Presented at the 23rd European PV Solar Energy Conference and Exhibition, Valencia, Spain, Sept. 1-5 2008

A COMPARISON OF ENERGY RATING METHODOLOGIES USING FIELD TEST MEASUREMENTS

Y. Poissant* , S. Pelland and D. Turcotte
CANMET Energy Technology Center – Varennes, Natural Resources Canada
1615 Lionel-Boulet Blvd., Varennes, QC, J3X 1S6, Canada
*Phone : +1 (450) 652-2471 Fax : +1 (450) 652-5177 email : y.poissant@nrcan.gc.ca

ABSTRACT: The aim of this work is to compare two types of energy rating methodologies in terms of their accuracy and their usefulness for guiding module selection for a given location. The IEC 61853 methodology currently under development was compared to the simpler ESTI-ER methodology proposed by the European Union Joint Research Center (JRC). Four PV module technologies (triple junction a-Si, laser grooved c-Si, back contact c-Si and heterojunction Si) were characterized in the field to obtain the input parameters required by the two energy rating methodologies. Local weather conditions (direct, diffuse, global and in-plane irradiances and PV module and ambient temperatures) were monitored over a year at a test location near Montréal, Canada. These were combined to PV module inputs to calculate their energy output over different days and over extended time periods, using both methodologies. The two methodologies were found to have comparable accuracies both for daily and for extended periods. While the median absolute errors for the more complex IEC 61853 method were generally lower (2% for extended periods, as opposed to 2.8% for the JRC method), it is not clear whether the gain in accuracy would justify the added cost in complexity of measurements and calculations involved. Both methods were useful in predicting specific yield rankings for the four modules under study. However, differences between the modules were often of the same order as the predictive error of the methods.
Keywords: Energy rating, energy performance, PV module

1 INTRODUCTION

Many energy rating methodologies have been developed to calculate the energy output of photovoltaic (PV) modules under different climatic conditions and provide a realistic estimate of how a module will perform at various locations. These energy rating methodologies combine three basic elements: PV module characteristics from performance testing, standardized weather data sets and a PV energy yield prediction model. Some methodologies use a complex modeling approach that takes into account all known effects that impact the performance of PV modules while others make simplifying assumptions about secondary effects such as angle of incidence and spectral irradiance to preserve the simplicity and applicability of the energy rating methodology.

The primary aim of this work is to compare both types of methodologies in terms of the accuracy of their energy predictions by comparing these to measured data. To this end, the IEC 61853 standard on PV module energy testing currently under development [1-3] was selected as representative of complex methodologies. Meanwhile, the ESTI-ER energy rating methodology proposed by the European Union Joint Research Center (JRC) was selected as the simpler approach, since it has already been compared to the IEC 61853 approach elsewhere [4-5], and since it has been found to yield accurate predictions over periods ranging from a few weeks to a full year [6].

Another objective of this work was to examine whether using reference days as the standardized weather data in energy ratings was useful from the point of view of selecting a module for a given location. The specific yield (kWh/kW) rankings of four modules as predicted for six reference days was thus compared to the rankings of their specific yields as measured in an outdoor field test over an extended period.

2 ENERGY RATING METHODOLOGIES

2.1 ESTI-ER/JRC

Kenny et al. have proposed an energy rating methodology where PV energy production is predicted from ambient temperature and from irradiance in the plane of the PV module [5]. It requires measuring a matrix or performance surface of maximum power point (P_m) or related parameters versus ambient temperature and global irradiance in the module plane. This performance surface is then fitted with a smooth, single-valued function with a “manageable number of fitted parameters” [5]. Here we consider the following function proposed in [7], which is a simplified version of the empirical equations of King et al. [8]:

$$P_m(G_i, T_m) = P_{m,STC}\frac{G_i}{G_o}\left(1+\alpha_i\,(T_m - T_o)\right)* \left[1 + c_1 \ln\left(\frac{G_i}{G_o}\right) + c_2\left(\ln\left(\frac{G_i}{G_o}\right)\right)^2 + \beta_v\left(T_m - T_o\right)\right] \quad (1)$$

where P_m is PV module power at the maximum power point (MPP), T_m is PV module temperature, G_i is the irradiance in the module plane, T_o and G_o are module temperature and irradiance at standard testing conditions (STC), $P_{m,,STC}$ is MPP power at STC, and the remaining parameters (α_i, β_v, c_1 and c_2) need to be determined through curve fitting.

Commonly available weather data (G_i and ambient temperature) forming a standard data set can then be combined with a thermal model of module temperature as a function of irradiance, ambient temperature (and possibly wind speed) to obtain module temperature. G_i and T_m then serve as inputs to the function in (1) to generate P_m for each element of the weather data. Finally, P_m values are summed over the selected time period to obtain the corresponding energy rating.

2.2 IEC 61853 draft standard

The IEC 61853 standard under development deals with both PV module energy rating and performance testing. Performance testing aims to fully characterize the dependence of PV output power on various parameters known to impact PV performance - namely irradiance, module temperature, the angle of incidence of light striking the module and its spectral distribution.

The main difference between the JRC approach and the draft IEC 61853 approach is the inclusion of spectral and angle of incidence effects by the latter, and the associated additional requirements both in terms of PV module characterization and in terms of weather data complexity. Essentially, for any given irradiance condition, the IEC 61853 approach calculates an effective, equivalent irradiance with normal (0°) incidence and AM1.5 spectrum, since these are the conditions under which the dependence of module performance on irradiance and module temperature is characterized.

For a given irradiance, the 0° incidence equivalent irradiance G_{mod} is simply the irradiance that enters the module corrected for cosine and reflection effects:

$$G_{\mathrm{mod}} = \tau(\theta) G_{dir} \cos(\theta) + \int \tau(\tilde{\theta}) G_{diff}(\tilde{\theta}) \cos(\tilde{\theta}) d\tilde{\theta} \qquad (2)$$

where $\tau(\theta)$ is the relative transmission of light into the module at angle of incidence θ, G_{dir} is the direct normal irradiance and $G_{diff}(\theta)$ is the angular distribution of total diffuse irradiance, which includes both sky diffuse and reflected irradiance [3].

Next, an effective irradiance with AM 1.5 spectral distribution is derived by requiring that it generate the same short-circuit current as G_{mod}. In other words:

$$G_{\mathrm{mod}\,AM\,15} = G_{\mathrm{mod}} \left(\frac{\int SR(\lambda) E(\lambda) d\lambda}{\int E(\lambda) d\lambda} \right) \left(\frac{\int E_{AM1.5}(\lambda) d\lambda}{\int SR(\lambda) E_{AM1.5}(\lambda) d\lambda)} \right) \quad (3)$$

where $SR(\lambda)$ is the module's spectral response at wavelength λ and at temperature T_o, $E(\lambda)$ is the relative solar spectrum of G_{mod} and $E_{AM1.5}$ is the relative solar spectrum for AM 1.5 [3].

Once $G_{modAM1.5}$ has been obtained, PV module temperature is calculated using a thermal model, as in the case of the JRC method. These thermal models were not evaluated here, since measured module temperatures were used whenever possible. From $G_{modAM1.5}$ and T_m, module output power can be obtained from the measured P_m (and Isc) versus G_i, T_m matrices. Here, the IEC 61853 method proposes a different approach than JRC based on linear and polynomial interpolations of these matrices [1]. Since this step is mainly a choice about how to treat the same input data, the JRC fit in equation (1) was used to derive P_m for the IEC 61853 case also; this made the comparison between the two approaches clearer, and in particular the impact of using $G_{modAM1.5}$ instead of simply using measured global irradiance in the module plane. Moreover, when approaches based on linear or spline interpolations (or regressions) were tested in the present case, the result was found to be sensitive to the interpolation method selected, and the energy yield estimates typically had larger errors than those of estimates derived using the JRC fit in (1).

2.3 The Modified IEC 61853 methodologies

Except in the case of the reference days proposed by the IEC 61853 draft standard, $G_{diff}(\theta)$ and $E(\lambda)$ were not available for the time periods considered, since these were not measured. A simplified version of the IEC 61853 methodology was therefore adopted for these periods. Since only the sky diffuse irradiance in a horizontal plane was measured, total diffuse irradiance in the plane of the module was obtained from:

$$G_{diff\,,\,i} = G_i - G_{dir} \cos(\theta) \qquad (4)$$

As a simplifying assumption, it was assumed that $G_{diff,\,i}$ arose from an isotropic distribution, in which case equation (2) becomes:

$$G_{\mathrm{mod}} = \tau(\theta) G_{dir} \cos(\theta) + G_{diff\,,\,i} \int \tau(\tilde{\theta}) \cos(\tilde{\theta}) d\tilde{\theta} \quad (5)$$

Since $\tau(\theta)$ was not measured directly, it was taken for each module from the Sandia database which gives $\tau(\theta)$ as a fourth order polynomial with module-specific coefficients [8-9].

Meanwhile, since no spectral data was available, equation (3) was replaced by an air-mass based spectral correction proposed by King et al. where the spectral correction is a fifth order polynomial in air mass with module specific coefficients available in the Sandia database [8-9]. Air mass was estimated from zenith angle and from the altitude of the PV module location according to the equations presented in [10].

3 OUTDOOR MEASUREMENTS AND PV MODULE CHARACTERIZATION

3.1 Outdoor measurements

Four PV modules issued from different technologies - laser grooved buried junction c-Si (c-Si 1), back contact c-Si (c-Si 2), triple junction a-Si (a-Si 3J), and heterojunction Si (HIT) were mounted on an open outdoor rack in Varennes, Canada (near Montreal). The modules were oriented with latitude tilt (45 degrees), facing South. They were connected to a multitracer which operated the modules at their maximum power point, and which read PV output power and back-of-module temperature every 5 seconds, recording 1 minute averaged values. IV curves were also traced for all modules at 5 minute intervals.

In addition, various weather inputs required by the JRC and IEC 61853 methodologies were also read every 5 seconds, with 1 minute averages recorded. Measurement with precision pyranometers and pyrheliometers included global irradiance in the module plane, direct normal/beam irradiance, sky diffuse irradiance in a horizontal plane and global horizontal irradiance. Ambient temperature and wind speed were also recorded.

3.2 PV module characterization: Constructing matrices of P_m vs G_i and T_m

Matrices of MPP power as a function of incident irradiance and module temperature were constructed for each module using the IV curve outdoor measurements. Maximum power points falling within ±1% of the selected irradiance and within ±1°C of the selected temperature were averaged. Special care was taken to use points that were free of the impact of large incidence angles and spectral shifts by eliminating outliers before averaging the points and by selecting hours close to solar noon whenever possible. Three points were selected at random for averaging for each matrix entry. The selected temperatures were 5, 15, 25, 35 and 45°C and irradiance levels 100, 200, 400, 600, 800, 1000 and 1100 W/m^2.

4 ENERGY RATING SIMULATION RESULTS

4.1 Standard days

Part 4 of the draft IEC 61853 standard describes standard time periods and contains the weather data that can be used to simulate the performance of a given module over these periods. The document defines six reference days with hourly datasets of ambient temperature, direct and diffuse irradiance, wind speed, angle of incidence and spectral distribution:

HIHT: High Irradiance, High Temperature
HILT: High Irradiance, Low Temperature
MIMT: Medium Irradiance, Medium Temperature
MIHT: Medium Irradiance, High Temperature
LILT: Low Irradiance, Low Temperature
NICE: Normal Irradiance, Cool Environment

These reference days were used as input to the ESTI-ER and to both the original and modified IEC 61853 energy rating methodologies to compare results in a case where input data was available for all three methods. Figure 1 compares the results obtained for the technologies under study for the NICE day and shows the rankings of each technology for that reference day. The specific yields obtained using all three methodologies are within 3% of each other for all technologies under study for this reference day. Over all reference days, the absolute value of the difference in specific yields between the original and modified IEC 61853 methodologies ranged from 0.2 to 3%, with a median difference of 1.0%. Meanwhile, the JRC method differed from the original IEC 61853 method by 0 to 4%, with a median of 1.8%. Table I lists the rankings obtained for all reference days using all three methodologies. Technologies with specific yields within 3% of each other were attributed the same ranking based on the median errors reported in 4.2 and 4.3

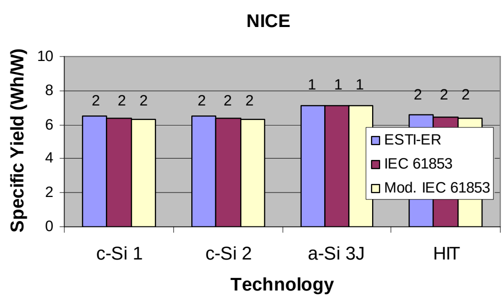

Figure 1: Specific yields of the technologies under study for the NICE reference day using the IEC 61853 and the ESTI-ER energy rating methodologies

Table I: PV module rankings for the reference days of interest as obtained from the two methodologies

Reference Day	Rankings from energy rating methodologies ESTI-ER, IEC 61853 & Simp. IEC 61853
HIHT	a-Si > HIT > c-Si 1 = c-Si 2
HILT	c-Si 1= c-Si 2 = HIT < a-Si
MIMT	a-Si > c-Si 1= HIT > c-Si 2
MIHT	a-Si > HIT = c-Si 1 > c-Si 2
LILT	c-Si 1 > c-Si 2 = HIT = a-Si
NICE	a-Si > HIT = c-Si 1 = c-Si 2

4.2 Measured days

Specific days observed in the field resembling the description of the six reference days proposed in the draft standard were used to compare the accuracy of the energy rating methodologies and to determine whether the rankings in the previous section for reference days carried over to measured days. Figure 2 compares the specific yields measured in the field for August 19th, 2007, a day similar to the NICE reference day, to those calculated using the energy rating methodologies and the weather data measured in the field for that day. The energy rating methodologies were both successful in predicting the ranking of the modules in the field, with the caveat that equal rankings were assigned for performance differences of 3% or less. Also, the ranking established for the NICE reference day (see 4.1) was the same as that obtained for Aug. 19, 2007 in the field.

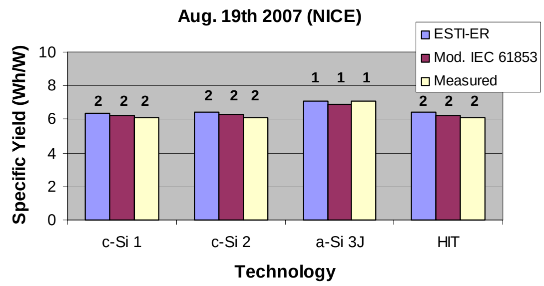

Figure 2: Specific yields of the technologies under study for August 19th, 2007 (a day similar to the NICE reference day) using the modified IEC 61853 and the ESTI-ER energy rating methodologies

Table II: Percent deviations of modeled specific yields from measured yields for selected days

Day	c-Si 1 (%)		c-Si 2 (%)		a-Si 3J (%)		HIT (%)	
	ESTI	IEC	ESTI	IEC	ESTI	IEC	ESTI	IEC
07/08/27 (HIHT)	2,0	-0,4	2,1	0,0	2,7	0,2	4,0	1,9
08/03/17 (HILT)	4,1	2,7	3,1	2,3	4,0	-0,6	4,7	4,0
08/04/11 (MIMT)	2,6	-0,4	2,3	-0,3	2,2	-3,3	2,2	-0,3
07/08/24 (MIHT)	3,8	1,2	4,4	2,1	6,1	2,2	3,6	1,4
07/12/21 (LILT)	4,7	3,4	4,4	5,2	-1,4	-19,7	9,6	10,8
07/08/19 (NICE)	4,9	1,9	5,5	2,8	0,0	-2,7	4,8	2,0

Table II lists the deviations of the calculated specific yields from the measured values in the field on selected days resembling the description of reference days. Overall, the median absolute deviations were 3.9% for the ESTI-ER methodology and 2.1% for the modified IEC 61853 methodology. Larger deviations were obtained when calculating the performance of the amorphous silicon triple junction module as well as for days where the irradiation was low.

4.3 Longer time periods

It would be difficult to apply the original IEC 61853 methodology to calculate the energy rating of PV modules over a long time period as it requires the input of parameters that are not commonly available. However, the modified IEC 61853 approach, detailed in section 2.3, makes it possible to carry out such calculations. To

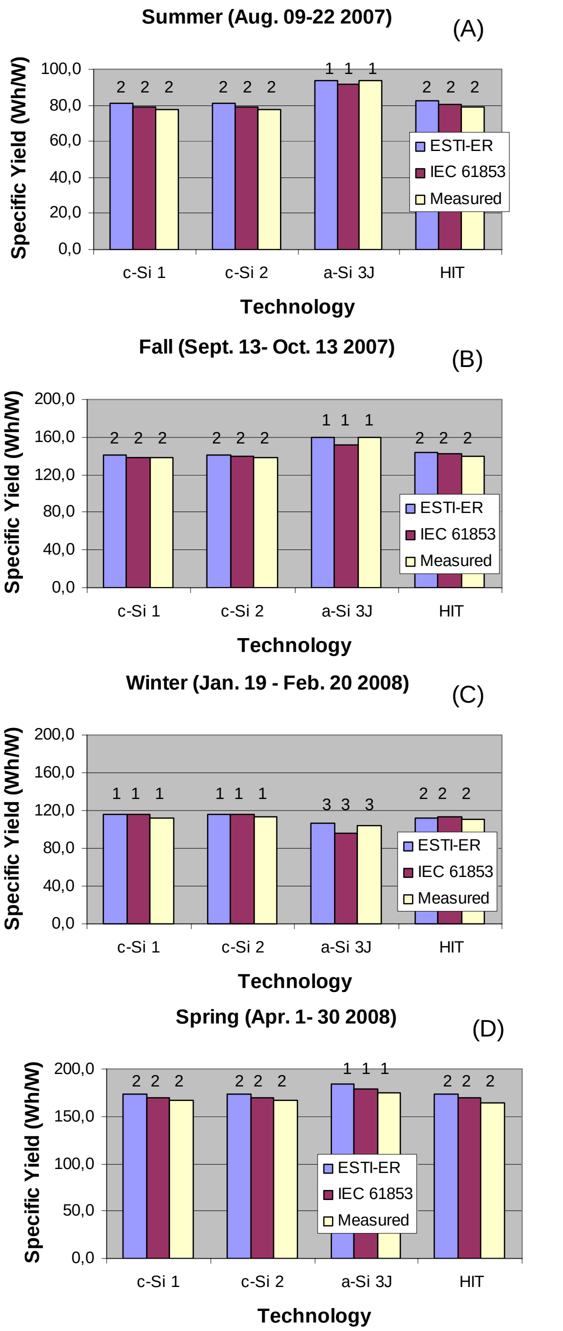

Figure 3: Specific yields measured and calculated for long time periods in (A) summer, (B) fall, (C) winter, (D) spring

this end, four time periods were selected: Aug. 9 – 22, 2007 (summer), Sept. 13 – Oct. 13, 2007 (fall), Jan. 19 – Feb 20, 2008 (winter) and Apr. 1 – 30, 2008 (spring). Figure 3 compares the specific yields measured in the field and calculated over these periods. The PV technologies under study were found to have similar performance and both the ESTI-ER and the modified IEC 61853 methodologies successfully predicted the technology rankings for the chosen time periods. Table III lists the difference between the yields measured in the field and those calculated. Overall, the median absolute deviations were 2.8% for the ESTI-ER methodology and 2.0% for the modified IEC 61853 methodology.

Table III: Percent deviations between modeled and measured specific yields for the chosen time periods

Period	c-Si 1 (%)		c-Si 2 (%)		a-Si 3J (%)		HIT (%)	
	ESTI	IEC	ESTI	IEC	ESTI	IEC	ESTI	IEC
Summer	3,9	1,2	4,0	1,5	-0,2	-2,5	4,2	1,6
Fall	1,7	0,3	1,9	1,1	0,1	-4,5	2,2	1,4
Winter	3,5	3,2	1,3	2,3	2,0	-8,4	1,5	2,9
Spring	3,3	1,0	3,7	1,6	5,4	2,5	5,8	3,6

5 DISCUSSION

5.1 Error analysis and accuracy of the methodologies

The previous analysis focused on the bias error of the energy yield predictions from the IEC 61853 and JRC methodologies, for periods ranging from a day to a month. In order to further assess the accuracy of the

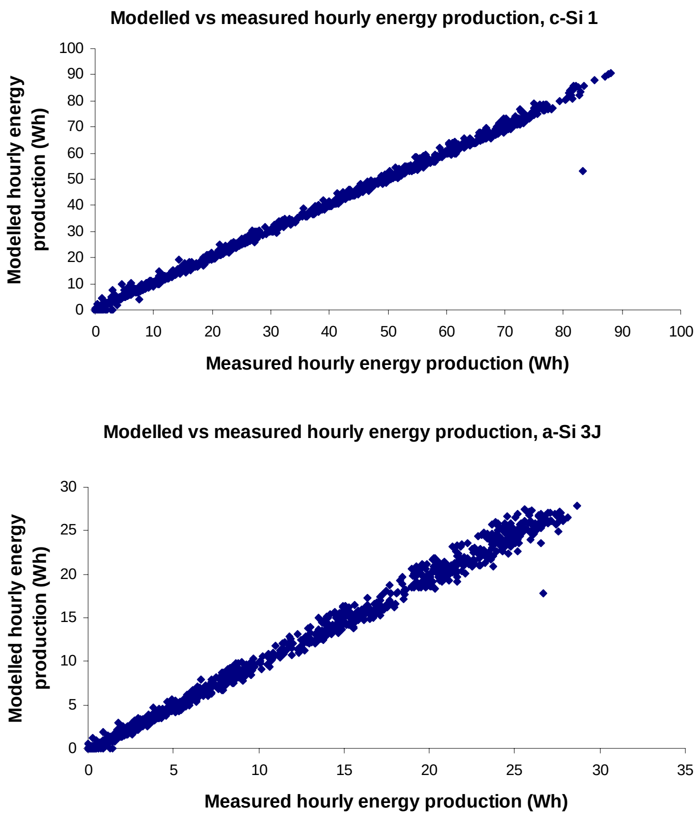

Figure 4: Modeled vs. measured hourly energy production for c-Si 1 and a-Si 3J with modified IEC 61853 method

methodologies, the root-mean-squared error (RMSE) was computed over the full period considered in 4.3. Figure 4 shows scatter plots of measured vs. modeled hourly energy production for the c-Si 1 and a-Si 3J modules. As in Section 4.3, the two methods yield very similar accuracies, with RMSEs of about 6-8% for the c-Si and HIT modules, and of 10-11% for the a-Si 3J module. RMSEs for the simplified IEC 61853 method are lower than those for the JRC method, but only by 1%. The RMSEs obtained for the c-SI and HIT modules are comparable to those of about 6-7% reported in [6] using the JRC and other methods excluding spectral and angle-of-incidence effects.

The reference day analysis in Section 4.1. indicated that whether spectral and angle of incidence effects are taken into account can lead to differences in daily energy ratings in the range of 0% to 4%. For longer periods, the original IEC 61853 method could not be applied, but a simplified version of it typically lead to a slight improvement over the JRC approach which does not take these effects into account (see Table II). A notable exception to this occurred for the a-SI 3J modules, where attempted spectral and angle of incidence corrections using the simplified version of the IEC 61853 approach actually proved counterproductive, leading to a decrease in accuracy. Along these lines, field test results such as those of King et al. [11] have indicated that spectral and angle-of-incidence corrections can have magnitudes of -5% to 0% and -3% to 1%, respectively over extended periods. Thus, properly accounting for such effects should lead to corresponding improvements in accuracy. On the other hand, as pointed out by Kenny et al. [5], it is not clear whether the benefits of including such effects in an energy rating methodology would outweigh the costs, even assuming that location specific, module-to-module variations in spectral response (and angle-of-incidence effects) could be adequately captured using synthetically generated “reference” spectra.

One issue to bear in mind when trying to determine the degree of accuracy that an energy rating methodology should aim for is that of module-to-module variability of energy production for modules of the same type (same manufacturer and model). For instance, Friesen et al. [6] found that energy prediction errors increased by roughly 10% when the characterization of one module was carried over to another module of the same type. This highlights the importance of limiting and/or quantifying such module-to-module variability. It also suggests a related limit to the usefulness of trying to make energy ratings arbitrarily accurate, if a similar accuracy cannot be expected for modules other than those used in the characterization process, but of the same type. A final remark is that the methodologies are based on measured (and interpolated) values of P_m. Thus the specific yields reported in this paper were calculated using the measured P_m of the PV modules and *not* the rated values given by the manufacturers. If such manufacturer values had been used (and unfortunately, this is the only information most consumers have access to), the specific yields and rankings established here would have been quite different as many modules were found to underperform their STC rating to a certain degree.

5.2 The case of the a-Si 3J module

The case of the a-Si 3J module deserves special attention, since its bias and RMS errors were notably greater than for the other modules, as exemplified by the greater dispersion of points for the a-Si 3J in Figure 4. In the case of this module, there were at least two significant and related complications. First, the STC power (and other points in the P_m vs. G_i, T_m matrix) experienced seasonal variations, with excursions from the yearly mean of the order of ±3% for STC power. (Note: The module was exposed outdoors for a prolonged period before measurement began and had thus reached a metastable state.) A related issue was the quality of the fit to the P_m vs. G_i, T_m matrix that was performed using equation (1). Deviations between matrix values and values based on the fit were calculated for each matrix point. Median absolute errors for the c-Si and HIT technologies were of the order of 1%, while the median absolute error for the a-Si 3J module was roughly 4%. Finally, while the impact of spectral irradiance on the a-Si 3J module could not be assessed directly, Figure 4 indicates that the a-Si 3J dispersion is greater than that of the other modules at all irradiance values, while a spectrally dominated influence would primarily impact the low irradiance end of the scatter plot corresponding to hours at the beginning and end of the day where spectral influence is usually greatest.

5.3 Applicability in the field

The aim of the IEC 61853 part 3 PV module energy rating standard under development is to “define a rating methodology, which provides the PV module energy (watt-hours) and the performance ratio at maximum power operation for a set of defined ambient conditions” [3]. This energy rating system, and a simpler one where PV energy production is predicted from ambient temperature and from irradiance in the plane of the PV module, have been applied to a number of different PV module types operating under standard days (as defined in part 4 of the standard), real actual days measured in the field and longer time periods to verify how useful the rating system is when selecting a PV module type for a given location.

For real days resembling the description of the reference days in the standard, both the ESTI-ER and IEC 61853 methodologies predicted an energy rating that matched what was observed in the field. The rankings established based on reference days were the same as those observed for measured days in most cases. The rating systems were thus useful for the selection of appropriate PV modules in this context, although predicted differences between modules were often of the same order as median errors.

For cases where the user is interested in selecting a technology according to its seasonal or annual performance, relying on reference days could provide an educated guess at best. Figure 5 presents the 365 days of the typical meteorological year (TMY) of the test location as a function of maximum direct normal irradiance and maximum ambient temperatures. Based on this representation, it might be supposed that the NICE day would be the best predictor among reference days of long term specific yield differences between modules, since it

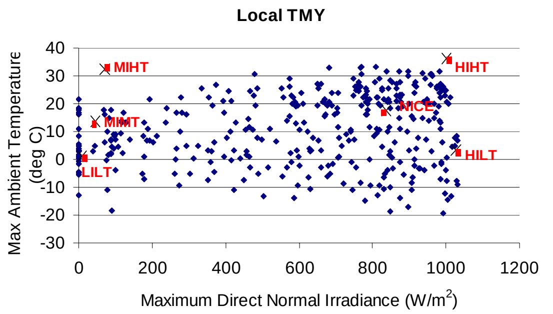

Figure 5: Local TMY displayed as a function of maximum ambient temperature and maximum direct normal irradiance

has the highest density of points around it and since its irradiance is greater than for the LILT, MIMT and MIHT days. One could thus use the NICE day to derive tentative performance rankings for the location under study. In this case, annual performance rankings would have been correct. However, this need not have been the case, and it would be very difficult to determine how to weigh different reference days in general. Instead, more accurate energy ratings would be obtained by using datasets representing these longer time periods.

6 CONCLUSIONS

The IEC 61853 and JRC/ESTI-ER energy rating methodologies currently under development were compared in terms of their accuracy and of their usefulness for guiding module selection for a given location. The two methodologies were found to have comparable accuracies when used to predict specific yields for measured days and for extended periods. While the median absolute errors for the more complex IEC 61853 method were generally lower (2.0% for extended periods, as opposed to 2.8% for the JRC method), it is not clear whether the gain in accuracy would justify the cost in complexity of measurements and calculations involved.

Both methods were useful in predicting specific yield rankings for the four modules under study. However, differences between the modules were often of the same order as the predictive error of the methods, in which case rankings were considered equal. Also, the usefulness of the ratings could be limited by the issue mentioned previously that there are currently significant module-to-module performance variations for modules of the same type (manufacturer and model).

The usefulness of reference days for predicting performance over measured days and longer time periods was also examined. The NICE reference day was judged to be the most representative of yearly average conditions at the test site. Rankings based on this day were indeed found to be the same as those measured in the field, although the procedure used may not work in other cases, and is difficult to systematize.

Finally, as indicated in 2.2, attempts to use linear or spline interpolations of the P_m vs. G_i, T_m matrices rather than the JRC fit indicated that results were sensitive to the interpolation method used. This may be an aspect of the IEC 61853 draft standard that would deserve closer study.

7 ACKNOWLEDGEMENTS

Financial support for this research project was provided by Natural Resources Canada through the Program on Energy Research and Development.

8 REFERENCES

[1] Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and Power Rating, 61853-1 Draft H (WG2 working draft)
[2] Photovoltaic (PV) module performance testing and energy rating – Part 2: Spectral response, incidence angle and module operating temperature measurements, 61853-2 Draft E (WG2 working draft)
[3] Photovoltaic (PV) module performance testing and energy rating – Part 3: Energy rating of PV modules, 61853-3 Draft C (WG2 working draft)
[4] S. Mau, S. Zamini, B. Bergmair, E. Ruppert, S. R. Williams, J. Roy, T. R. Betts, R. Gottschalg, H. Müllejans, Quantifying environmental effects for different device technologies based on proposed energy rating standard, Proceedings of the 22nd EPVSEC, Milano, Italy, September 2007.
[5] R. P. Kenny, E. D. Dunlop, H. A. Ossenbrink, H. Müllejans, A practical method for the energy rating of c-Si photovoltaic modules based on standard tests, Prog. Photovolt: Res. Appl. 2006; **14**: 155-166
[6] G. Friesen, R. Gottschalg, H. G. Beyer, A. Guerin de Montgareuil, N. van der Borg, W. G. J. H. M. van Sark, T. Huld, B. Müller, A. C. de Keizer, Y. Niu, Intercomparison of different energy prediction methods within the European project "PERFORMANCE" – Results of the 1st round robin, Proceedings of the the 22nd EPVSEC, Milano, Italy, September 2007.
[7] R. P. Kenny, G. Friesen, D. Chianese, A. Bernasconi, E. D. Dunlop, Energy rating of PV modules: comparison of methods and approach, Proceedings of the 3rd World Conference on PVEC, May 2003, Osaka, Japan.
[8] D. L. King, W. E. Boyson, J. A. Kratochvill, Photovoltaic array performance model, Sandia report SAND2004-3535, December 2004.
[9] Sandia National Laboratories, http://photovoltaics.sandia.gov/docs/Database.htm August 27, 2008.
[10] D. L. King, J. A. Kratochvil, W. E. Boyson, W. Bower, Field experience with a new performance characterization procedure for photovoltaic arrays, Proceedings of the 2nd World PVSEC, July 1998, Vienna, Austria.
[11] D. L. King, W. E. Boyson, J. A. Kartochvil, Analysis of factors influencing the annual energy production of photovoltaic systems, Conference Record of the IEEE PVSC, 2002, Pages 1356-1361.