Horse Palace Photovoltaic Pilot Project: Update Report

January 2012

Technology

Monitoring

Best Practices

SolarCity Partnership

Photo provided by Carmanah.

Executive Summary

In 2005, Exhibition Place initiated a solar photovoltaic (PV) feasibility study and field test as part of the organization's 2010 energy self-sufficiency plan. At the time of installation, the 100 kW plant was the largest urban PV array in Canada. Since the enactment of the Green Energy and Green Economy Act, 2009, hundreds of rooftop solar energy systems have sprung up across Southern Ontario. While several larger rooftop PV projects have been implemented, the Horse Palace's four arrays, specially configured for research and evaluation, continue to yield important insights into the performance of photovoltaic systems in real world settings. They also continue to meet a portion of Exhibition Place's electricity demand, helping to advance the organization's goal of becoming energy self-sufficient. This report provides a short update to an earlier report entitled 'Horse Palace Photovoltaic Pilot Project Findings Report' based on an additional two years of monitoring data.

The Horse Palace pilot project was set-up under the Province of Ontario's Renewable Energy Standard Offer Program (RESOP), which provided a premium price of $0.42/kWh for PV generation. Later when the RESOP was replaced with the 'Feed in Tariff' (FIT) program in the spring of 2009, a successful application was submitted to have the Horse Palace system grandfathered into the new FIT program, which provided an improved price of $0.71/kWh.

The four Horse Palace arrays include two types of panels (Sharp and Evergreen models) installed at angles between 0 and 20 degrees, each with a differ inverter (Xantrex and SMA, respectively). Overall, the Horse Palace PV arrays were found to have performed roughly according to expectations, producing an average of 1,008 kWh/kW annually. While this output is lower than other Toronto-area PV systems, it matches production levels predicted by RETScreen modeling software based on local weather and temperature data, and realistic array and power conditioning loss factors. Key factors contributing to reduced performance include power conditioning losses caused by isolation transformers on the Xantrex inverters, sub-optimal installation angles and minor shading.

As expected, the system type and angle of installation both had important impacts on performance. Between the two Sharp arrays, the 20 degree array performed on average three percent better over four years than the array at 10 degrees. The 20 degree Evergreen array performed 10 percent better than the horizontal Evergreen array and 9% better than the 20 degree Sharp array. The difference between the Sharp/Xantrex and Evergreen/SMA arrays installed at the same angle is largely attributed to differences in the efficiency of the two inverters.

Based on FIT revenue of 71.3 cents/kWh, the Horse Palace PV project was calculated to recoup its initial costs after grants within 8 years. However, since the transition to FIT only occurred in 2010, before which the project was receiving lower RESOP payments, the actual payback will be slightly longer. Nevertheless, the payback is significantly shorter than the expected life of the panels, and therefore the owners are expected to generate a substantial return on their investment.

Section One

Project Overview

Over a three-year period, from 2005 to 2008, Exhibition Place carried out an on-site solar photovoltaic (PV) field test as part of the organization's 2010 energy self-sufficiency plan. Four PV arrays with a combined nameplate capacity of 100 kW were installed in 2006 on the Horse Palace building. Exhibition Place partnered with the Toronto Atmospheric Fund (TAF), the Better Buildings Partnership (BBP) of the City of Toronto's Energy Efficiency Office, Business and Strategic Innovation Section, and the Federation of Canadian Municipalities' (FCM) Green Municipal Fund to fund the project. The intent of the partnership was to develop institutional capacity for a subsequent 1-2 megawatt PV system.

Through a public tender process, Carmanah Technologies Inc. was chosen to design, install and monitor the installation. Carmanah, in turn, engaged Fat Spaniel for the system monitoring and Ontario Electric for the installation of the arrays and associated electrical equipment.

The Horse Palace PV Pilot Project compared the performance of technology alternatives under otherwise common environmental and operating conditions. The project investigated factors affecting the viability of solar PV projects in the Ontario context. Such factors include initial capital cost, installation complexity, ongoing operating and maintenance costs, robustness under local environmental conditions, effects of different mounting angles, and overall electrical performance efficiencies.

After two years of data collection, performance results were evaluated through the SolarCity Partnership and recommendations offered in a 40-page final report, Horse Palace Photovoltaic Pilot Project Findings Report, June 2009. The present report updates this analysis based on an additional two years of data from 2009 to 2010, and offers conclusions based on a total of four years of monitoring data, collected between January 2007 and December 2010.

Description of Installed PV Arrays

Table 1 shows the configuration and specification of the four Horse Palace arrays. The arrays consisted of two different types of panels (Sharp and Evergreen models) each with a different inverter (Xantrex and SMA, respectively). They were installed at three different angles (0, 10 and 20 degrees) to evaluate the effect of angle on PV performance.

Table 1: Installed PV Arrays

Array #	#1	#2	#3	#4
Manufacturer	Sharp	Sharp	Evergreen Solar	Evergreen Solar
Panel Model	ND-200U1, 200 watt panels	ND-200U1, 200 watt panels	EV-115, 115 watt panels	EV-115, 115 watt panels
PV Module Type	Solar Crystalline Silicon	Solar Crystalline Silicon	Thin Ribbon Silicon	Thin Ribbon Silicon
# of Panels	216	216	40	40
Array Size	45,600 W	45, 600 W	4,600 W	4,600 W
Slope	10 degree	20 degree	0 degree	20 degree
Azimuth	20 degrees east	20 degrees east	20 degrees east	20 degrees east
Inverter Name	Xantrex PV-45 Grid Tie	Xantrex PV-45 Grid Tie	SMA 5200 Watt Grid Tie	SMA 5200 Watt Grid Tie
Inverter Model	P45	P45	SB6000U	SB6000U

Monitoring Approach

Data acquisition and monitoring has been carried out under contract for five years by Carmanah. The monitoring system includes voltage and current meters on both the AC and DC sides of the inverters; a pyranometer to measure solar irradiance; ambient air temperature and module temperature sensors; data loggers and communication equipment. The monitoring equipment installed at the site is described in the original report.

Performance data from the Fat Spaniel system were collected from November 1, 2006 to December 31, 2010. These data were provided to SolarCity's third party auditors for analysis. As indicated in the original report, on-site irradiance data from 2007 to 2008 were not reliable; therefore data from the Toronto and Region Conservation's Glen Haffy station in Mono Mills just north of Toronto were used for these two years instead.

The Ex Place pyranometer was replaced in late 2008 and performed well until midway through 2010. Two periods of exceptionally low values in 2010 from August 3rd to September 8th, and again from December 12th to 23rd were estimated based on Glenn Haffy data. The Glenn Haffy data were used because measured irradiance from the Ex Place and Glenn Haffy pyranometers were well correlated (R^2=0.99) during 2009 and the first 6 months of 2010 when the Ex Place pyranometer was considered to have provided reliable data. Irradiance data from these and other GTA meteorologic are compared in Appendix A.

Performance and Research Findings

System Performance

The Horse Palace PV system has been operational since October of 2006. A team of project supporters, composed mainly of Exhibition Place staff, have been monitoring and managing the site and hold regular meetings to ensure that data flows and technical matters are handled quickly and effectively.

Extensive data was available from 2007 through to the end of 2010 for each of the installed arrays. Aggregate electricity production and array performance data is summarized in Table 2. Data by month and array is provided in Appendix B.

Table 2: Horse Palace PV Arrays: 2007-2010 electricity generation and array performance

Array #	#1	#2	#3	#4	System Total
Panel Manufacturer	Sharp	Sharp	Evergreen	Evergreen	-
Inverter Manufacturer	Xantrex	Xantrex	SMA	SMA	-
Slope of Array Installation	10 degree	20 degree	0 degree	20 degree	-
kW installed	45.6	45.6	4.6	4.6	100.4
Electricity production (kWh/yr)					
2007	42,409	44,746	4,491	4,835	96,481
2008	43,272	44,575	4,442	4,436	96,724
2009	45,427	45,825	4,605	5,479	101,336
2010	44,589	46,161	4,633	5,257	100,639
2007 - 2010 average	43,924	45,327	4,543	5,002	98,795
Electricity production standardized per unit of capacity (kWh/kW/yr)					
2007	930	981	976	1,051	985
2008	949	978	966	964	963
2009	996	1005	1,001	1,191	1,048
2010	978	1,012	1,007	1,143	1,035
2007-2010 average	963	994	988	1087	1008

* The data for November-December 2008 is from Toronto Hydro, because the Fat Spaniel monitoring system was down from November 6 to December 15. Values have been prorated for each array based on the array size/total system size.

Performance modelling

As in the original study, actual electricity production at the Horse Palace site was compared to three model scenarios in order to benchmark system performance. These three scenarios are described in Table 3. The first is the scenario (RET Prefeas.) used in the original pre-feasibility assessment of the proposed system and is largely based on RETScreen model default factors. The second (RET4yrOnSite) uses irradiance and temperature data collected from at or near the Horse Palace, averaged over four-years. The model RET20yr uses historic irradiance data over 20 years for Toronto from Environment Canada. The latter two models incorporate more realistic efficiency losses than were included in the original pre-feasibility modelling. These losses account for site-specific conditions, namely shading and orientation, and estimates of array and power conditioning efficiencies recommended by the California Energy Commission[1].

Table 3: Key Variables in RETScreen PV Performance Models

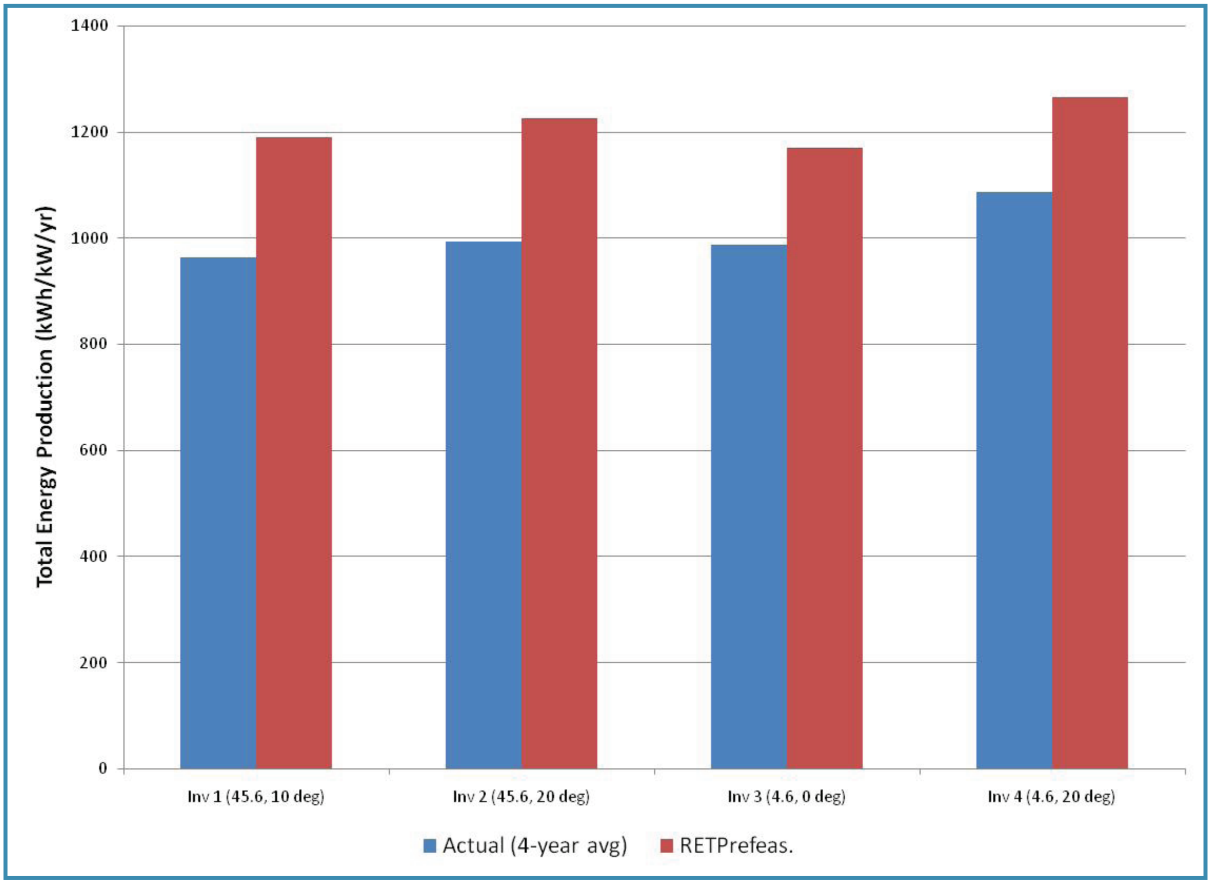
Model Scenario	De-rating Factors for Miscellaneous Losses	Shading Losses	Irradiance and Temperature Data
RET Prefeas.	5% Miscellaneous PV array losses; 0% Miscellaneous power conditioning losses. (Default factors in RETSscreen.)	Not accounted for.	Historic (20yr) data for Toronto, ON, from Environment Canada.
RET4yrOnSite	17% Miscellaneous PV array losses; 1% miscellaneous power conditioning losses.	Actual shading losses from Solar Pathfinder (by month) incorporated into miscellaneous array losses.	2007-2010 annual average data measured at Exhibition Place when the pyranometer was functioning, and at another station in the GTA when it was not.
RET20yr	17% Miscellaneous PV array losses; 1% miscellaneous power conditioning losses.	Actual shading losses from Solar Pathfinder (by month) incorporated into miscellaneous array losses.	Historic (20yr) data for Toronto, ON, from Environment Canada.

Performance Compared to Feasibility Study

The original report revealed that the prefeasibility study had significantly overestimated PV electricity production, due to flawed assumptions around efficiency losses. After the model was re-run using more realistic estimates of array and power conditioning efficiencies, the Horse Palace PV project was found to be performing within acceptable limits. This continued to be true in 2009 and 2010. Data from this and other PV sites in the GTA indicate that under typical solar irradiance conditions, roof-mounted arrays should produce between 1000 and 1250 kWh/kW/yr. The Horse Palace arrays are at the lower end of this range in large part due to higher than normal efficiency losses from isolation transformers connected to the Xantrex inverters, sub-optimal angles of installation, and some minor shading at the site. Since 2006, Xantrex inverters no longer require isolation transformers. Night-time tare losses caused by isolation transformers are therefore not likely to affect the efficiency of future PV installations.

1 California Energy Commission, A guide to Photovoltaic (PV) System Design and Installation, June 2001, www.energy.ca.gov/reports/2001-09-04_500-01-020. PDF

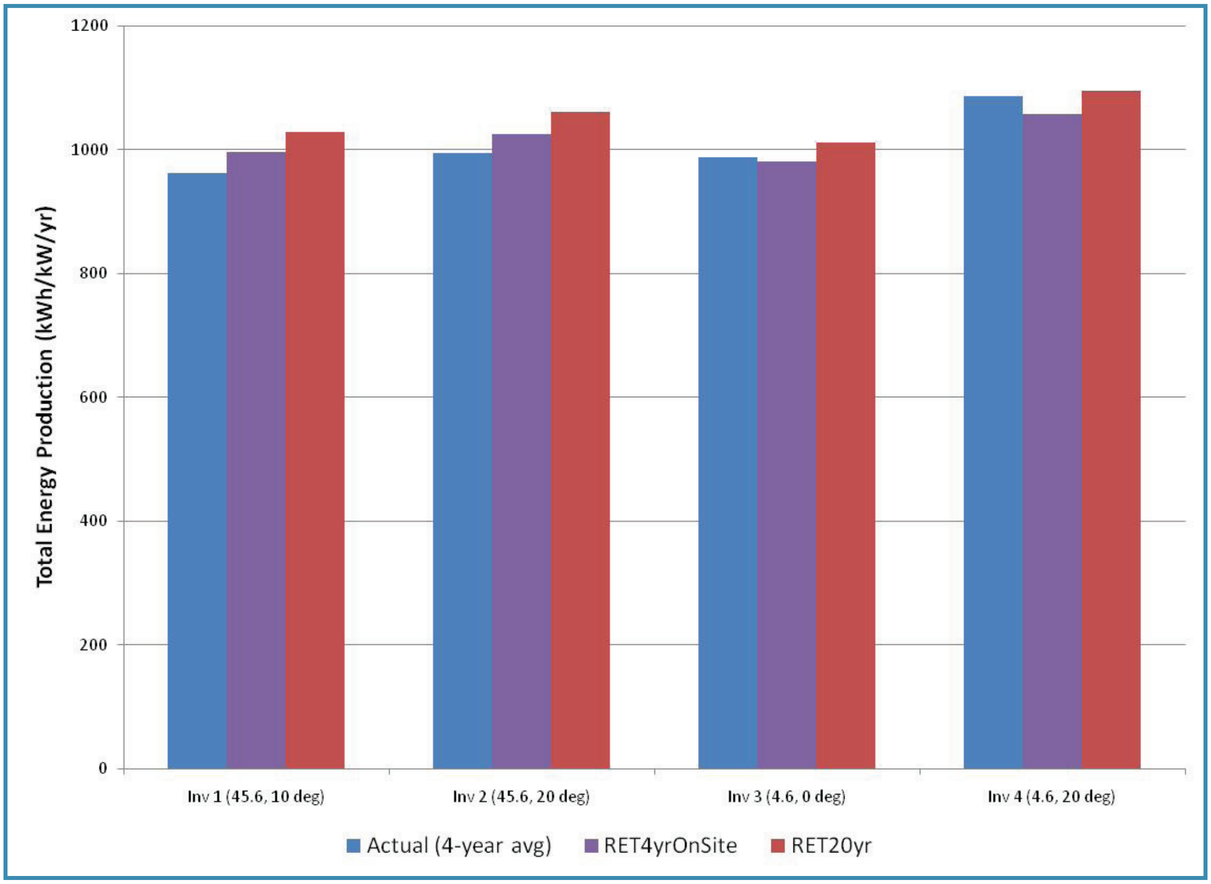
Figure 1: **Average energy production per kW installed from 2007-2010 vs the RETScreen pre-feasibility model**



Actual performance vs. RETScreen models

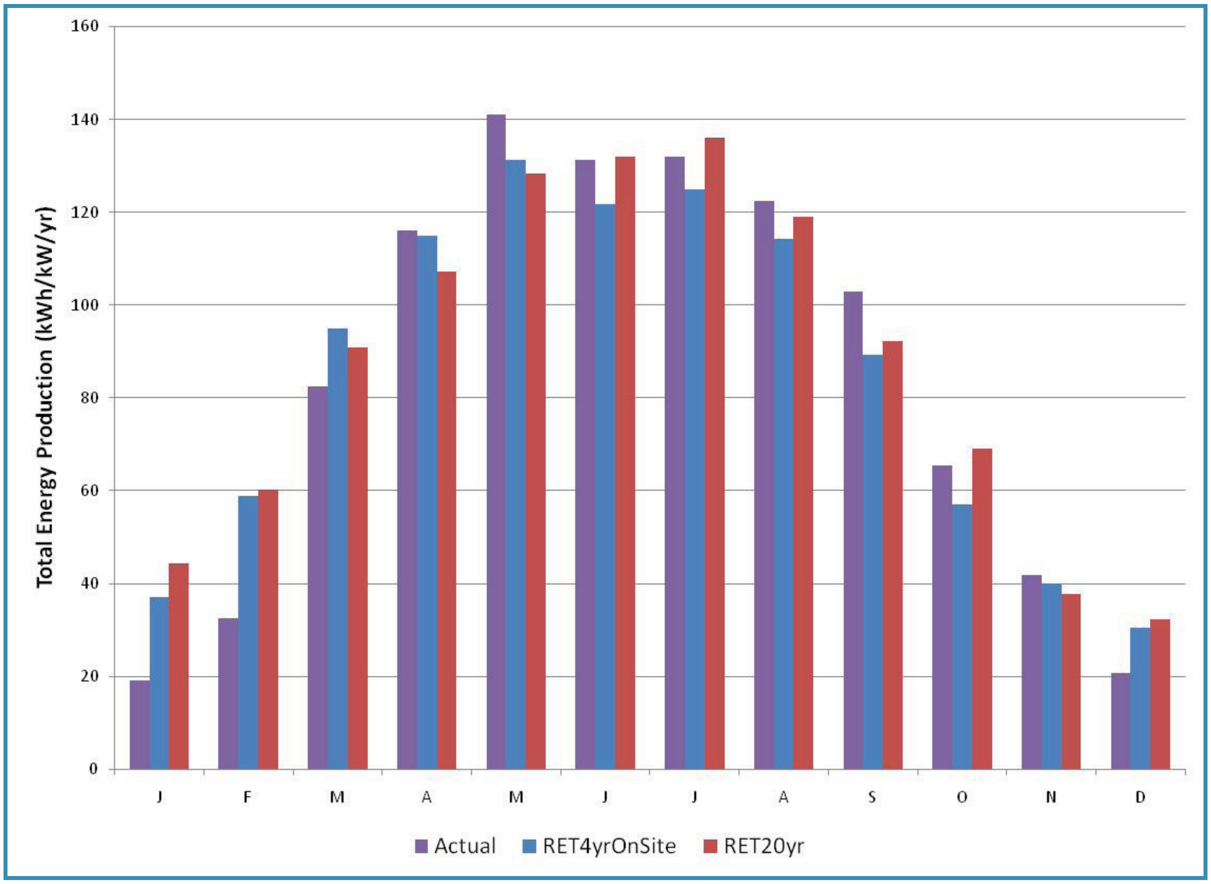
The close match between actual and the modeled outputs shown in Figure 2 indicates that the Horse Palace PV arrays are performing roughly according to expectations. RET4yrOnSite with 17% array loss factors proved to be the most accurate model for predicting total energy output from the four arrays. Using this scenario as a benchmark for expected performance, the Evergreen/SMA systems (arrays 3 and 4) are performing above expected levels (by 0.7% and 2.8% respectively), while the Sharp/Xantrex systems (arrays 1 and 2) continue to perform slightly below expectations (by 3.3% and 3.0% respectively), even though the lower Xantrex rated inverter efficiencies are incorporated into the model (92% for Xantrex vs 95% for SMA). More detailed charts by array and by month are provided in Appendix B.

Figure 2: Average Energy Production and RETScreen model output per KW Installed (2007-2010).



Patterns in the winter performance data indicate snow cover on the panels. When snow was covering the panels, the facility operator occasionally shut off the panels for short time periods in order to prevent isolation transformers on the Xantrex inverters from drawing power when the systems are not producing. The RETScreen models do not account for snow, which causes them to overestimate winter production levels (Figure 3). From December to February, the RET4yrOnSite and RET20yr models overestimated energy production by 74% and 89%, respectively. Despite the large percentage overestimation during winter months, the models' overall accuracy is minimally affected because irradiance is much lower during the winter than at other times of the year.

Figure 3: **Average Monthly actual and modeled energy production per kW installed (2007-2010)**

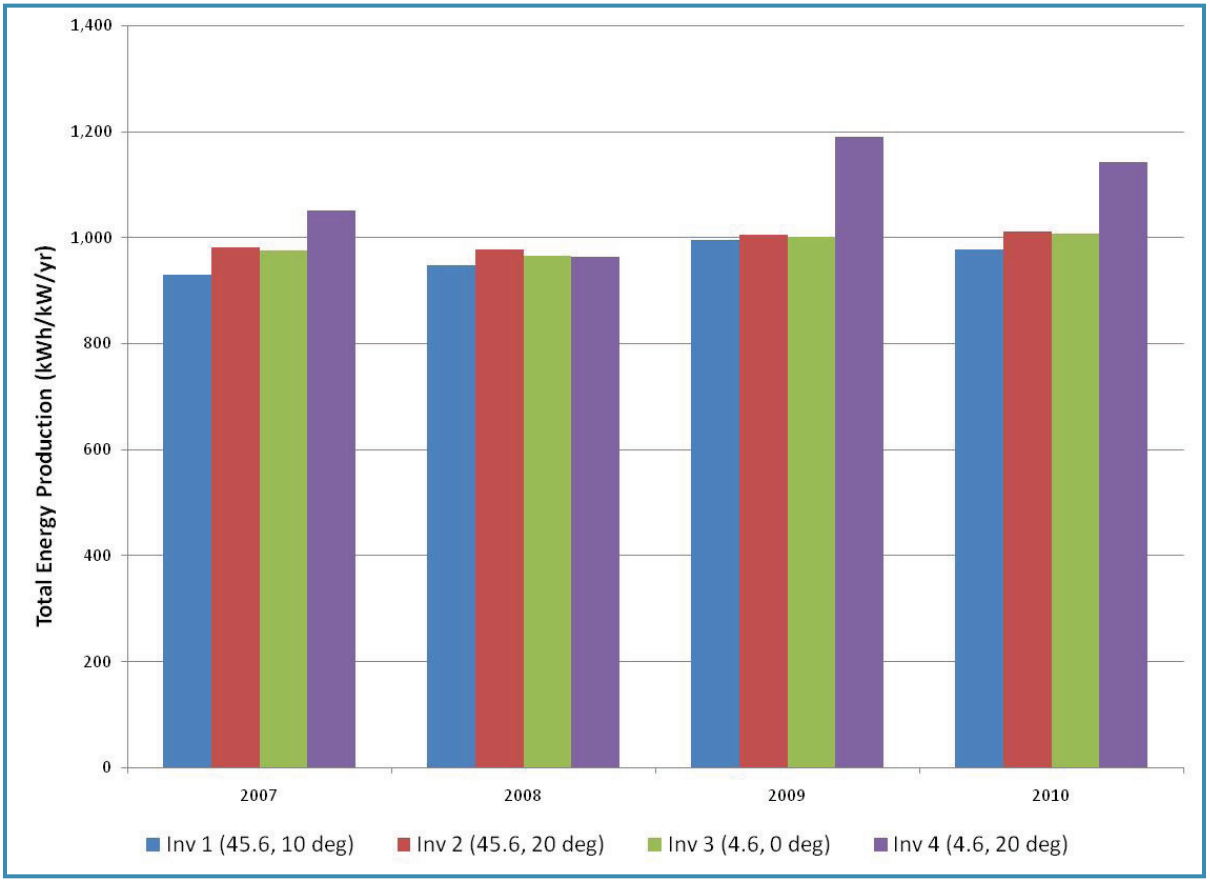


Performance of the different angled arrays

The arrays at the Horse Palace were installed at various angles (0, 10 and 20 degrees) in order to compare performance of the system at different slopes. The ideal angle of installation is roughly 32 degrees when local weather (increased cloudiness in the winter, clearer skies in the summer) is taken into account. It is therefore not surprising that the arrays set at 20 degree tilts performed better than their lower-inclination counterparts, as shown in Figure 4. Between the two Sharp arrays (#1 and #2), the 20 degree array performed three percent better over four years than the array at 10 degrees. The 20 degree Evergreen array (# 4) performed 10 percent better than the horizontal Evergreen array (#3) and 9% better than the 20 degree Sharp array (#2). The difference between the Sharp/Xantrex and Evergreen/SMA arrays installed at the same angle is largely attributed to differences in inverter efficiencies. The lower performance of the zero and 10 degree arrays is most distinct in the winter months (when the sun is lower), as shown in Figure 5.

Despite better performance of the angled panels, flat arrays should still be considered as it is possible that they could be installed at a lower cost than angled panels on racks. The lower costs are due to the lower roof loads, less expensive racking and more efficient use of available roof space. Panels installed flat make better use of available space because they don't need to be spaced to avoid shading one another. This means that more of them can be installed, potentially resulting in higher yields overall.

Figure 4: Total Energy Production per KW of PV Installed from 2007 to 2010



Updated Business Case

The original report provided a business case based on 2008 performance data and the final as-built system cost of $1,103,273. Table 4 shows an updated business case based on the 4 years of data collected to date. Calculating pay back based on the longer time period provides a better approximation of actual revenue than would be the case if only one year were available because the 4 year average more accurately reflects conditions over the longer term. The initial estimate and feasibility study scenarios shown in the Table were calculated based on RESOP revenue of 42 cents/kWh, details of which are provided in the original report. Based on FIT revenue of 71.3 cents/kWh, and actual production over 4 years, the Horse Palace PV project would be expected to recoup its initial costs within 8 to 9 years.[2] In effect, the payback period will be slightly longer because the transition to FIT only occurred in 2010, before which the project was receiving lower RESOP payments. Nevertheless, the payback is significantly shorter than the expected life of the panels, and therefore the owners are expected to generate a substantial return on their investment.

2 This is in fact a conservative estimate because average daily irradiance over the 4 year measurement period (3.47 kWh/m^2/d) was 3.2% lower than the 20 year average for Toronto (3.58 kWh/m^2/d).

Figure 5 Average Monthly Energy production per KW of PV installed (2007-2010)

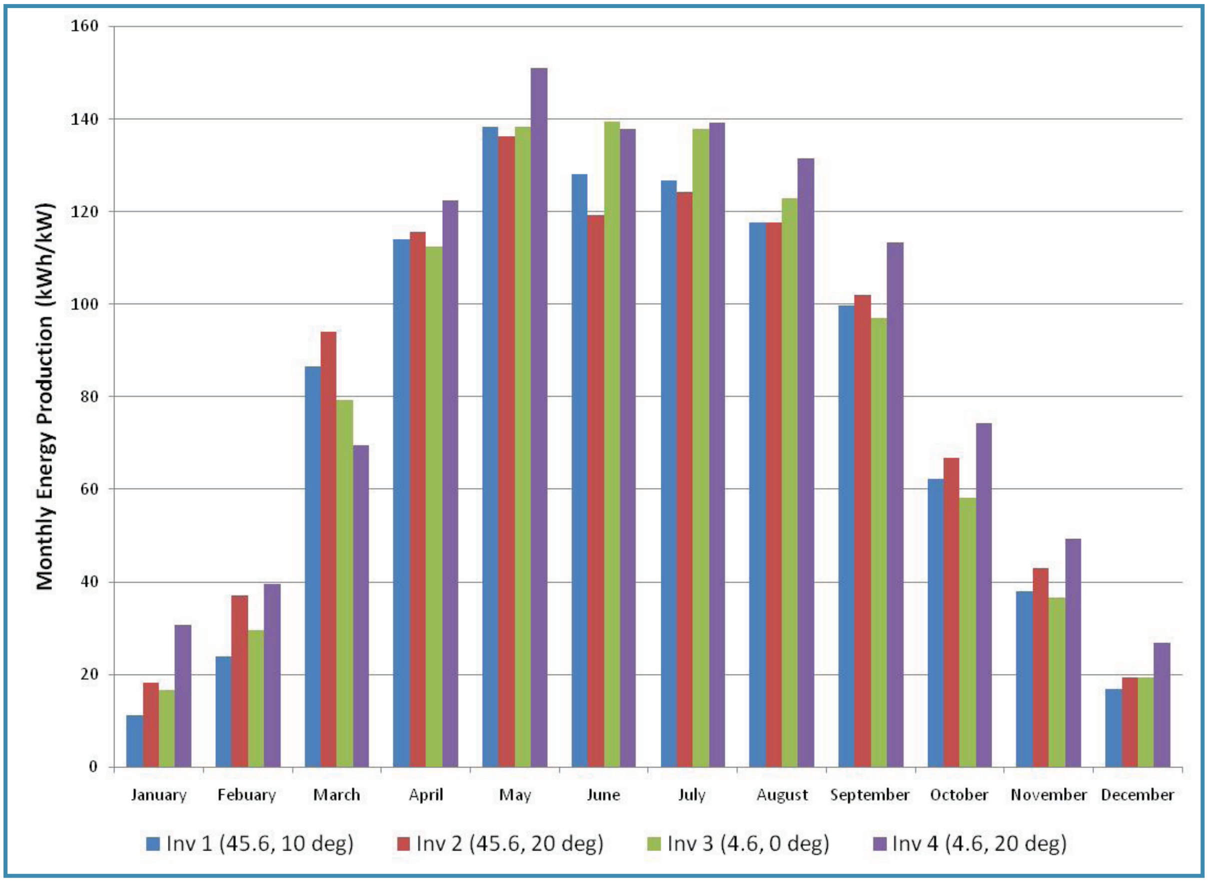


Table 4: Horse Palace PV Pilot Project Updated Business Case

	Total Cost Installed	Grants	Loan	Array Output (average kWh/yr)	Income from Electricity Sales ($/yr)	Simple Payback (years)	Payback after grants (years)
Initial Estimate	$1,100,000	$500,000	$600,000	110,000	$46,200	23.8	13.0
Feasibility Study (using RET20yr model and Re-sop revenue)	$946,144	$500,000	$446,144	103,275	$43,376	21.8	10.3
Actual (using final installed cost, 2007-2010 performance data, and FIT revenue	$1,103,273	$500,000	$600,000	98,795	$70,441	15.7	8.6

Conclusions

The Horse Palace pilot project has provided a wealth of data and information on the performance of rooftop photovoltaics, as well as offering unique insights into the process of installing, monitoring and developing a revenue stream from photovoltaic projects. Many of these were documented in the original 2009 report. In this update, improvements to modeling accuracy, using validated on-site irradiance data, and a longer record of data, have allowed the effects of efficiency vs. panel angle and module type to be better assessed.

Results over 4 years have shown that an array installed at 20 degrees performs roughly 3% better than one installed at 10 degrees, and approximately 10% better than a horizontal array. The type of system installed also proved to be an important factor. At the same angle, the Sharp/Xantrex system produced 9% less output on average than the Evergreen/SMA system, largely due to continuous power draws from the Xantrex isolation transformer. Newer Xantrex inverters do not require a separate transformer. However, this and other performance issues encountered at the site highlight the need for careful monitoring and evaluation of systems to ensure that investors in solar energy meet their financial goals, and problems encountered at one site are not repeated elsewhere.

Appendices

Appendix A: Irradiance

Figure A1: Monthly irradiance for 2007 and the 20 year Toronto average from RETScreen. Note: In this update, data from the Glen Haffy station were substituted for Ex Place data in 2007 and 2008.

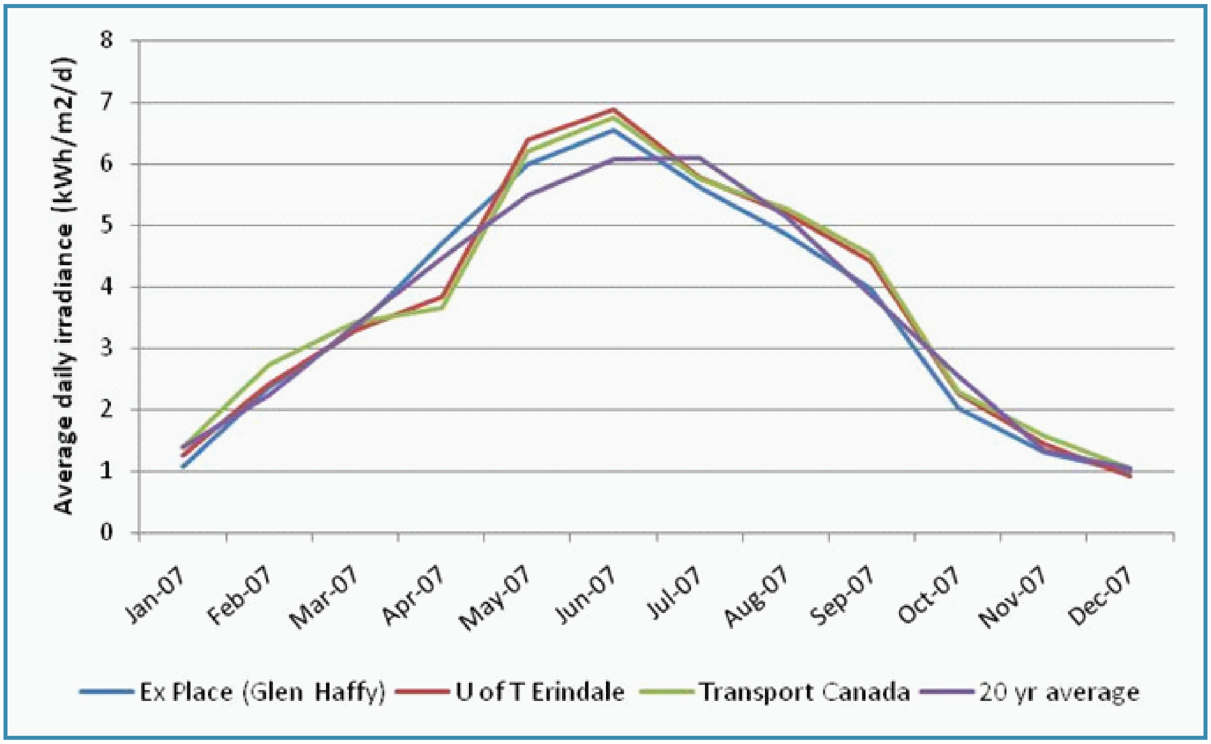


Figure A2: **Monthly irradiance for 2008 and the 20 year Toronto average from RETScreen. Note: In this update, data from the Glen Haffy station were substituted for Ex Place data in 2007 and 2008.**

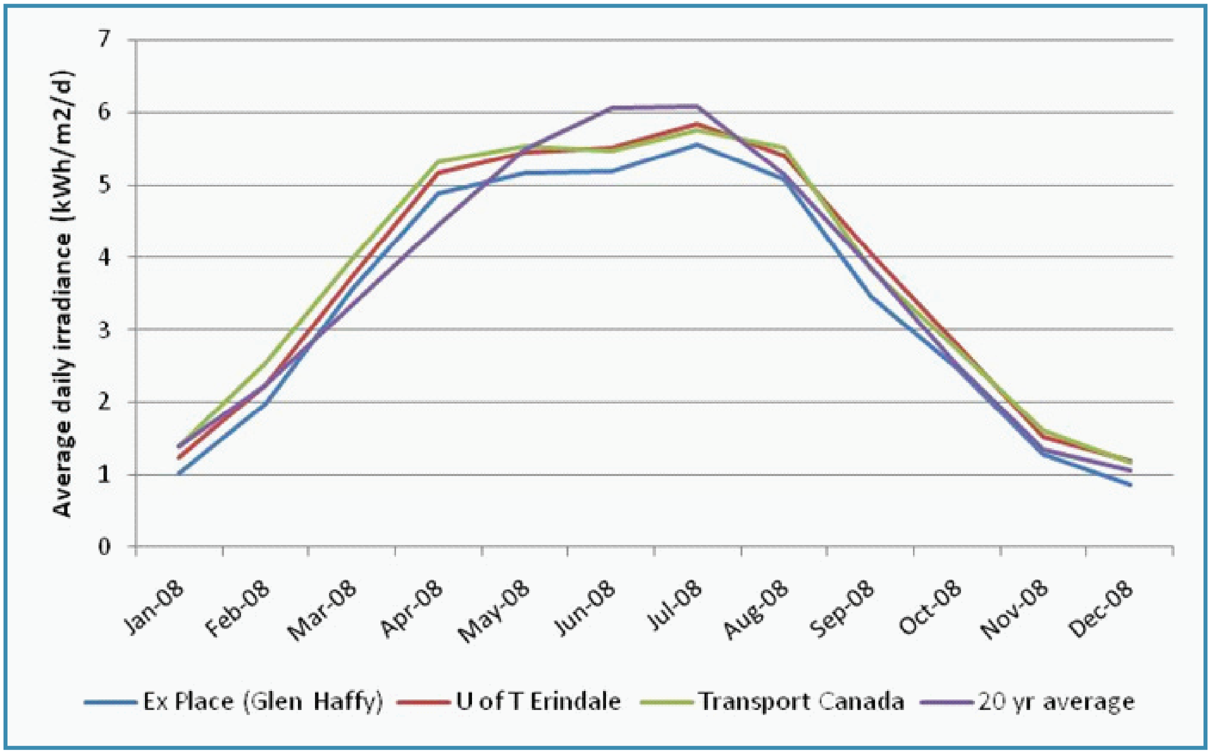


Figure A3: **Monthly irradiance for 2009 and the 20 year Toronto average from RETScreen.**

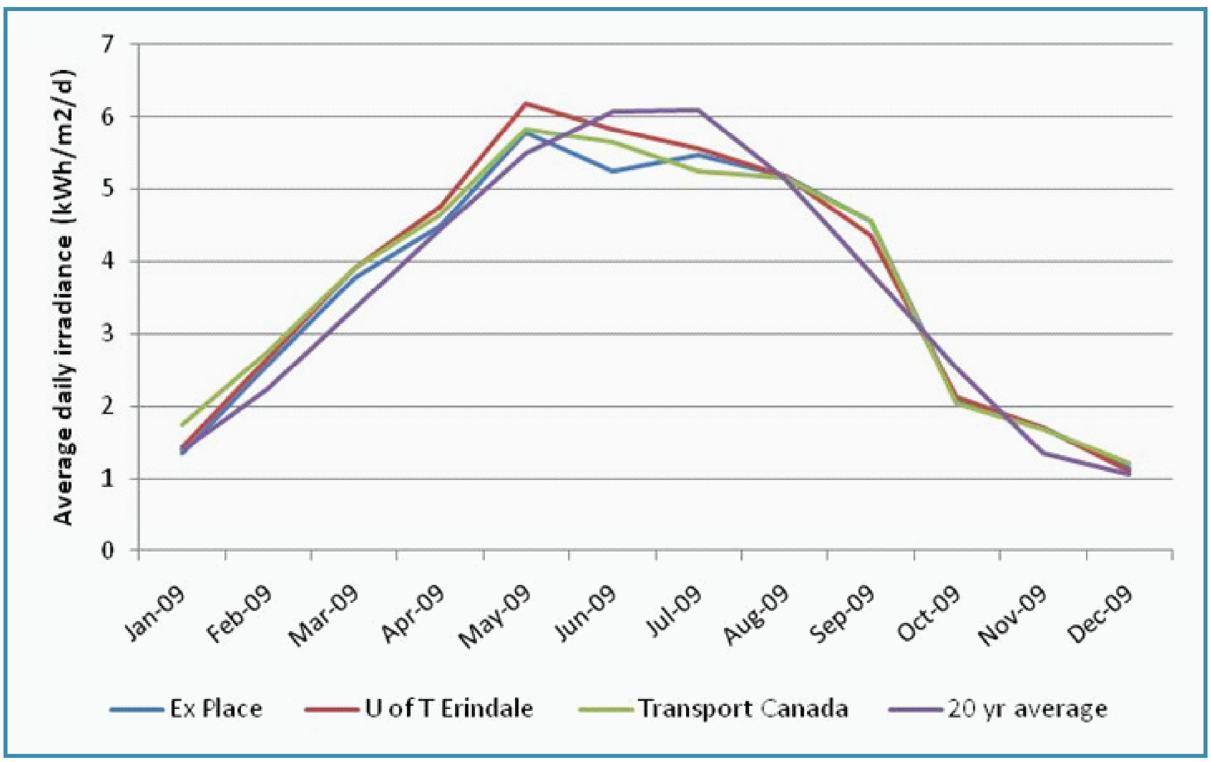
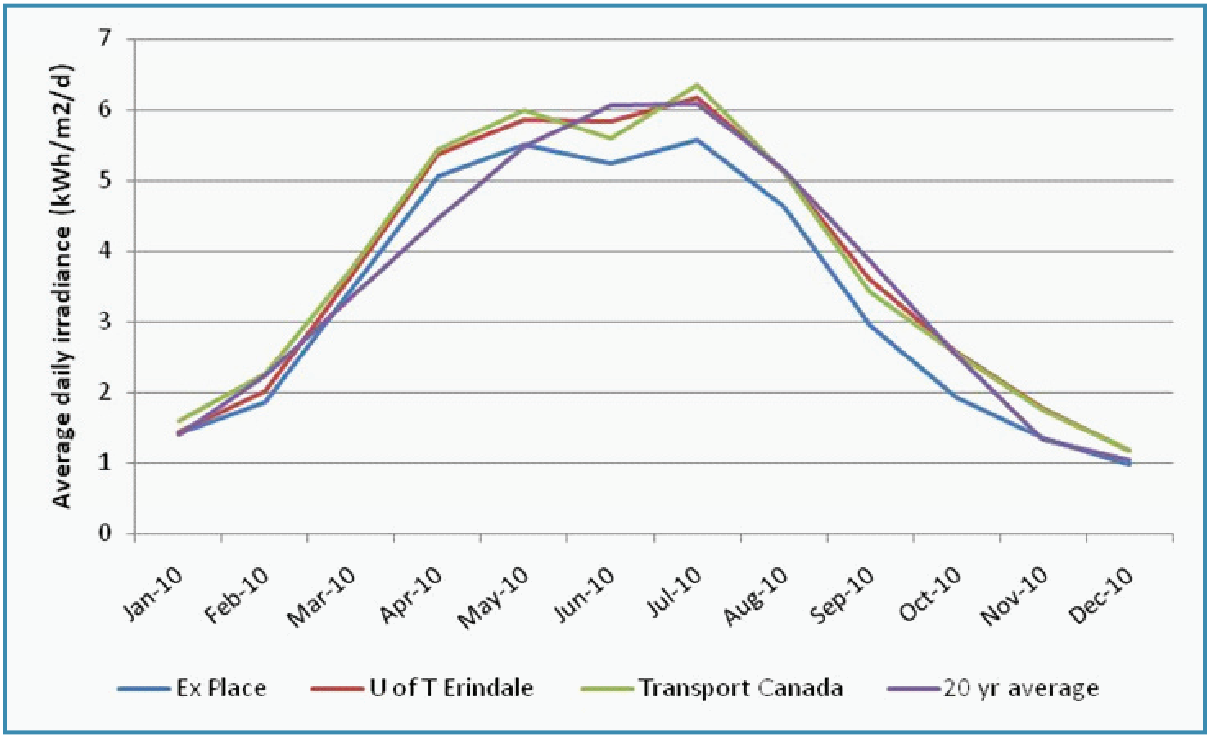


Figure A4: Monthly irradiance for 2010 and the 20 year Toronto average from RETScreen.



Appendix B: Four year production and modeling data

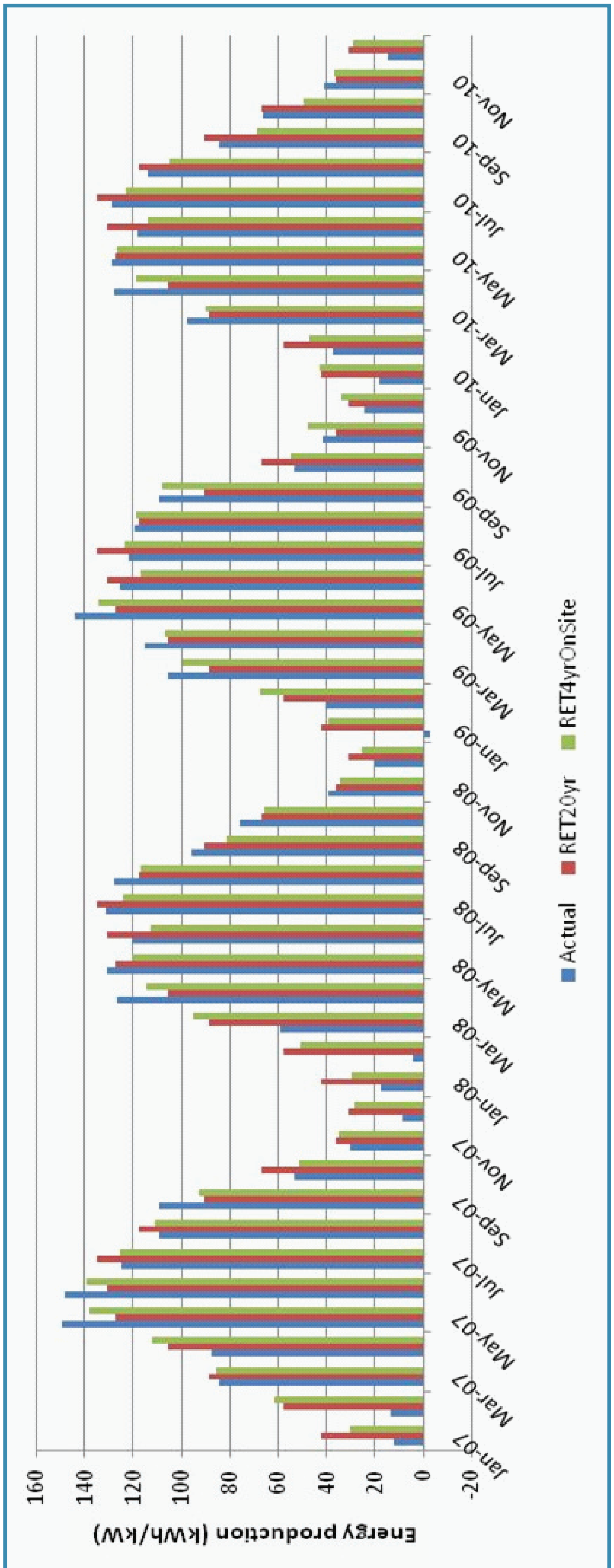
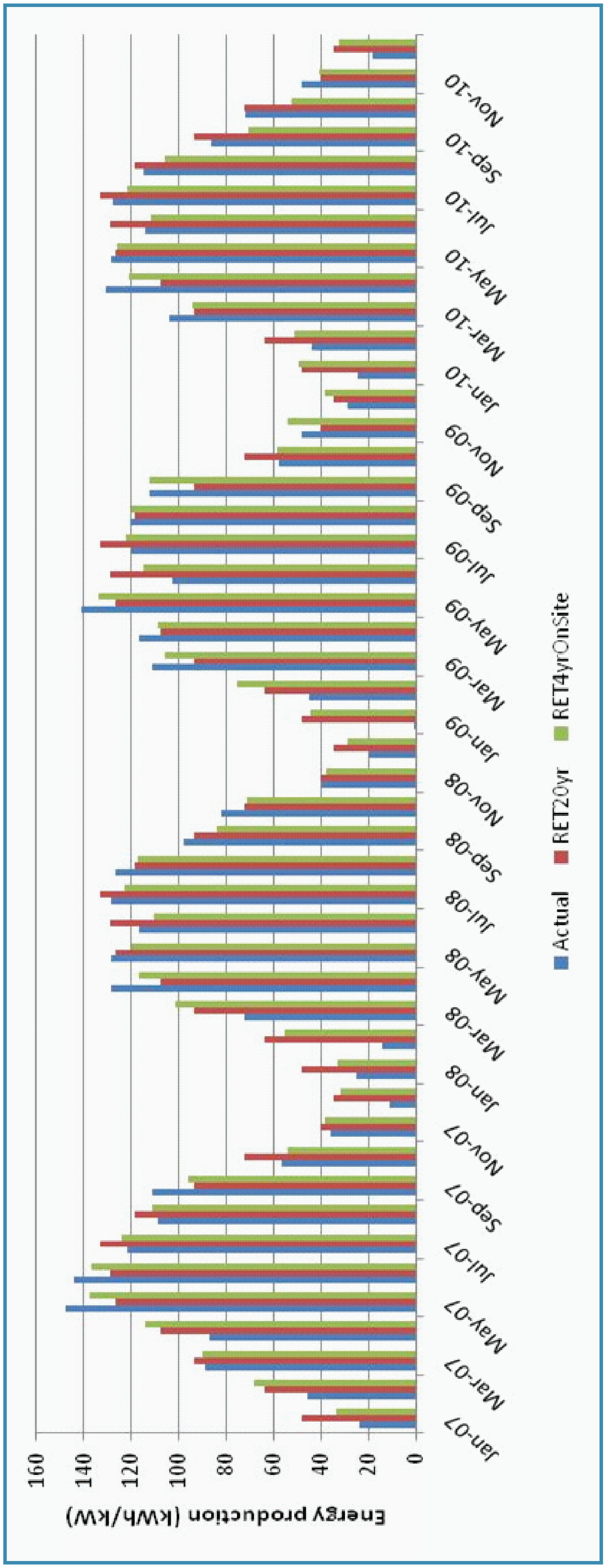


Figure B1. 2007 to 2010 actual and simulated energy production at Inverter 1.

Figure B2. 2007 to 2010 actual and simulated energy production at Inverter 2.



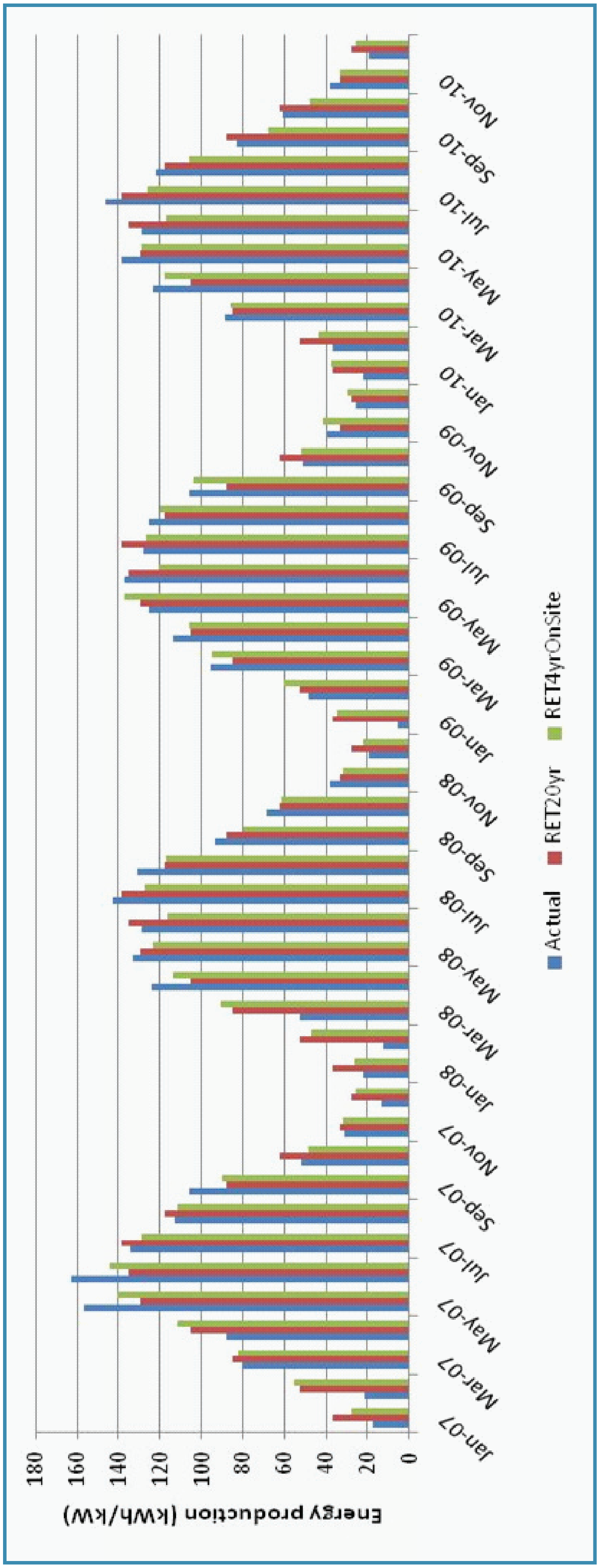


Figure B3. 2007 to 2010 actual and simulated energy production at Inverter 3.

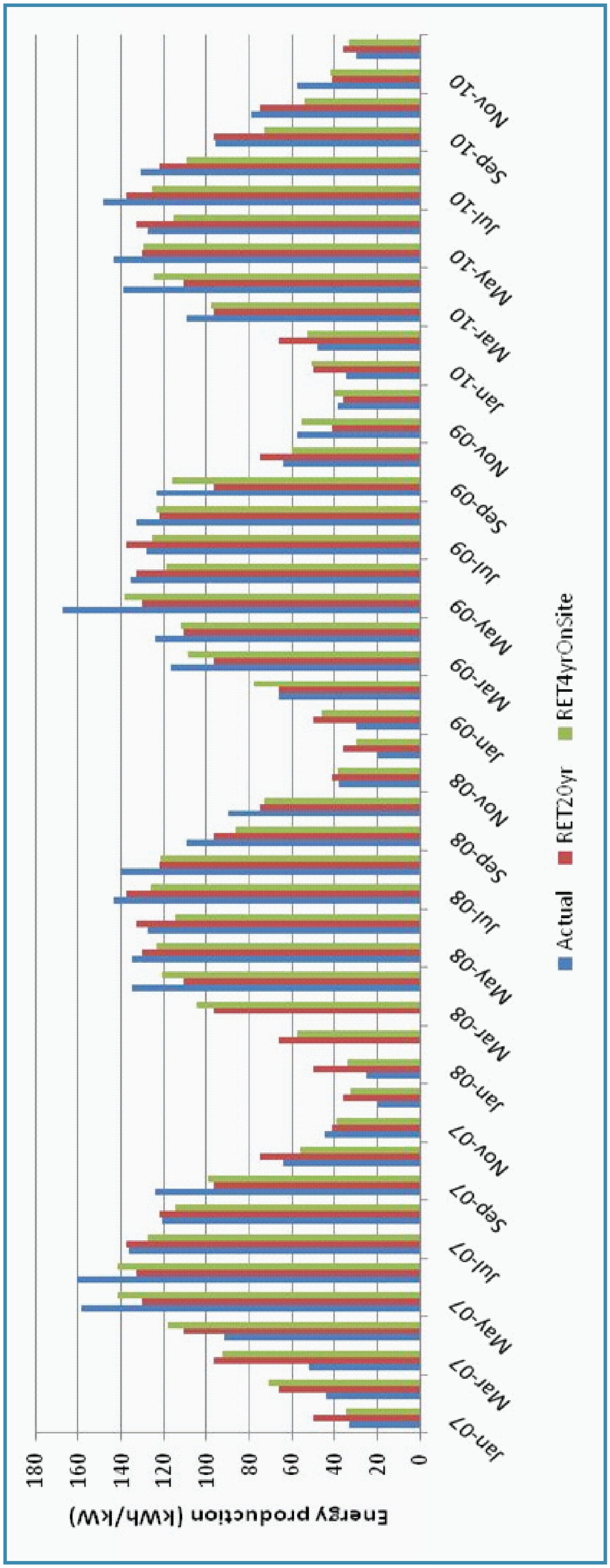


Figure B4. 2007 to 2010 actual and simulated energy production at Inverter 4.

About the SolarCity Partnership

The SolarCity Partnership is a joint initiative of the Toronto Atmospheric Fund, Toronto and Region Conservation Authority and the City of Toronto designed to promote best practices and careful monitoring of large solar installations. SolarCity Partnership is an information-sharing hub for both public and private organizations involved in deploying solar power. Our **SolarCityPartnership.ca** website provides case studies, research, and solar weather data to help with the effective use of zero emissions energy from the sun.

Toronto Atmospheric Fund | Toronto and Region Conservation for The Living City | Toronto | FCM Green Municipal Fund / Fonds municipal vert

We want to hear from you!

If you have further best practices recommendations, insights into system design, deployment or maintenance or a project to profile, please get involved with the SolarCity Partnership! Contact us at:

Technology | Monitoring | Best Practices — SolarCity Partnership

info@solarcitypartnership.ca
416-661-6600 ext. 5337
www.solarcitypartnership.ca

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