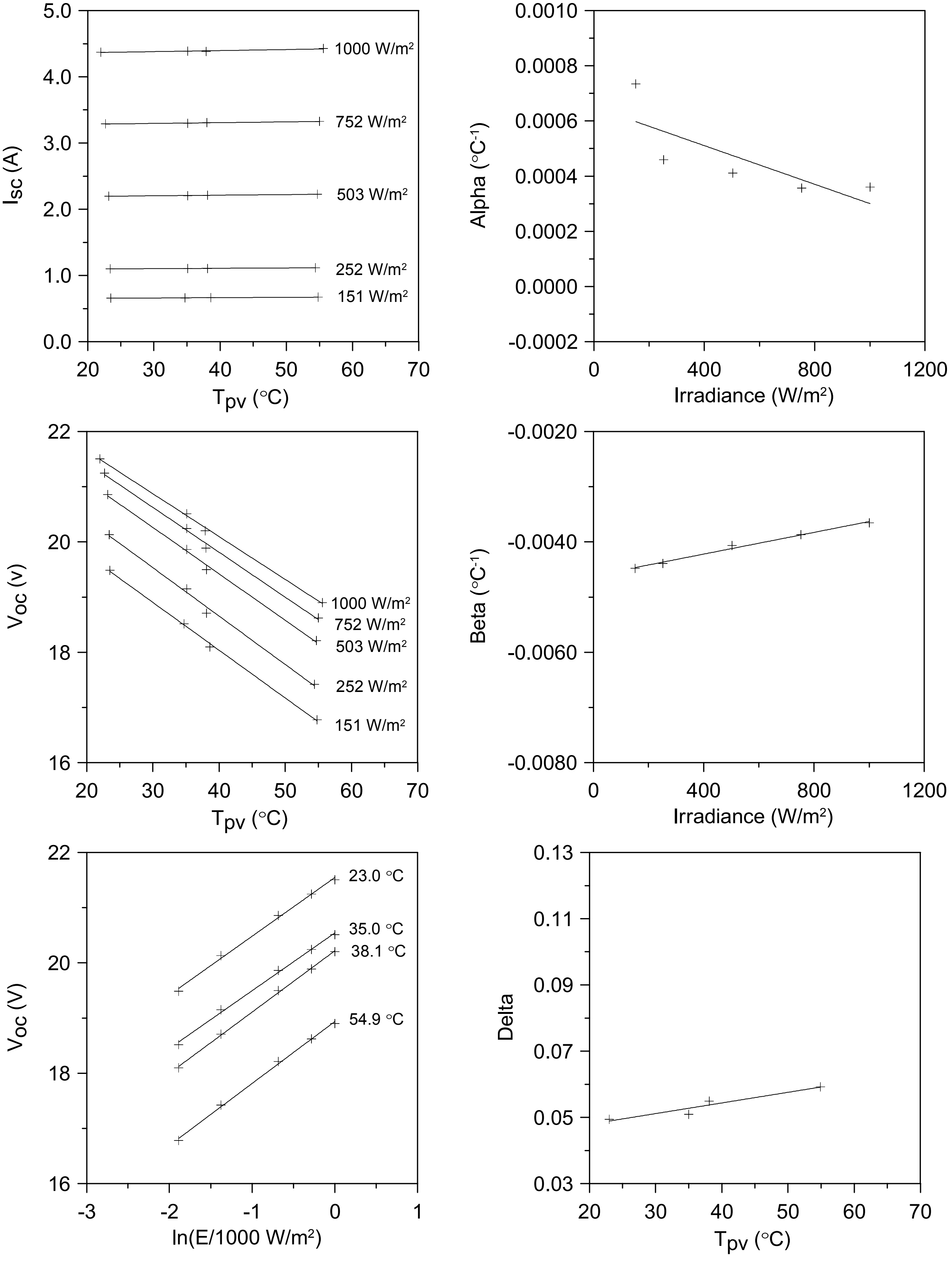
CdS/CuInGaSSe PV Module, S/N 5165



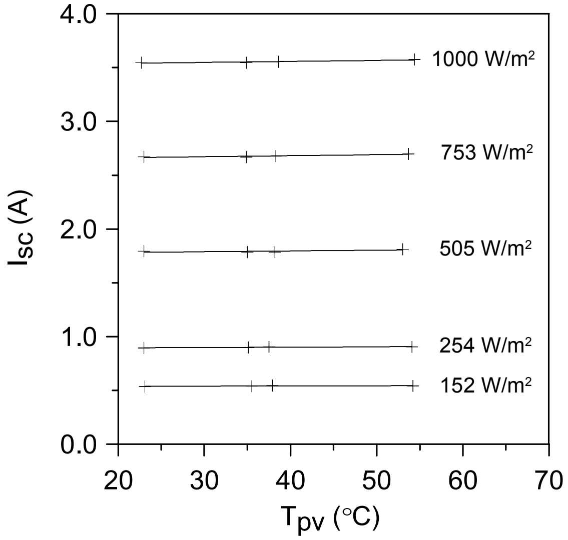
CIS PV Module, S/N 114

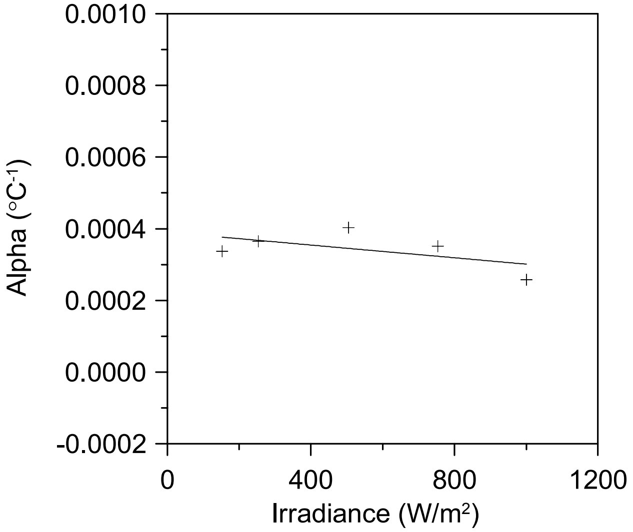


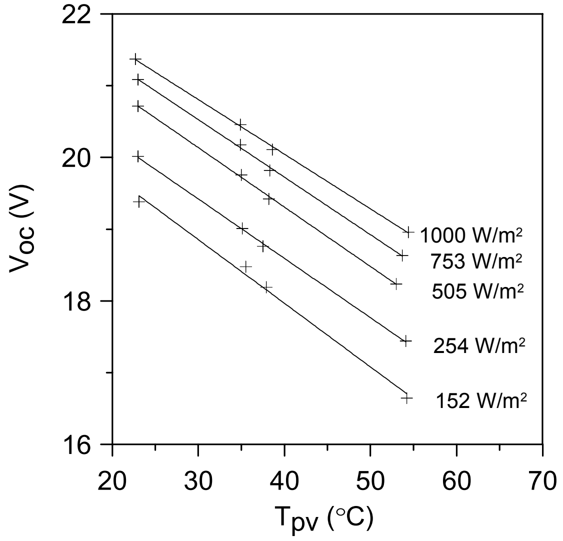
Mono-Crystalline Si PV Module, S/N 0442

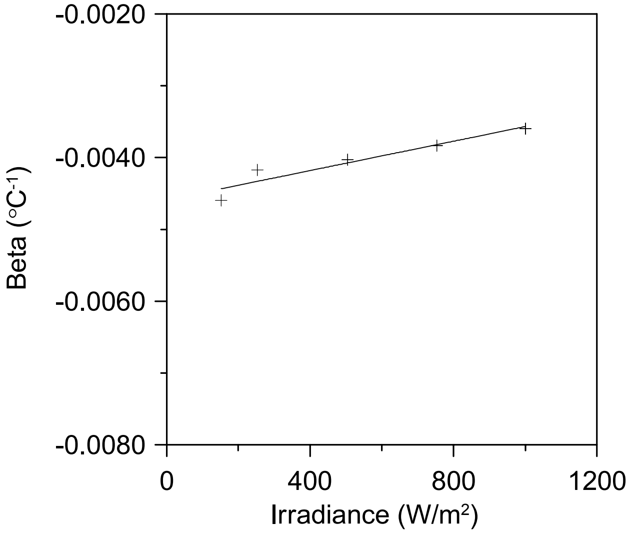


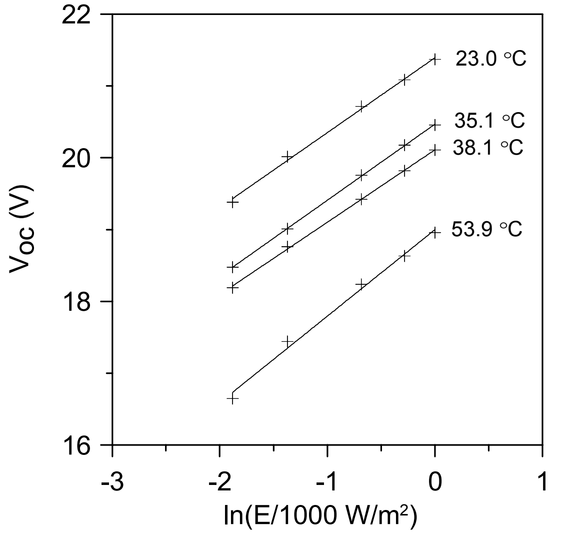
Multi-Crystalline Si PV Module, S/N 581836

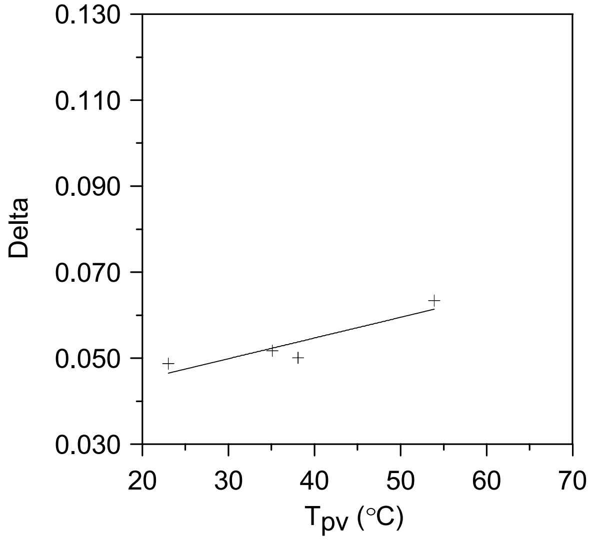




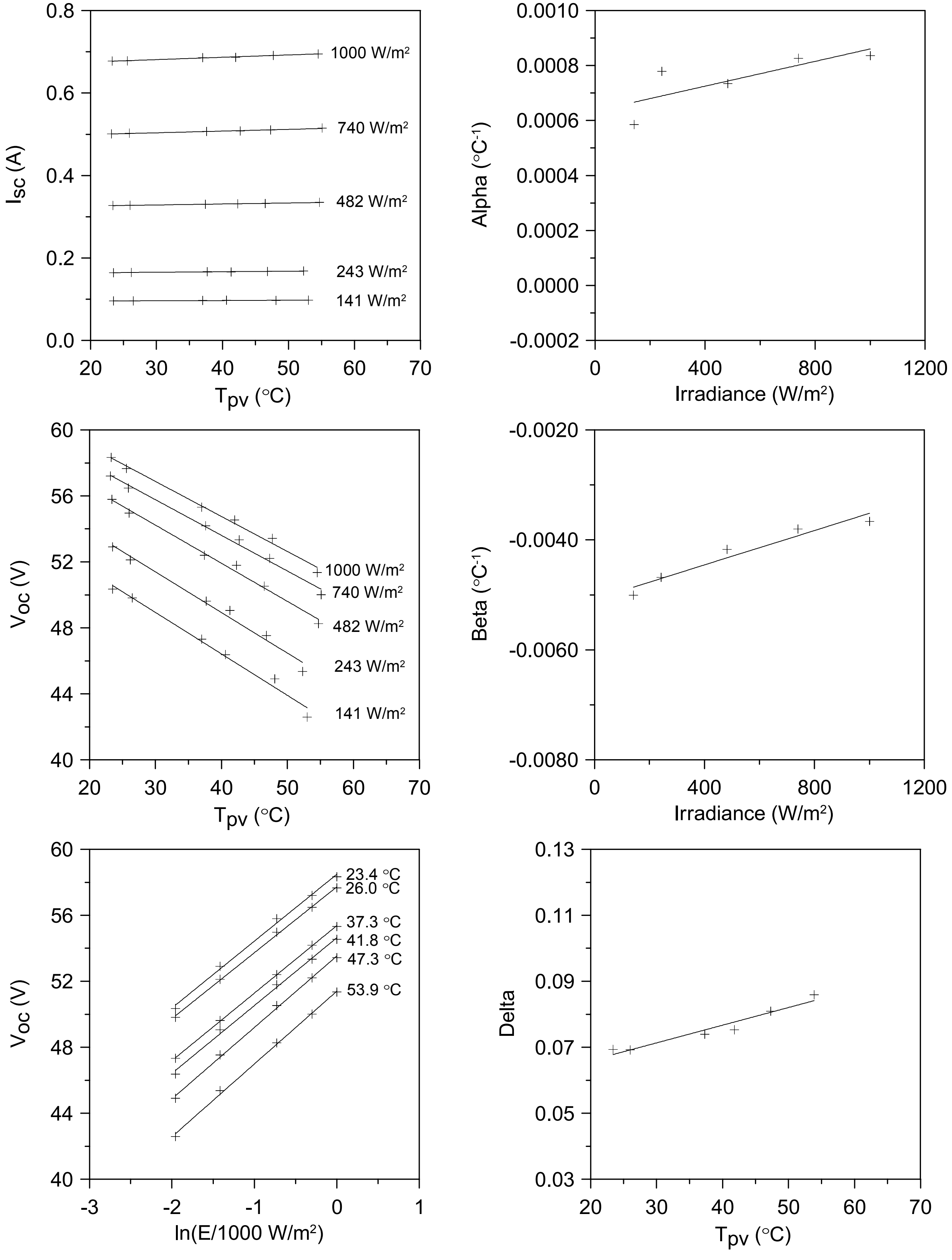




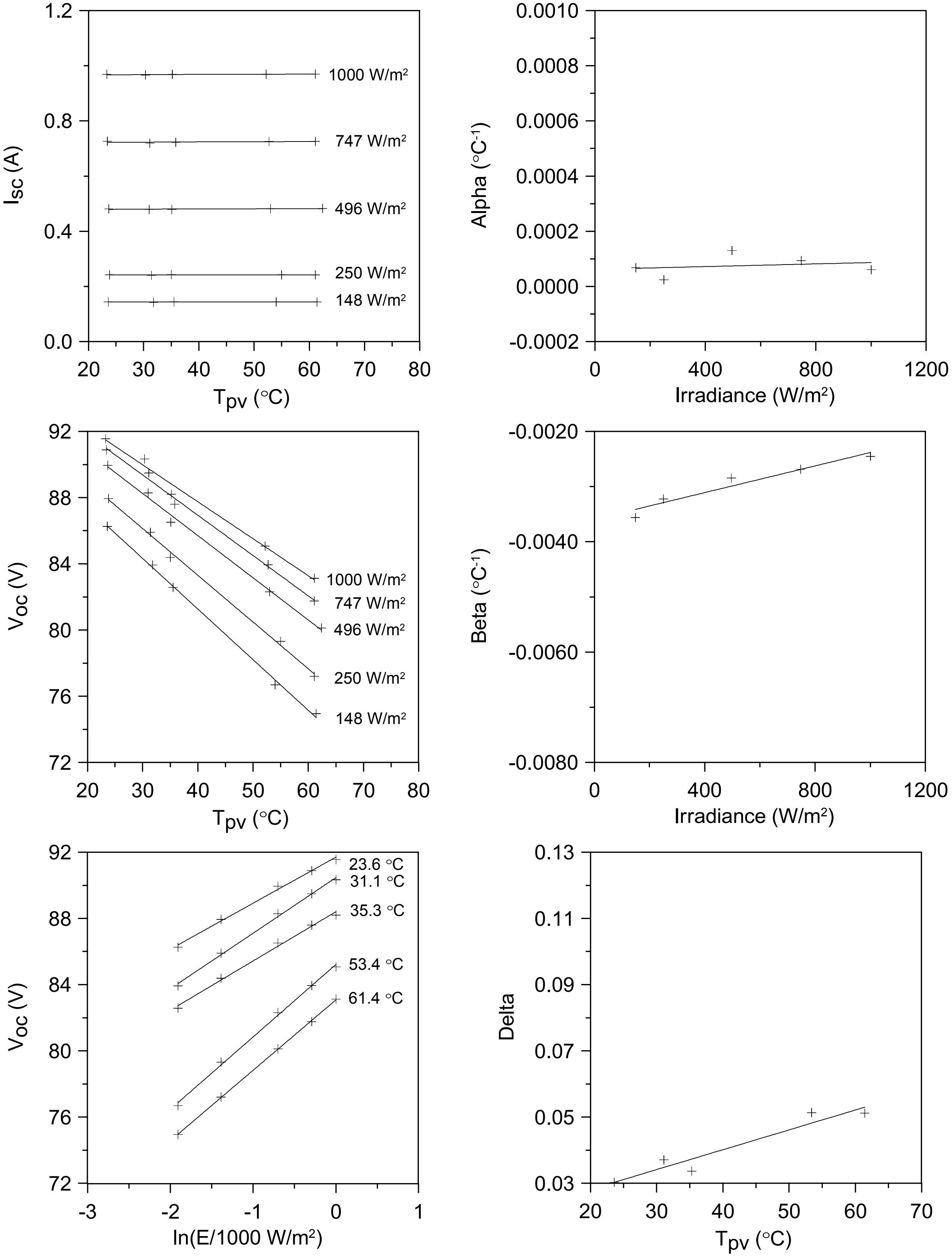




a-Si/a-Si:Ge PV Module, S/N SYS49



CdS/CdTe PV Module, S/N 14407



Appendix D

RMSEs and MBEs Between Measured and Modeled Incident Irradiance, Modeled PV Module Temperature, and Maximum Power by Month

Table D.1 Monthly RMSEs and MBEs for Modeled Values of Incident Irradiance, PV Module Temperature, and Maximum Power for a-Si/a-Si/a-Si:Ge PV Module, S/N 1736

Month	Test Hours	Average Incident Irradiance (W/m^2)	Incident Irradiance		PV Module Temperature		Maximum Power	
			RMSE (%)	MBE (%)	RMSE (°C)	MBE (°C)	RMSE (%)	MBE (%)
1	251	456	6.3	1.4	2.0	-0.6	11.8	5.7
2	251	438	5.6	-1.3	2.6	-1.7	13.5	7.5
3	93	564	3.2	-1.1	1.4	-0.5	10.5	6.9
4	158	555	3.5	-1.4	1.7	-0.6	9.0	5.8
5	392	450	4.9	-0.8	1.8	-0.9	10.3	5.7
6	331	397	4.1	-0.2	2.1	-0.9	10.0	5.4
7	425	389	4.6	-1.4	1.9	-0.6	7.0	1.9
8	376	425	3.5	-0.5	2.1	-0.5	8.3	3.1
9	334	521	3.0	-0.4	1.5	-0.5	7.6	3.9
10	341	424	4.1	-0.9	1.8	-1.0	9.8	4.6
11	187	431	5.1	1.0	1.8	-0.8	9.4	4.2
12	223	469	4.6	1.0	1.5	-0.2	9.8	4.3

Table D.2 Monthly RMSEs and MBEs for Modeled Values of Incident Irradiance, PV Module Temperature, and Maximum Power for CdS/CuInGaSSe PV Module, S/N 5165

Month	Test Hours	Average Incident Irradiance (W/m^2)	Incident Irradiance		PV Module Temperature		Maximum Power	
			RMSE (%)	MBE (%)	RMSE (°C)	MBE (°C)	RMSE (%)	MBE (%)
1	250	458	6.3	1.4	3.3	-1.6	5.9	-1.9
2	251	438	5.6	-1.3	4.2	-2.9	6.9	-2.8
3	93	564	3.2	-1.1	2.7	-1.2	3.9	-1.9
4	158	555	3.5	-1.4	2.9	-1.6	4.5	-2.1
5	392	450	4.9	-0.8	3.2	-1.7	5.1	-0.6
6	328	401	4.1	-0.2	3.1	-1.7	4.5	0.4
7	423	391	4.6	-1.4	3.0	-1.5	4.8	-0.6
8	373	428	3.5	-0.4	3.5	-1.7	5.5	0.2
9	333	523	3.0	-0.4	3.2	-1.9	3.2	-0.5
10	339	427	4.1	-0.9	3.4	-2.4	4.2	-0.6
11	187	431	5.1	1.0	3.5	-2.2	4.8	0.5
12	223	469	4.6	1.0	3.2	-1.5	4.3	0.2

Table D.3 Monthly RMSEs and MBEs for Modeled Values of Incident Irradiance, PV Module Temperature, and Maximum Power for CIS PV Module, S/N 114

Month	Test Hours	Average Incident Irradiance (W/m^2)	Incident Irradiance		PV Module Temperature		Maximum Power	
			RMSE (%)	MBE (%)	RMSE (°C)	MBE (°C)	RMSE (%)	MBE (%)
1	254	471	5.8	0.5	3.9	-2.7	6.6	1.3
2	250	448	5.4	-2.1	4.6	-3.6	6.5	-0.3
3	106	562	3.5	-1.4	3.4	-2.3	4.7	1.6
4	242	501	4.4	-1.0	3.7	-2.8	5.9	2.1
5	411	448	5.0	-0.9	4.0	-3.0	6.1	2.4
6	393	424	3.8	-0.5	3.8	-2.7	5.7	2.9
7	405	393	4.7	-1.6	3.6	-2.5	7.1	3.1
8	416	426	3.5	-0.6	3.2	-2.2	7.0	3.6
9	352	542	3.1	-0.6	3.1	-2.0	5.6	3.2
10	337	432	4.2	-1.1	3.3	-0.7	6.4	1.9
11	237	450	4.9	0.2	4.1	2.0	7.0	2.1
12	220	465	4.5	0.5	4.9	0.4	6.3	2.0

Table D.4 Monthly RMSEs and MBEs for Modeled Values of Incident Irradiance, PV Module Temperature, and Maximum Power for Mono-Crystal Si PV Module, S/N 0442

Month	Test Hours	Average Incident Irradiance (W/m^2)	Incident Irradiance		PV Module Temperature		Maximum Power	
			RMSE (%)	MBE (%)	RMSE (°C)	MBE (°C)	RMSE (%)	MBE (%)
1	256	467	5.8	0.5	3.6	-2.3	5.7	0.7
2	254	441	5.4	-2.1	4.5	-3.4	6.2	-1.0
3	107	556	3.5	-1.4	3.0	-1.9	3.4	-0.6
4	249	487	4.4	-1.0	3.4	-2.4	6.7	0.1
5	416	443	5.0	-0.9	3.6	-2.4	5.1	-0.5
6	408	408	3.9	-0.5	3.4	-2.1	4.7	-0.5
7	417	382	4.8	-1.6	3.2	-1.9	5.4	-1.1
8	428	414	3.6	-0.6	3.3	-1.9	4.8	-0.8
9	368	519	3.1	-0.6	3.4	-2.0	3.8	-0.6
10	342	425	4.3	-1.1	3.6	-2.6	4.6	0.0
11	240	445	5.0	0.2	3.3	-2.2	5.5	1.0
12	221	463	4.5	0.5	3.2	-1.8	5.6	1.4

Table D.5 Monthly RMSEs and MBEs for Modeled Values of Incident Irradiance, PV Module Temperature, and Maximum Power for Multi-Crystal Si PV Module, S/N 581836

Month	Test Hours	Average Incident Irradiance (W/m^2)	Incident Irradiance		PV Module Temperature		Maximum Power	
			RMSE (%)	MBE (%)	RMSE (°C)	MBE (°C)	RMSE (%)	MBE (%)
1	255	469	5.8	0.5	3.3	-2.0	5.9	-0.3
2	253	443	5.4	-2.1	4.1	-3.0	6.1	-1.3
3	106	562	3.5	-1.4	2.7	-1.8	4.1	-0.0
4	248	489	4.4	-1.0	3.2	-2.3	7.3	0.6
5	414	445	5.0	-0.9	3.6	-2.6	5.2	0.6
6	407	409	3.8	-0.5	3.4	-2.2	4.7	0.6
7	416	383	4.8	-1.6	3.2	-2.2	5.2	-0.7
8	428	414	3.6	-0.6	3.0	-2.0	4.8	-0.3
9	365	523	3.1	-0.6	2.9	-1.8	3.9	-0.2
10	341	427	4.3	-1.1	3.3	-2.4	4.6	-0.1
11	239	447	5.0	0.2	3.0	-2.1	5.1	-0.2
12	221	463	4.5	0.5	3.0	-1.7	5.2	0.2

Table D.6 Monthly RMSEs and MBEs for Modeled Values of Incident Irradiance, PV Module Temperature, and Maximum Power for a-Si/a-Si:Ge PV Module, S/N SYS49

Month	Test Hours	Average Incident Irradiance (W/m^2)	Incident Irradiance		PV Module Temperature		Maximum Power	
			RMSE (%)	MBE (%)	RMSE (°C)	MBE (°C)	RMSE (%)	MBE (%)
1	242	494	5.7	0.4	3.3	-1.4	7.6	-1.0
2	234	477	5.2	-2.0	4.0	-2.6	5.7	0.1
3	105	567	3.5	-1.4	2.6	-0.9	3.8	0.2
4	146	585	3.8	-1.5	2.5	-0.5	5.4	0.7
5	392	469	4.9	-0.9	2.8	-0.9	5.6	1.7
6	373	445	3.7	-0.5	2.8	-0.9	4.7	1.4
7	383	415	4.6	-1.6	2.6	-0.7	5.4	-1.7
8	373	473	3.3	-0.5	2.5	-0.8	4.1	-1.4
9	346	551	3.0	-0.6	2.3	-0.5	4.4	-2.4
10	313	463	4.1	-1.0	2.5	-1.1	5.8	-2.9
11	222	480	4.8	0.2	2.6	-0.9	7.2	-4.1
12	207	494	4.4	0.5	2.7	-0.5	6.9	-3.3

Table D.7 Monthly RMSEs and MBEs for Modeled Values of Incident Irradiance, PV Module Temperature, and Maximum Power for CdS/CdTe PV Module, S/N 14407

Month	Test Hours	Average Incident Irradiance (W/m^2)	Incident Irradiance		PV Module Temperature		Maximum Power	
			RMSE (%)	MBE (%)	RMSE (°C)	MBE (°C)	RMSE (%)	MBE (%)
1	245	488	5.7	0.4	6.8	-5.2	6.1	-0.7
2	33	394	6.7	-2.7	8.2	-6.8	7.6	-0.2
3	57	595	3.2	-1.6	3.2	-1.9	3.6	0.4
4	219	529	4.3	-1.0	3.9	-2.9	5.5	1.7
5	318	458	5.0	-0.9	4.0	-2.7	6.4	3.5
6	263	375	4.2	-0.9	4.0	-2.5	7.7	5.6
7	308	376	5.1	-1.9	3.7	-2.2	6.9	4.1
8	364	455	3.4	-0.6	3.7	-2.4	5.2	3.2
9	350	545	3.0	-0.6	3.8	-2.2	4.0	1.6
10	331	439	4.2	-1.1	4.1	-2.9	4.7	1.5
11	230	464	4.9	0.2	4.1	-2.7	5.3	0.4
12	149	478	4.9	0.5	3.8	-2.3	5.9	-0.5

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13. ABSTRACT *(Maximum 200 words)*

The procedure determines the energy production of a PV module for five reference days. The reference days represent possible operating environments and are qualitatively described as *Hot Sunny*, *Cold Sunny*, *Hot Cloudy*, *Cold Cloudy*, and *Nice*. Based on statistical weather criteria, these days were selected from the National Solar Radiation Database (NSRDB). Besides the hourly solar radiation and meteorological data from the NSRDB, the reference days include air mass, angle of incidence, plane of array, and spectral irradiance for a south-facing PV module at latitude tilt, battery-charging voltage, and parameters f_1 and f_2 for determining PV module temperature. Indoor I-V curve measurements over a range of temperatures and irradiances characterize the electrical performance of a PV module and are used to determine factors to correct for non-linear performance when irradiance and temperature vary. They also serve as a matrix of reference I-V curves for translating to reference-day conditions. The sensitivity of a PV module to variations in the spectral distribution of the incident radiation is accounted for by using an incident irradiance. Differences in PV module thermal characteristics are accounted for by using a PV module's installed nominal operating cell temperature (INOCT) for input to the Fuentes temperature model. The procedure does not consider radiation and transmittance losses at large incident angles. These losses were judged too small, and not sufficiently different, for various PV modules to justify the complexity of their measurement and inclusion in the procedure. PV performance measurements from NREL's Outdoor Test Facility during calendar-year 1998 were used to validate the procedure by comparing modeled and measured maximum power values for seven flat-plate PV modules representing different technologies. On an annual basis, modeled values compared within 5% of measured values. Taking into account reproducibility errors from ratings being performed by different facilities and the modeling errors, the following statement applies to the ability of this procedure to show relative differences in the energy production of two PV modules: "Because of errors in measurements and energy rating methodology, differences of 8% or less in the energy ratings of two PV modules are not significant. If one of the PV modules is amorphous silicon, differences of 13% or less in the energy ratings of two PV modules are not significant." This work was performed to develop and validate a PV module energy rating procedure for incorporation into IEEE PAR1479, "Recommended Practice for the Evaluation of Photovoltaic Module Energy Production."

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