Solar PV Generation Performance Load Research Study

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Executive Summary:

Manitoba Hydro had 1086 customers participate in the Power Smart Solar PV pilot program. These customers installed a total of 36,339 kW DC of solar panel capacity.

To help understand the individual performance of various types of solar installations and the overall effects of the totalized solar capacity on the Manitoba Hydro grid, a research study was conducted to gain statistical information. This study monitored the solar production of 20 customers for a one-year period. The systems monitored were at 10 residential homes, 5 commercial buildings, 4 agricultural operations, and one communal living colony. The sample group included 13 ground and 7 rooftop solar installations and included 12 electric, 6 natural gas, 1 geothermal (ground source heat pump) and 1 coal heated premises.

A further objective of the study was to measure real world solar production to determine the accuracy of the Power Smart program's estimated solar production which was based on the PV-Watts® energy modeling tool.

PV-Watts® is a solar production calculator developed by the National Renewable Energy Laboratory (NREL). NREL PV-Watts® was used to estimate the annual energy production for customers that participated in the solar PV pilot program. Initial energy modelling estimated a blended average solar PV system production of 1317 kWh per installed DC kW. This value is derived if the PV-Watts ® calculator's advanced inputs are left at default settings and will produce an overrated estimate for solar PV output

This study shows that rooftop installations had an average normalized energy production of 1020 kWh per installed DC kW. Ground installations had an average normalized energy production of 1200 kWh per DC kW. It is believed ground installations performed much better than rooftop installations since, generally they are installed in open areas and are less prone to snow accumulation and the shading effects of trees, buildings or structures, and it is much easier to remove snow and dirt from a ground installation. The ground installations will also perform better since they all face due south and are at the optimum tilt of 40-45 degrees compared to a rooftop installation that will be pointed in whatever direction the roof faces and set at a lower tilt to match the roof slope. The increased slope of the ground installations also made it easier to naturally shed snow and dirt.

There was a total of 36,339 kW of solar panels installed as part of the pilot program. 6397 kW (18%) of panels were installed on rooftops, and 29,942 kW (82%) of panels installed on the ground. The blended average annual electricity production for the pilot program is 1168 kWh per installed kW of rooftop and ground solar panels based on 1020 kWh per kW for rooftop installations and 1200 kWh per installed kW for ground installations. This is an 11.3% decrease from the PV-Watts® generated estimate used for the pilot program.

The PV-Watts ® energy modelling tool can produce results near equal to the monitoring study results if the advanced parameter settings are used. Some of the advanced parameters include additional system losses categories due to soiling, snow cover, and panel degradation. However, most PV-Watts® users are unaware of these advanced parameters and therefore use default settings.

One other key finding of the study is the portion of electricity the solar customers exported to the grid versus consumed on site. Electrically heated residential, commercial, and agricultural customers had similar portions of export electricity sales. Electrically heated residential customers exported 64% of their solar production and consumed 36% on-site. The export portion was 60% for commercial customers, 64% for agricultural customers, and zero for the one communal living colony customer. Gas heated customers export less and consume more on site.

Gas heated residential customers exported 50% of the electricity generated and consumed 50% of the energy on-site. The export portion for commercial gas heat customers was 50%. There were no agricultural customers in the study that had access to natural gas.

The differences in export energy portion versus energy consumed on-site between gas heated and electrically heated customers was due to the pilot programs sizing rules, seasonal solar production variations and customer consumption load shape differences. The program rules limited the size of the installed solar system so the energy it was predicted to generate (using PV-Watts®) would be less than or equal to the customer's average electricity usage over the previous 3-year period. Electrically heated buildings have much higher electricity usage in the winter months when solar production is at its lowest while generating the most during summer months when customers are using the least. Natural gas heated homes have more consistent monthly electricity usage with higher usage in the summer months (most have air conditioning) which makes for a better load match with solar system energy production than electrically heated homes. In general, solar PV and electric heating systems have a very poor load shape match.

One large customer system monitored was a communal living colony. This customer utilized all the solar generated electricity on-site and had no export power. Communal living colonies generally are a large user of electricity due to multiple residential, commercial, agricultural, and often industrial loads.

Power quality issues were identified with some of the installations. In order to export energy to the grid, the solar system's inverter voltage level needs to be slightly higher than the grid's voltage level. One manufacturer shipped inverters set at voltage levels higher than allowed by the Manitoba Hydro Power Quality standard. This created flicker complaints and high voltages. It appears the high voltages led to equipment failure. This issue was resolved by enabling the inverter's reactive power control settings.

High voltage issues may arise in the future if multiple solar systems are added to individual utility feeders. This may cause solar systems sharing the same feeder to compete and increase their inverter voltages in order to export energy.

Table of Contents:

2.0 Introduction

The Manitoba Hydro Market Forecast and Load Research department conducted a twelve-month study on a sample of customer owned solar photovoltaic generation systems with the purpose of acquiring annual system performance information that is not attainable using the basic monthly energy readings from the bi-directional revenue meters. The statistical data from this study can be applied to determine the cost-benefit to the customer and to gain insight into the overall performance of solar generation installations in Manitoba.

The monthly revenue meter readings are used to calculate the total kWh energy purchased (delivered) from the utility and the kWh energy exported (received) to the utility grid which is applied to the monthly customer billing charge and/or credit. If a customer required more energy than the solar produced in a month, then there would be a charge on the bill. If the customer's solar installation generated more energy than the customer load required, and the net amount is exported to the grid, then there would be a credit.

The revenue meter does not record the total kWh energy or kW demand a solar installation produces. During periods when a solar installation generates energy, either a portion of, or all the energy produced may be sent to the customer load depending on how large the load requirements are at any moment. Whatever amount of solar energy sent directly to the customer load is not recorded by the revenue meter because the meter only records what is bought from the utility or exported to the utility. Therefore, it is not possible to calculate the electricity generated from the solar installation by evaluating only the credit value on the monthly billing statement. Refer to Appendix A for further information and diagrams which will help explain and demonstrate this topic.

The only way the total energy from a solar installation can be recorded is to measure the energy generated directly at the point of connection. Since this cannot be accomplished using the monthly meter readings alone, a research study was conducted involving the installation of a data logger at test points allowing the measurement and recording of the following:

1. Total kW energy generated directly at the solar output.
2. Total kWh energy delivered.
3. Total kWh energy received.

With these measurements, the total solar energy delivered to the customer load, and total customer energy consumption can be calculated.

This study allowed the development and analysis of other statistical information such as the daily, monthly and annual load profiles using the average kW demand and accumulated kWh energy data recorded over 5-minute intervals. The statistics from this study can be used to evaluate the overall performance of all the solar installations in Manitoba and their effect on the Manitoba Hydro grid.

3.0 Overview of Solar Energy Pilot Program Installations

Table 1 is a summary of the solar PV installations in Manitoba that were completed as part of the 2-year Solar Energy Pilot Program launched in April 2016.

Residential installations account for almost 77% of the total number of installations and 43% of the total installed kW DC capacity. In contrast, Communal living colonies account for only 3.5% of all installations but represent almost 21% of the total installed kW DC capacity. The reason for this offset is that 37 of the 38 colonies have large solar installations in the 200 kW DC range and one colony with a 120 kW DC installation.

Table 1: Pilot Program Solar Installation Totals in Manitoba

	Number of Installations	Total kW DC	Percent of Total Manitoba Installations	Percent of Total Manitoba kW DC
Total installations	1086	36,339		
Residential	834	15,652	76.8%	43.1%
Commercial	102	6,590	9.4%	18.1%
Agricultural	88	5,660	8.1%	15.6%
Communal Colony	38	7,586	3.5%	20.8%
Other*	24	851	2.2%	2.3%

*Other: campgrounds, church, kennel, storage, lift station, pump house, condo, stables, hobby shop, cottage/cabin

Table 2 compares the total number of installations of ground-type and rooftop-type. There are four installations with a combination of both ground and rooftop and these were grouped with the ground-type values in the table below.

Table 2: Ground and Rooftop Solar Installations in Manitoba

			Percent of Total Manitoba Installations	
	Ground	Rooftop	Ground	Rooftop
Total number	643	443	59.2%	40.8%
Residential	446	394	41.1%	36.3%
Commercial	72	33	6.6%	3.0%
Agricultural	77	1	7.1%	0.1%
Communal Colony	37	1	3.4%	0.1%
Other	11	14	1.0%	1.3%

Table 3 shows 13% of all installations in Winnipeg are ground-type whereas 67% of all installations outside of Winnipeg are ground-type. It appears the availability of real estate for customers located outside of Winnipeg makes ground-type installations the preferred choice.

The Winnipeg locations include all installations within the Winnipeg Perimeter.

Table 3: Solar Installation Type - Winnipeg vs. Other

				Percent of Location Total	
Location	Total	Ground	Rooftop	Ground	Rooftop
Winnipeg	162	21	141	13%	87%
Outer Winnipeg	924	621	302	67%	33%

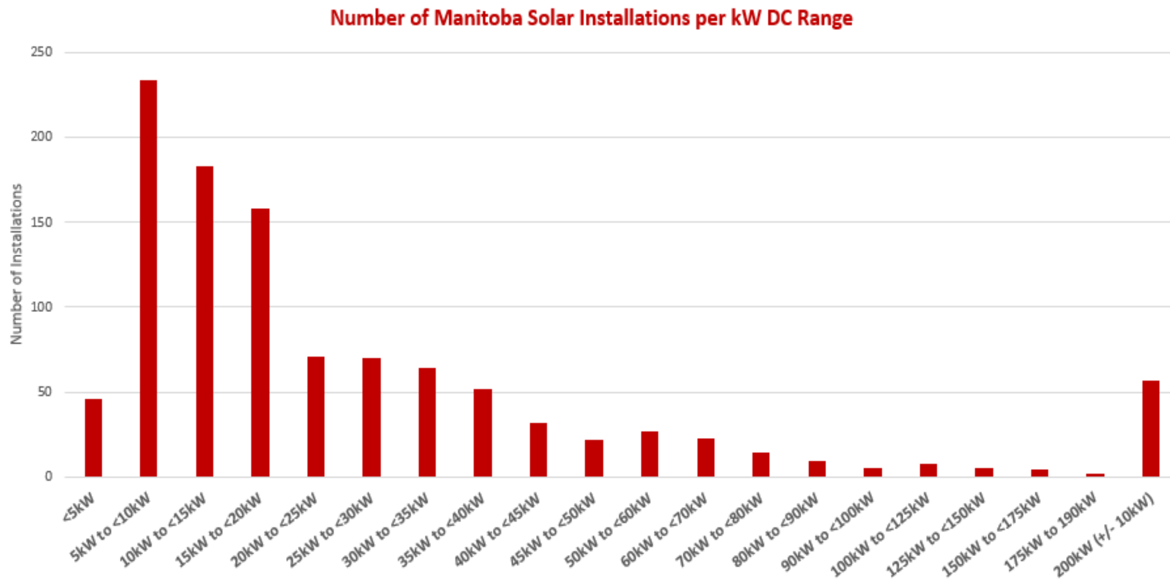
Manitoba Installations

Table 4 and Graph 1 below list and display the totals and percent representation for various kW DC nameplate rating ranges in Manitoba. Installations rated less than 10 kW DC represent 26.8% of all installations and 5.8% of the total kW DC capacity in Manitoba whereas installations in the 200 kW DC range total 5.2% of all installations and 31% of the total capacity.

Table 4: Overview of All Manitoba Installations

kW DC Range	No. of Inst. in kW DC Range	% of Total Manitoba Installations	Total kW DC	Percent of Total Manitoba kW DC
Less Than 5kW	45	4.1%	165	0.5%
5kW to <10kW	247	22.7%	1,943	5.3%
10kW to <15kW	175	16.1%	2,126	5.8%
15kW to <20kW	132	12.2%	2,326	6.4%
20kW to <25kW	91	8.4%	2,001	5.5%
25kW to <30kW	70	6.4%	1,917	5.3%
30kW to <35kW	64	5.9%	2,028	5.6%
35kW to <40kW	53	4.9%	2,028	5.6%
40kW to <45kW	31	2.9%	1,322	3.6%
45kW to <50kW	23	2.1%	1,093	3.0%
50kW to <60kW	27	2.5%	1,454	4.0%
60kW to <70kW	24	2.2%	1,560	4.3%
70kW to <80kW	14	1.3%	1,047	2.9%
80kW to <90kW	9	0.8%	774	2.1%
90kW to <100kW	5	0.5%	482	1.3%
100kW to <125kW	8	0.7%	1,041	2.9%
125kW to <150kW	5	0.5%	559	1.5%
150kW to <175kW	4	0.4%	644	1.8%
175kW to 190kW	3	0.3%	551	1.5%
200kW (+/- 10kW)	56	5.2%	11,278	31.0%
Totals	1,086 Manitoba Installations		36,339 kW DC in Manitoba	

Graph 1


Number of Manitoba Solar Installations per kW DC Range
Number of Installations
250
200
150
100
50
0
<5kW
5kW to <10kW
10kW to <15kW
15kW to <20kW
20kW to <25kW
25kW to <30kW
30kW to <35kW
35kW to <40kW
40kW to <45kW
45kW to <50kW
50kW to <60kW
60kW to <70kW
70kW to <80kW
80kW to <90kW
90kW to <100kW
100kW to <125kW
125kW to <150kW
150kW to <175kW
175kW to 190kW
200kW (+/- 10kW)

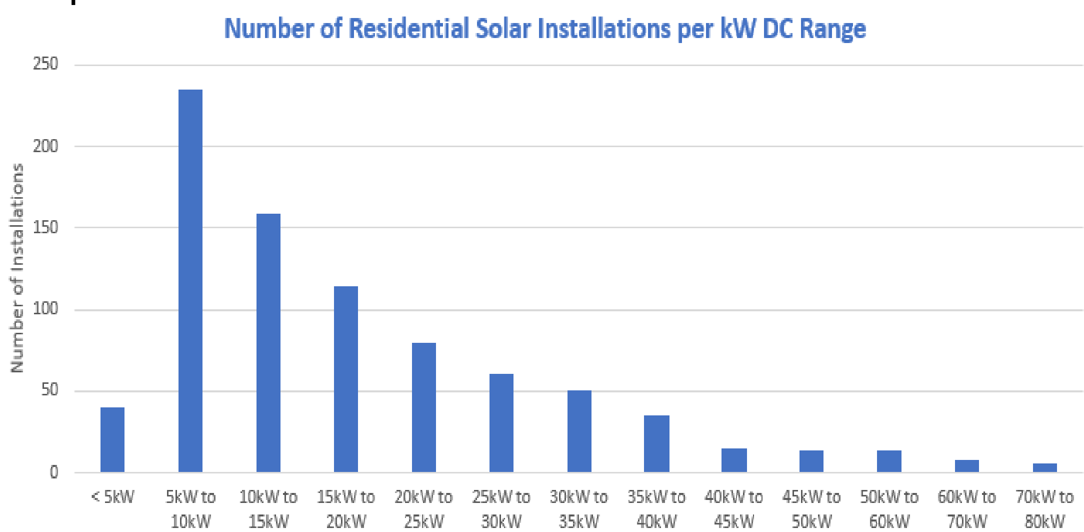
Residential Installations

Table 5 and Graph 2 below list and display the totals and percent representation for kW DC nameplate rating ranges for residential installations in Manitoba. The blue-shaded rows show the highest number of installations are in the 5-to-40kW DC range, representing 88% of all residential installations and 33% of the total solar kW DC capacity in Manitoba.

Table 5: Residential Solar Installations

kW DC Range	No. Inst. in kW DC Range	% of Total Residential Installations	Total kW DC	Percent of Total Manitoba kW DC
< 5kW	40	4.8%	143	0.4%
5kW to <10kW	235	28.2%	1,849	5.1%
10kW to <15kW	159	19.1%	1,941	5.3%
15kW to <20kW	114	13.6%	2,005	5.5%
20kW to <25kW	80	9.6%	1,755	4.8%
25kW to <30kW	61	7.3%	1,672	4.6%
30kW to <35kW	50	6.0%	1,621	4.5%
35kW to <40kW	35	4.2%	1,324	3.6%
40kW to <45kW	15	1.8%	643	1.8%
45kW to <50kW	14	1.7%	669	1.8%
50kW to <60kW	14	1.7%	752	2.1%
60kW to <70kW	8	1.0%	517	1.4%
70kW to <80kW	6	0.7%	450	1.2%
80kW to <90kW	1	0.1%	90	0.2%
90kW-<100kW	0	0.0%	0	0.0%
100kW-125kW	2	0.2%	221	0.6%
	834 Residential Installations		15,652	43.1%

Graph 2



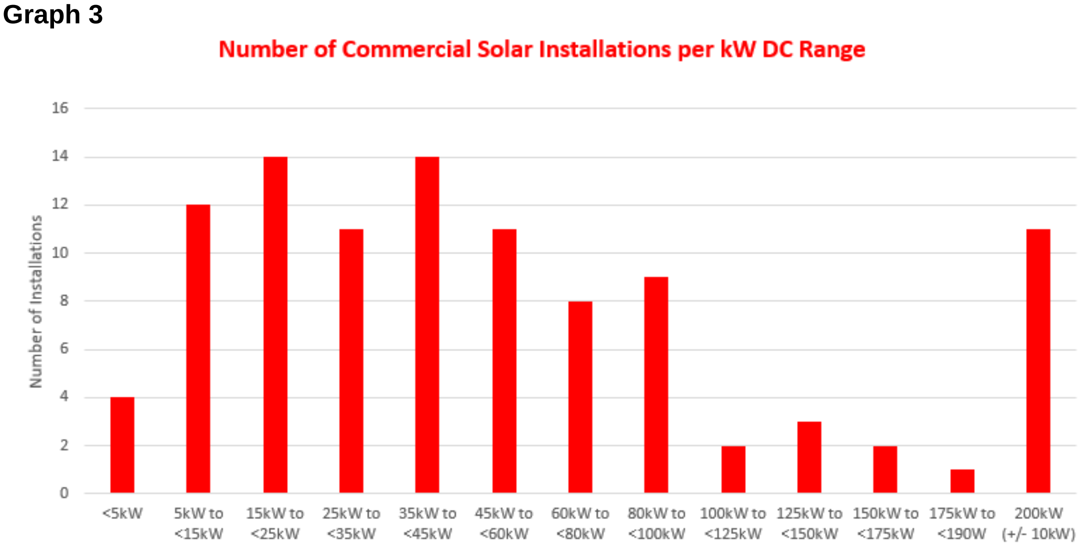
Commercial Installations

Table 6 and Graph 3 below list and display the totals for kW DC nameplate rating ranges for commercial installations in Manitoba. The shaded rows show the largest number of commercial installations spanning from 5-to-100 kW DC. Each range in this span are balanced at approximately 8%-to-12% per range group. The span of 5-to-100 kW DC represents 77% of all installations and 9% of the total kW DC solar capacity in Manitoba.

Table 6: Commercial Solar Installations

kW DC Range	No. Inst. in kW DC Range	% of Total Commercial Installations	Total kW DC	Percent of Total Manitoba kW DC
<5kW	4	3.9%	14	0.0%
5kW to <15kW	12	11.8%	114	0.3%
15kW to <25kW	14	13.7%	276	0.8%
25kW to <35kW	11	10.8%	336	0.9%
35kW to <45kW	14	13.7%	565	1.6%
45kW to <60kW	11	10.8%	568	1.6%
60kW to <80kW	8	7.8%	558	1.5%
80kW to <100kW	9	8.8%	805	2.2%
100kW to <125kW	2	2.0%	217	0.6%
125kW to <150kW	3	2.9%	428	1.2%
150kW to <175kW	2	2.0%	327	0.9%
175kW to <190W	1	1.0%	177	0.5%
200kW (+/- 10kW)	11	10.8%	2,205	6.1%
Totals	102 Commercial Installations		6,590	18.1%

Graph 3



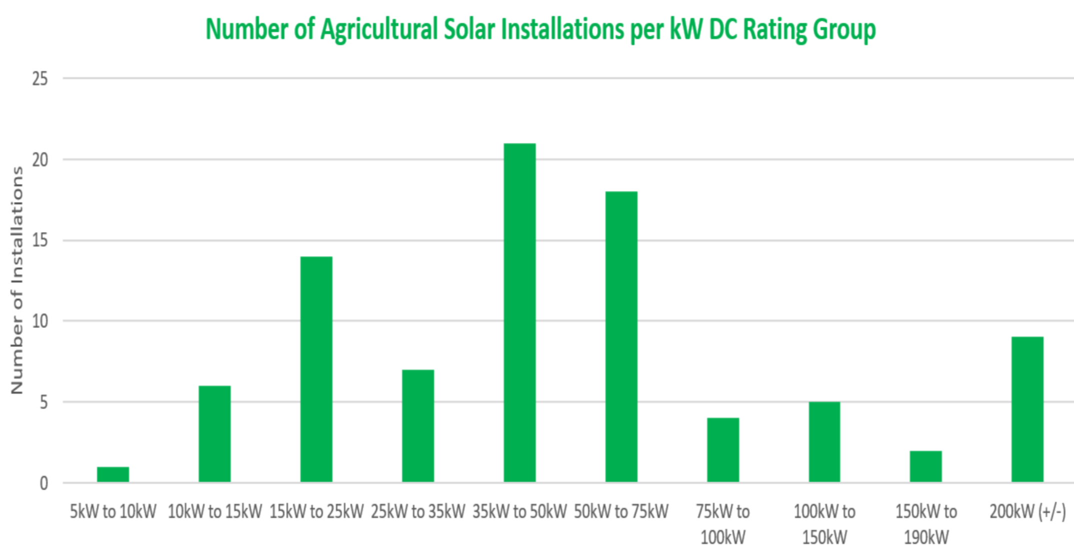
Agricultural Installations

Table 7 and Graph 4 below list and display the totals for agricultural kW DC nameplate rating ranges in Manitoba. The shaded rows show the highest number of installations are in the 5-to-80kW DC range, representing 78% of all residential installations and 7% of the total solar kW DC capacity in Manitoba. Installations in the 200 kW DC range total 10% of all agricultural installations and represent 5% of all Manitoba capacity.

Table 7: Agricultural Solar Installations

kW DC Range	No. Inst. in kW DC Range	% of Total Agricultural Installations	Total kW DC	Percent of Total Manitoba kW DC
<5kW	0	0.0%	0	0.0%
5kW to <15kW	9	10.2%	97	0.3%
15kW to <25kW	11	12.5%	220	0.6%
25kW to <35kW	9	10.2%	265	0.7%
35kW to <45kW	18	20.5%	700	1.9%
45kW to <60kW	7	8.0%	364	1.0%
60kW to <80kW	15	17.0%	1,014	2.8%
80kW to <100kW	3	3.4%	265	0.7%
100kW to <125kW	3	3.4%	360	1.0%
125kW to <150kW	2	2.3%	256	0.7%
150kW to <175kW	2	2.3%	318	0.9%
175kW to <190W	0	0.0%	0	0.0%
200kW (+/- 10kW)	9	10.2%	1,801	5.0%
Totals	88 Agricultural Installations		5,660	15.6%

Graph 4



Communal Living Colony Installations

The one 200 kW DC communal living colony included in this study showed 100% of the solar energy generation was delivered directly to the customer load with 0% exported to the grid.

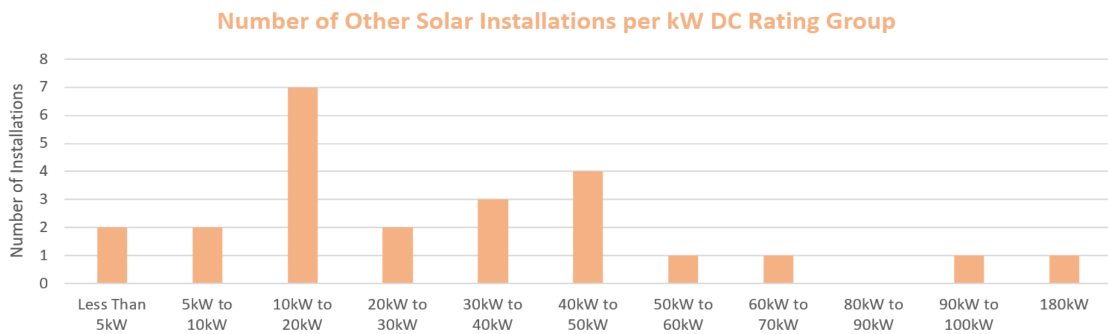
Other Types of Installations

Table 8 and Graph 5 below list and display the totals for Manitoba installations that could not be grouped into a category.

Table 8: Other Solar Installations (campgrounds, church, kennel, storage, lift station, pump house, condo, stables, hobby shop, cottage/cabin)

kW DC Range	No. Inst. in kW DC Range	% of Total Agricultural Installations	Total kW DC	Percent of Total Manitoba kW DC
<5kW	2	8.3%	7	0.0%
5kW to <10kW	2	8.3%	15	0.0%
10kW to<20kW	7	29.2%	106	0.3%
20kW to <30kW	2	8.3%	54	0.1%
30kW to <40kW	3	12.5%	97	0.3%
40kW to <50kW	4	16.7%	180	0.5%
50kW to <60kW	1	4.2%	50	0.1%
60kW to <70kW	1	4.2%	67	0.2%
70kW to <80kW	0	0.0%	0	0.0%
80kW to <90kW	0	0.0%	0	0.0%
90kW to <100kW	1	4.2%	97	0.3%
100kW to <125kW	0	0.0%	0	0.0%
125kW to <150kW	0	0.0%	0	0.0%
150kW to <175kW	0	0.0%	0	0.0%
180kW	1	4.2%	178	0.5%
Totals	24 Other Installations		851 kW DC	2.3%

Graph 5



4.0 Research Study Sample Group Sites

Twenty solar installations ranging from 3 kW to 200 kW were selected for this study from the following customer usage groups:

10	Residential
5	Commercial
5	Agricultural/farm

All twenty installations are in southern Manitoba. Only six of the 1,086 solar installations are in northern Manitoba. One of the purposes of this study is to gain statistical data representative of the majority, therefore no northern sites were selected.

Installation type:	13	ground installations
	7	rooftop installations
Primary heating:	12	electricity
	6	natural gas
	1	geo-thermal (GEO)
	1	coal
Invertor type:	11	micro inverters
	9	string inverters

5.0 Research Study Method

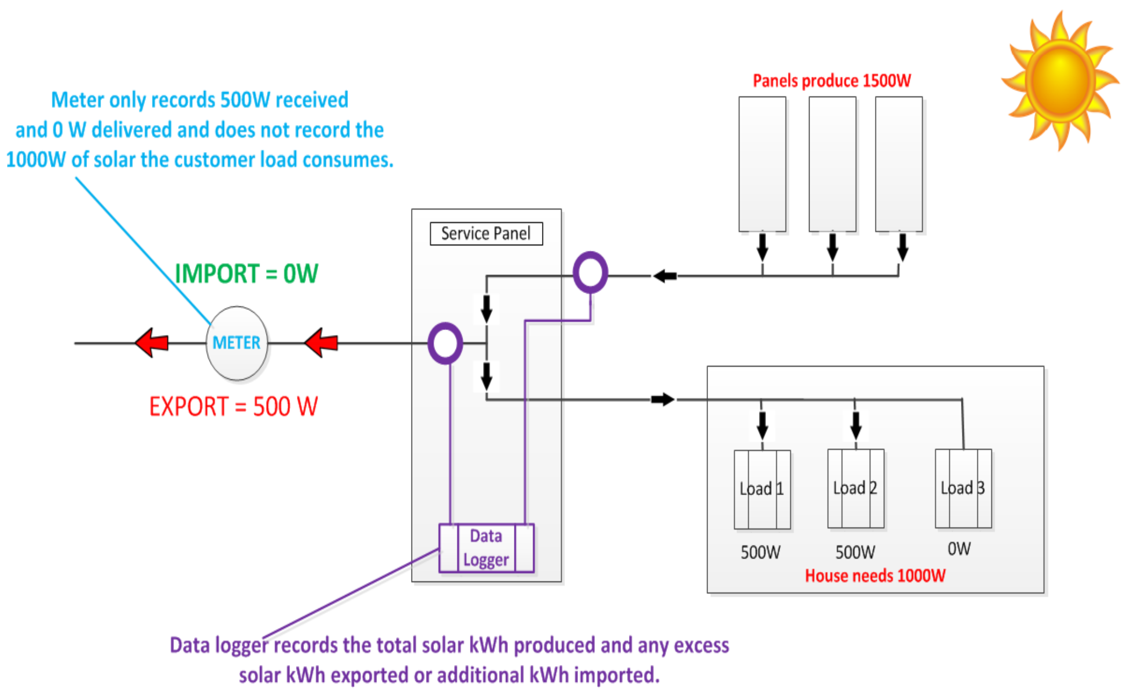
A load research data logger was connected at the solar panel output conductors and at the main electrical service conductors to measure the total energy produced by the solar array and the energy either purchased from, or exported to, the grid. Refer to Appendix A and B for installation details and drawings

The data logger recorded:

1. Total kWh energy delivered (purchased from the utility).
2. Total kWh energy received (exported to the utility).
3. Total kWh energy produced by the solar panels.

Using these three values the total solar energy sent to the customer load is calculated.

The data logger also recorded the average kW demand values over 5-minute intervals. This allowed the overall daily, monthly, seasonal and yearly load profiles to be evaluated and used to determine peak kW demand output, time of day of peak output, and total hours per day of solar generation which varies seasonally and with weather conditions.



In this case, 1500W of solar and 500W of export power is recorded therefore it can be calculated that 1000W of solar was supplied to the domestic load.

6.0 Sample Group Study Results: Calendar Year 2020

The sections below present the data collected and data analysis for the research sample group.

6.1 Average Annual kWh Output vs. DC Nameplate Rating

The totalized annual AC kWh output of the solar installations divided by the totalized DC kW nameplate ratings produces a statistical value that can be used to accurately estimate the total annual solar AC kWh output for ground, rooftop or combined solar installations.

This study showed a difference between the annual AC kWh output of ground installations and rooftop installations therefore Tables 9 and 10 provide separate calculation factors for ground and rooftop types. The main factor in output variance is the tilt angle between ground and rooftop installations; the overall average tilt angle of ground installations is 41^{o} and compared to rooftop installation average of 23^{o}. Other factors are snow-cover and shading which affects rooftop installations more than ground installations.

Table 9: Ground Installations Annual kWh Output:

Installation	Inst Type	DC kW Nameplate Rating	Measured AC kWh Solar Output (O/P)
14	Ground	11.7	15,543
1	Ground	22.8	22,403
16	Ground	23.6	29,004
20	Ground	44.9	60,681
18	Ground	44.9	52,427
19	Ground	49.5	65,140
2	Ground	55.3	74,505
7	Ground	62.1	75,781
3	Ground	65.6	84,215
9	Ground	95.2	114,694
4	Ground	96.5	129,481
10	Ground	155	199,796
5	Ground	200	233,403
	Total	927	1,157,073
		Average annual AC kWh output per kW DC nameplate rating	**1,248***

***Refer to Section 5.3 for Normalized Solar Calculation to be used for standard ground installation estimates.**

Table 10: Rooftop Installations Annual kWh Output:

Installation	Inst Type	DC kW Nameplate Rating	Measured AC kWh Solar O/P
11	Rooftop	3.9	4,592
6	Rooftop	9.9	10,435
12	Rooftop	10.2	12,337
13	Rooftop	11.1	10,735
15	Rooftop	12.0	15,483
17	Rooftop	35.9	33,320
8	Rooftop	67.7	73,045
	Total	151	157,947
		Average annual AC kWh output per kW DC nameplate rating	**1,059***

***Refer to Section 5.3 for Normalized Solar Calculation to be used for standard rooftop installation estimates.**

6.2 NREL PV-Watts® Solar Energy Calculator

When the sample study results in Section 5.1 were compared to the PV-Watts® solar production calculator provided by the National Renewable Energy Laboratory (NREL), they were found to be within 1.7% for the ground installations, and within 3.0% for rooftop.

It is important to note that to attain acceptable accuracy when using the PV-Watts® calculator, the applicable estimated system losses and advanced parameters must be entered into the calculator. Refer to Appendix C for further information on the PV-Watts® solar production calculator.

If only the DC nameplate rating is entered and all other calculator inputs are left at the default settings, the errors could be as high as 14% overrated kWh output for ground-type installations and 29% overrated kWh output for rooftop-type.

6.3 Normalized Solar Output Calculations

The following calculations below were derived using the findings from the study group from year 2020 normalized to a 30-year statistical average using pyrometer records for the Manitoba geographic location, attained from the NASA Power Laboratory. Refer to Appendix E for further information.

These calculations can be used to estimate the total annual kWh output for **NEW*** solar installations in Manitoba with reasonable accuracy:

Calculation 1: Annual Ground kWh output based on kW DC Nameplate Rating (NPR)

$$\text{Estimated annual kWh solar output}_{\text{Ground Inst}} = \text{DC kW}_{\text{NPR}} \times 1200 \text{ kWh/DC kW}_{\text{NPR}}$$

Calculation 2: Annual Rooftop kWh output based on kW DC Nameplate Rating (NPR)

$$\text{Estimated annual kWh solar output}_{\text{Rooftop Inst}} = \text{DC kW}_{\text{NPR}} \times 1020 \text{ kWh/DC kW}_{\text{NPR}}$$

Example:

The estimated annual kWh output estimate for a 95 kW DC rated ground installation

= 95 kW x 1200 kWh/kW DC

= 114,000 kWh total annual output

***These calculations are for new (0-to-3years old) installations. Solar PV installations decline in performance by approximately 0.80% per year. Most warrantees guarantee 90% of original installed performance at 10 years declining to 80% at 25 years. Refer to Appendix D for further information.**

6.4 Solar Energy Pilot Program Calculated Savings vs. Research Study Results

When the Solar Energy Pilot was originally launched, the estimated annual kWh solar savings, entered in the DRIP (Distributed Resource Interconnection process) application database, was derived using the following calculation:

$$\boxed{\text{Estimated annual kWh output} = \text{DC kW NPR} \times 1317 \text{ kWh/DC kW NPR}}$$

The value of 1317 kWh-per-kW DC-nameplate rating is the relationship produced if only the geographic area and DC nameplate rating is entered in the PV-Watts® solar production calculator and all other inputs left at default settings.

To attain accurate solar savings estimates important advanced inputs need to be entered such as installed tilt angle, DC-to-AC ratio, percent snow cover, and age of the installation. Refer to Appendix C for information on advanced input values.

6.5 Percent of Solar kWh Exported – Percent of Solar to Customer Load

The intent of this section is to provide statistical inputs for calculating estimated annual output and savings for specific customer installation types.

Table 11 lists the individual study group annual average percent of total solar kWh output exported and percent sent to the customer load for the year 2020.

Table 11: Overall Annual Average Solar Export-Solar to Customer (YR2020):

Installation	Total Solar Gen kWh	Solar Exported kWh	Solar to Customer Load kWh	% Solar kWh Exported	% Solar kWh to Customer Load	Primary Heating
16	29,004	18,258	10,765	63%	37%	Natural Gas
13	10,735	2,628	7,895	24%	76%	Natural Gas
7	75,781	39,077	36,703	52%	48%	Natural Gas
12	12,337	4,831	7,506	39%	61%	Natural Gas
11	4,592	2,249	2,342	49%	51%	Natural Gas
8	73,045	35,410	37,635	48%	52%	Natural Gas
17	33,320	18,509	14,815	56%	44%	Electricity GEO
19	65,140	36,917	28,137	57%	43%	Electricity
1	22,403	10,263	12,153	46%	54%	Electricity
14	15,543	8,395	7,122	54%	46%	Electricity
15	15,483	8,370	7,096	54%	46%	Electricity
10	199,796	126,744	72,998	65%	35%	Electricity
3	84,215	56,305	27,908	67%	33%	Electricity
6	10,435	8,612	1,841	82%	18%	Electricity
9	114,694	59,144	55,529	52%	48%	Electricity
18	52,427	38,653	14,107	74%	26%	Electricity
4	129,481	88,488	40,993	68%	32%	Electricity
20	60,681	44,285	16,397	73%	27%	Electricity
5*	233,403	0	233,403	0%	100%	Electricity
2	74,505	43,415	31,122	58%	42%	Coal

Totals All Twenty			Overall Average	
1,317,020	650,553	666,647	49%	51%

Totals Excluding Installation 5*			Averages Excluding Installation 5*	
1,083,617	650,553	433,064	60%	40%

*Installation 5 is a Communal colony that uses 100% of all solar generation for their domestic load.

Tables 12 and 13 compare the export/import annual averages of natural gas and electrically heated customers

Table 12: Natural Gas Heated Premises (YR 2020):

Installation	Total Solar Gen kWh	Solar Exported kWh	Solar to Customer Load kWh	% Solar kWh Exported	% Solar kWh to Customer Load	Primary Heating
16	29,004	18,258	10,765	63%	37%	Natural Gas
13	10,735	2,628	7,895	24%	76%	Natural Gas
7	75,781	39,077	36,703	52%	48%	Natural Gas
12	12,337	4,831	7,506	39%	61%	Natural Gas
11	4,592	2,249	2,342	49%	51%	Natural Gas
8	73,045	35,410	37,635	48%	52%	Natural Gas

Totals Natural Gas Heated			Overall Average	
205,494	102,453	102,846	50%	50%

Table 13: Electrically Heated Premises (YR 2020):

Installation	Total Solar Gen kWh	Solar Exported kWh	Solar to Customer Load kWh	% Solar kWh Exported	% Solar kWh to Customer Load	Primary Heating
17	33,320	18,509	14,815	56%	44%	Electricity GEO
19	65,140	36,917	28,137	57%	43%	Electricity
1	22,403	10,263	12,153	46%	54%	Electricity
14	15,543	8,395	7,122	54%	46%	Electricity
15	15,483	8,370	7,096	54%	46%	Electricity
10	199,796	126,744	72,998	65%	35%	Electricity
3	84,215	56,305	27,908	67%	33%	Electricity
6	10,435	8,612	1,841	82%	18%	Electricity
9	114,694	59,144	55,529	52%	48%	Electricity
18	52,427	38,653	14,107	74%	26%	Electricity
4	129,481	88,488	40,993	68%	32%	Electricity
20	60,681	44,285	16,397	73%	27%	Electricity

Totals Electrically Heated			Overall Average	
803,618	504,685	299,096	63%	37%

Tables 14-to-16 compare the export/import annual averages for residential, commercial, and agricultural installations. The last two rows of each table summarize the differences between natural gas and electrically heated installations for each group. Communal colonies export 0% of total solar kWh output.

A table was not provided for the various "other" customer installation types. These represent only 2.2% of all solar installations in Manitoba and 2.3% of the total Manitoba solar capacity.

Table 14: Residential Installations (YR 2020):

Installation	Total Solar Gen kWh	Solar Exported kWh	Solar to Customer Load kWh	% Solar kWh Exported	% Solar kWh to Customer Load	Primary Heating
16	29,004	18,258	10,765	63%	37%	Natural Gas
13	10,735	2,628	7,895	24%	76%	Natural Gas
12	12,337	4,831	7,506	39%	61%	Natural Gas
11	4,592	2,249	2,342	49%	51%	Natural Gas
17	33,320	18,509	14,815	56%	44%	Electricity GEO
19	65,140	36,917	28,137	57%	43%	Electricity
14	15,543	8,395	7,122	54%	46%	Electricity
15	15,483	8,370	7,096	54%	46%	Electricity
18	52,427	38,653	14,107	74%	26%	Electricity
20	60,681	44,285	16,397	73%	27%	Electricity

Totals all Residential			Overall Average	
299,262	183,095	116,182	61%	39%

Totals Natural Gas Residential			Overall Average	
56,668	27,966	28,508	50%	50%

Totals Electric Residential			Overall Average	
242,594	155,129	87,674	64%	36%

Table 15: Commercial Installations (2020):

Installation	Total Solar Gen kWh	Solar Exported kWh	Solar to Customer Load kWh	% Solar kWh Exported	% Solar kWh to Customer Load	Primary Heating
7	75,781	39,077	36,703	52%	48%	Natural Gas
8	73,045	35,410	37,635	48%	52%	Natural Gas
10	199,796	126,744	72,998	65%	35%	Electricity
6	10,435	8,612	1,841	82%	18%	Electricity
9	114,694	59,144	55,529	52%	48%	Electricity

Totals Commercial			Overall Average	
473,751	268,987	204,706	57%	43%

Totals Commercial Natural Gas			Overall Average	
148,826	74,487	74,338	50%	50%

Totals Commercial Electricity			Overall Average	
324,925	194,500	130,368	60%	40%

Table 16: Agricultural Installations (YR 2020):

Installation	Total Solar Gen kWh	Solar Exported kWh	Solar to Customer Load kWh	% Solar kWh Exported	% Solar kWh to Customer Load	Primary Heating
1	22,403	10,263	12,153	46%	54%	Electricity
3	84,215	56,305	27,908	67%	33%	Electricity
4	129,481	88,488	40,993	68%	32%	Electricity
5*	233,403	0	233,403	0%	100%	Electricity
2	74,505	43,415	31,122	58%	42%	Coal

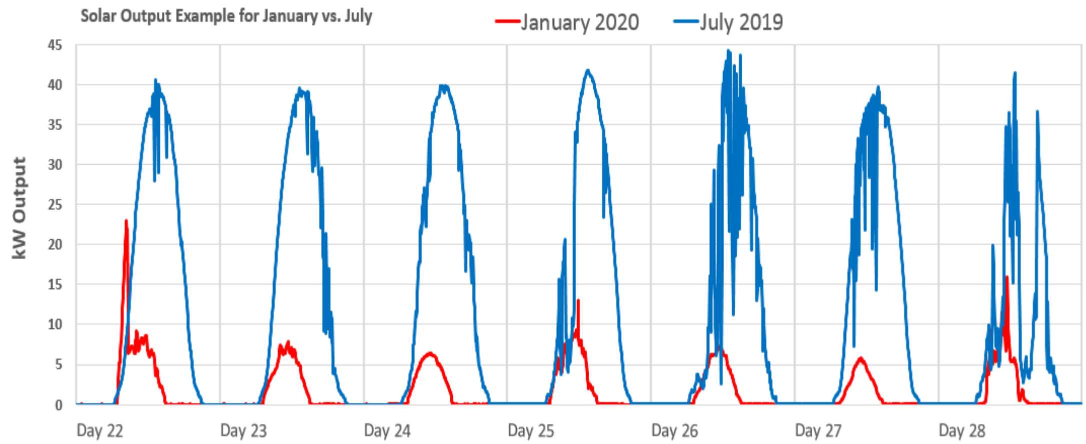
Totals All Agricultural			Overall Average	
544,007	198,471	345,579	36%	64%

*Totals Excluding Communal Living Customer			Overall Average	
310,604	198,471	112,176	64%	36%

6.6 Seasonal Solar Output Performance

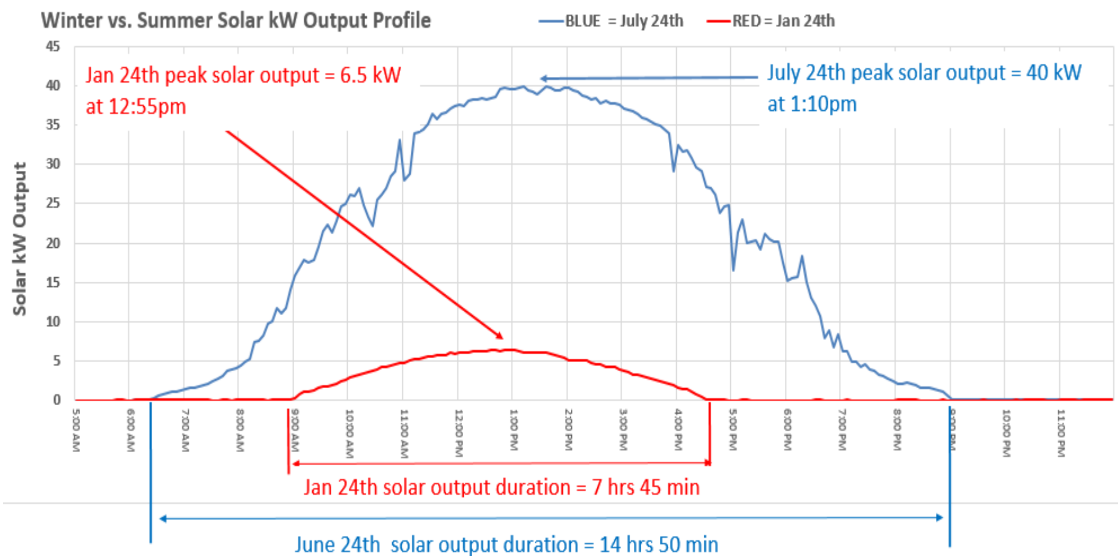
Graph 6 below shows an example of solar kW output for one week in the winter vs. one week in the summer for one installation. It demonstrates the effects of the seasonal position of the sun relative to the installed (fixed) angle of the solar array, lower sunlight hours, overcast conditions and possible snow cover on the panels. These variables lead to reduced solar kW demand and kWh energy in the peak heating season. Note that the data for the last week of January and July for *this installation* was specifically chosen because it provides a very good, one full week example of the potential extremes of seasonal solar performance.

GRAPH 6



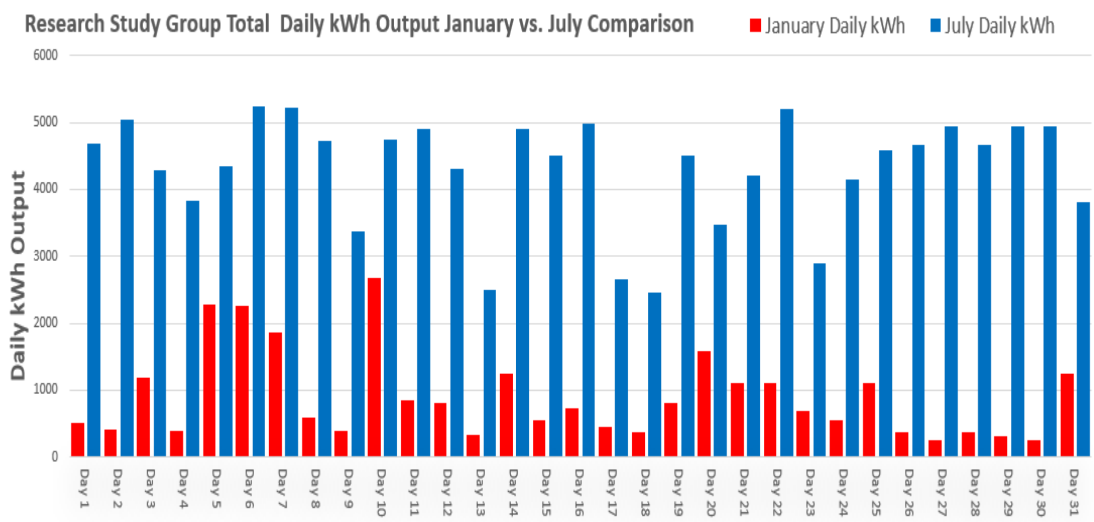
Graph 7 below focuses on Day 24 of Graph 6 above. This day was chosen because the smooth output curves help demonstrate a good example of lower solar output and reduced daylight hours when comparing one winter day to one summer day.

GRAPH 7



Graph 8 displays an example of seasonal kWh output variance using data for January and July 2020. The values in the graph are the total combined output for 19 installations in the research study group. It demonstrates the reduced daily kWh output in winter months vs. higher output in summer months. The total kWh for the month of January for the sample group was 27, 641 kWh vs. 133, 729 kWh in July.

GRAPH 8



6.7 Monthly Solar Generation Hours

Graph 9 and Table 17 display the total number of hours per month (averaged from the 20 sample installations) of solar generation capacity and the variation from winter to summer seasons. The ground-type and rooftop-type data shows there is little difference between ground and rooftop installations.

GRAPH 9

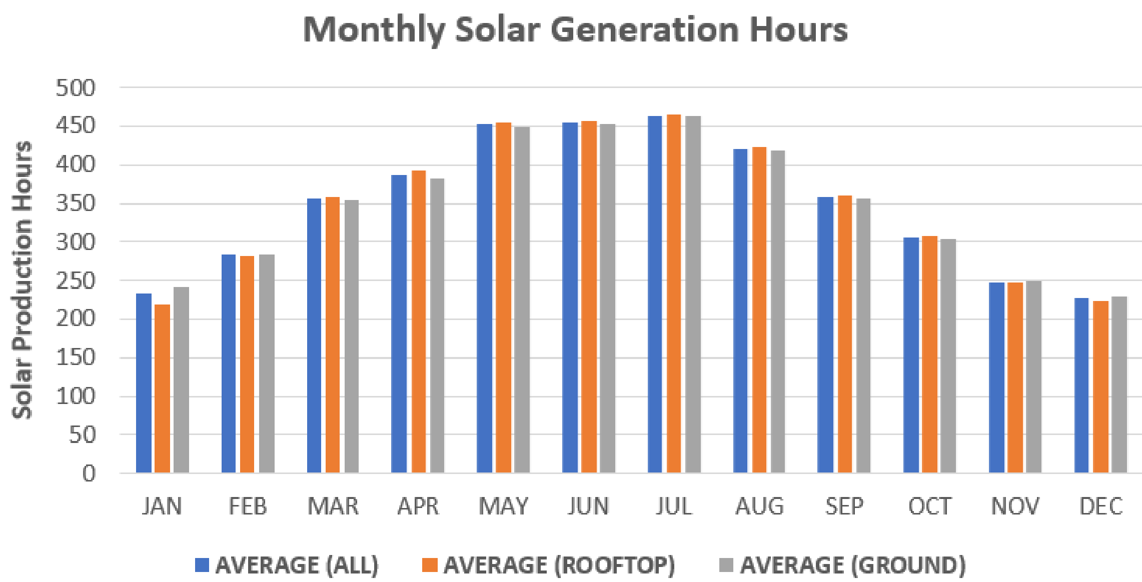


Table 17 Average Monthly Solar Generation Hours

Average Monthly Solar Generation Hours			
MONTH	All Installations	Rooftop Installations	Ground Installations
JAN	232	219	242
FEB	283	281	284
MAR	356	358	355
APR	387	392	383
MAY	452	456	450
JUN	456	458	454
JUL	464	465	463
AUG	421	423	419
SEP	358	360	356
OCT	305	307	304
NOV	248	248	249
DEC	227	223	229
ANNUAL Total 2020	4,189	4,190	4,188

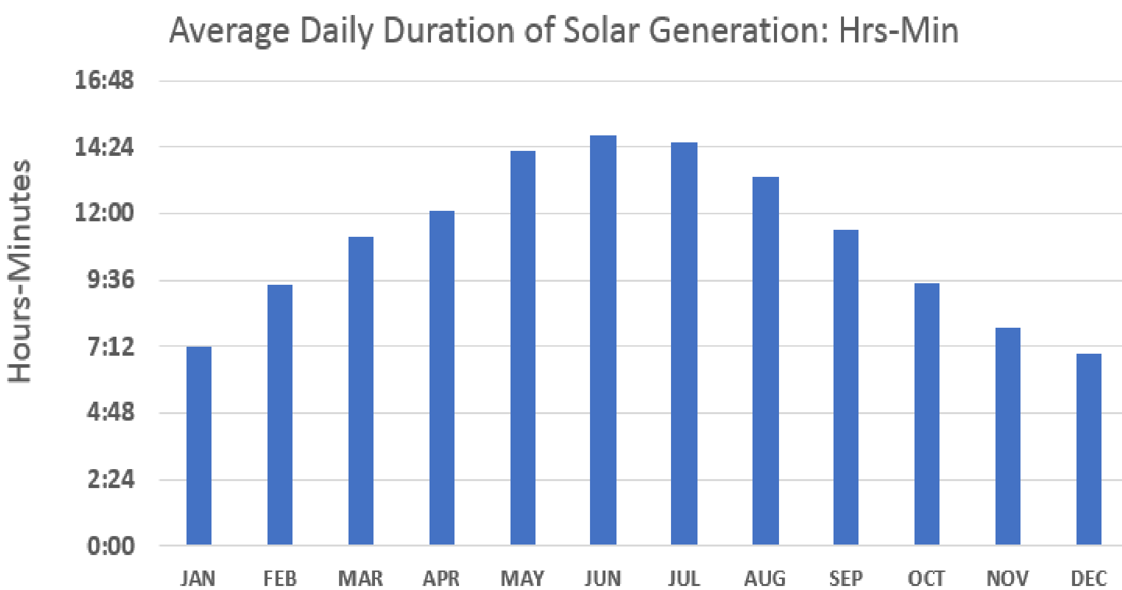
6.8 Average Daily Start-End-Duration of Solar Generation per Month

The intent of this section and Section 5.9 below is to help customers determine the best times of day per month to operate their largest electrical loads or combined electrical loads to gain the most benefit from their solar installations.

These sections demonstrate that customers should plan to use large electrical loads at peak generation periods. For the month of July, solar generation begins at approximately 6:30am, peaks at approximately 1:00pm-to-2pm, and ends at approximately 9:00pm. Using this guideline, the customer should plan to use large loads such as clothes dryers, dish washers or pool heaters in the 11:00am-to-3:00pm time range (for example) to gain the most dollar savings. If the customer pays $0.0874/kWh to import and is credited $0.03253/kWh (NUG rate) for exporting, it makes more sense to consume as much solar energy for domestic load instead of exporting at peak times.

Graph 10 demonstrates that in the winter months there is an average of 7-8 hours of generating potential, and in the summer months 14-to-15 hours.

GRAPH 10



Graph 11 and Table 18 below demonstrate that in the winter months solar generation does not begin until approximately 9:00am and stops approximately 4:30pm, totaling approximately 7-to8 hours of solar generation potential. In the summer months generation begins at approximately 6:00am and ends at approximately 9:00pm, totaling approximately 14-to-15 hours of generating potential.

GRAPH 11

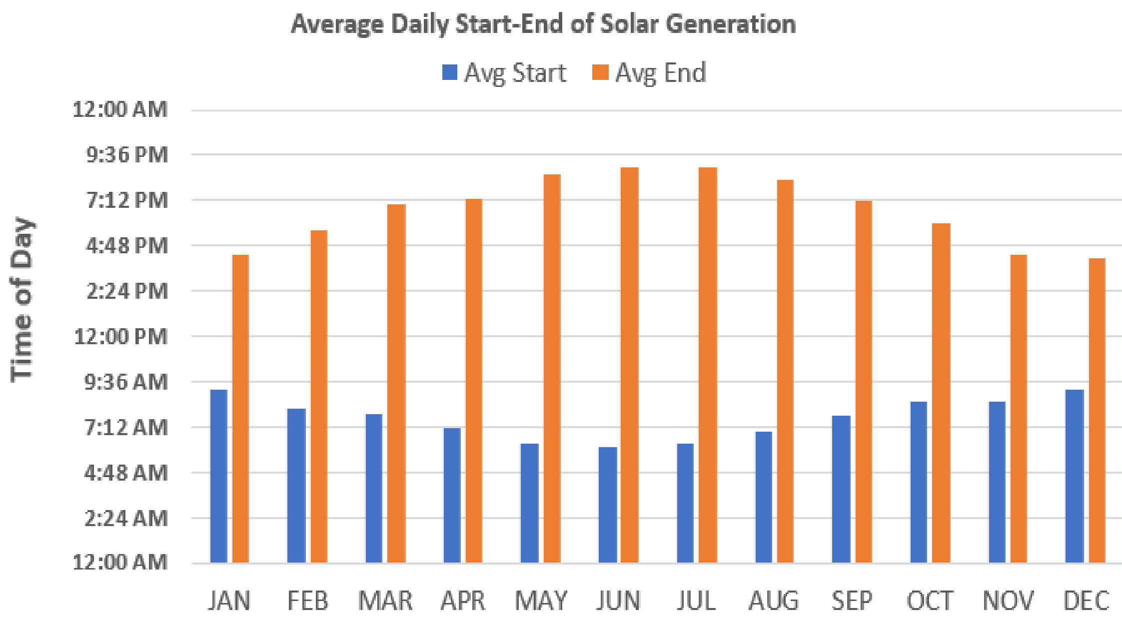


Table 18: Solar Generation Start-End-Duration

Solar Generation Start-End-Duration

	Avg Start	Avg End	Avg Duration Hr-Min
JAN	9:10 AM	4:20 PM	7:10
FEB	8:10 AM	5:35 PM	9:25
MAR	7:50 AM	7:00 PM	11:10
APR	7:10 AM	7:15 PM	12:05
MAY	6:20 AM	8:35 PM	14:14
JUN	6:05 AM	8:55 PM	14:50
JUL	6:20 AM	8:55 PM	14:35
AUG	6:55 AM	8:15 PM	13:20
SEP	7:45 AM	7:10 PM	11:24
OCT	8:30 AM	6:00 PM	9:30
NOV	8:30 AM	4:20 PM	7:50
DEC	9:10 AM	4:05 PM	6:55

6.9 Average Monthly Times of Peak Solar kW Demand Output

Graph 12 and Table 19 display the average time of day per month for the peak solar output with daylight-savings-time (DST) applied. Peak solar production occurs from approximately 1:00-to-1:30PM in the summer months, and 12:00-to-1:00PM in the winter months. This data from the sample group was verified to closely match peak-time-of-day output values from the PV-Watts® Calculator.

GRAPH 12

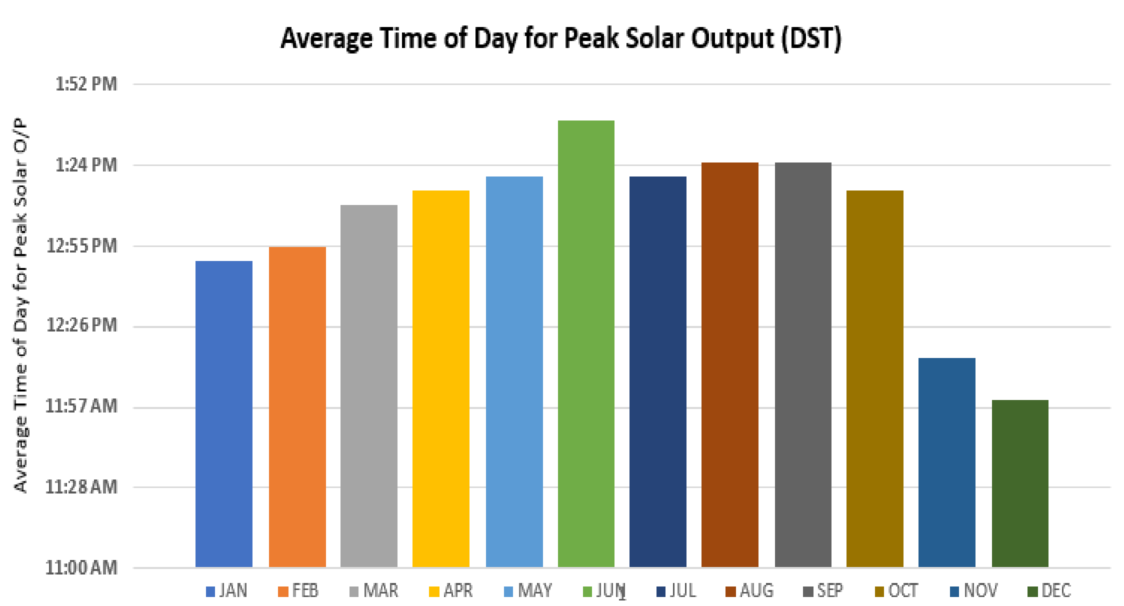


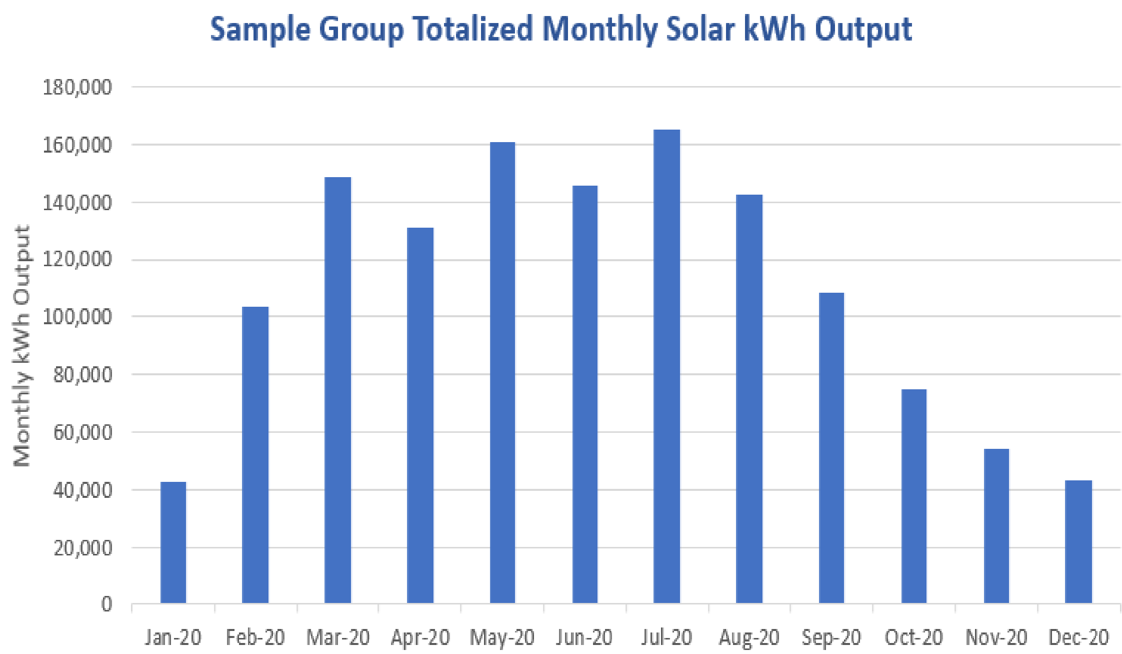
Table 19: Average Time of Day for Peak Solar Output (shaded area DST)

Month	Average Time of Peak Solar Output - DST	Average Time of Peak Solar Output
JAN	12:50 PM	12:50 PM
FEB	12:55 PM	12:55 PM
MAR	1:10 PM	12:10 PM
APR	1:15 PM	12:15 PM
MAY	1:20 PM	12:20 PM
JUN	1:40 PM	12:40 PM
JUL	1:20 PM	12:20 PM
AUG	1:25 PM	12:25 PM
SEP	1:25 PM	12:25 PM
OCT	1:15 PM	12:15 PM
NOV	12:15 PM	12:15 PM
DEC	12:00 PM	12:00 PM

6.10 Monthly Solar kWh Output (20 installations sample group)

Graph 13 displays the range in monthly solar kWh output demonstrating the rising/declining output capacity from summer-to-winter months. **The data below represents the totalized results for all twenty sample installations. Refer to Section 6.0 below for statistical estimates for the output of all solar installations in Manitoba.**

GRAPH 13



6.11 Monthly Peak Solar kW AC Demand Output vs. DC Nameplate Rating

Graph 14 and Tables 20-to-22 display the totalized peak AC kW demand output per month as percent of DC nameplate rating. For example: the totalized DC nameplate value for all 20 study locations is 1,078 kW and the totalized AC kW output for April was 860 kW, therefore for the month of April, the solar AC kW output was only 80% of the totalized DC nameplate ratings.

The intent of this section to apply to these study results to estimate the peak output of the totalized installations in Manitoba. It is important to note that the peak demand may occur only once, or only a few times, per month depending on the weather conditions for any given month. in Section 7.4.

GRAPH 14

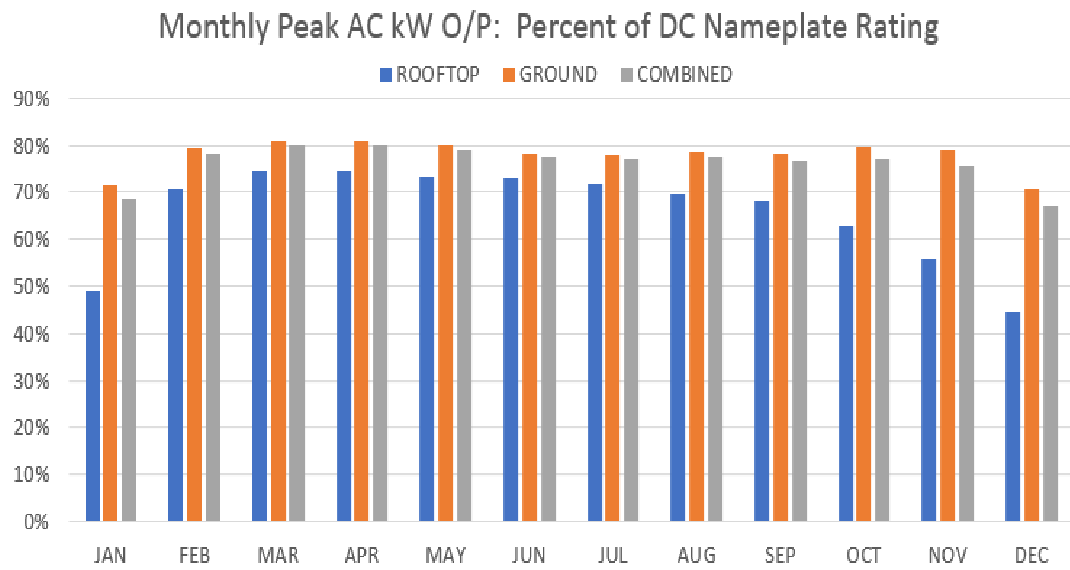


Table 20: Monthly Peak AC kW Output vs DC kW Nameplate Rating

Total DC Nameplate Rating = 1078 kW DC

MONTH	Peak AC kW Output	% of DC Nameplate Rating
JAN	737	68%
FEB	842	78%
MAR	860	80%
APR	860	80%
MAY	850	79%
JUN	834	78%
JUL	829	77%
AUG	832	77%
SEP	827	77%
OCT	830	77%
NOV	814	76%
DEC	721	67%

Table 21: Ground Type Monthly Peak AC kW Output vs DC kW Nameplate

Totalized Ground Type DC Nameplate Rating = 927 kW DC

MONTH	Peak AC kW Output	% of DC Rating
JAN	663	72%
FEB	735	79%
MAR	748	81%
APR	748	81%
MAY	740	80%
JUN	725	78%
JUL	720	78%
AUG	727	79%
SEP	724	78%
OCT	735	79%
NOV	730	79%
DEC	654	71%

Table 22: Rooftop Type Monthly Peak AC kW Output vs DC kW Nameplate

Totalized Rooftop Type DC Nameplate Rating = 151 kW DC

MONTH	Peak AC kW Output	% of DC Rating
JAN	74	49%
FEB	107	71%
MAR	112	74%
APR	112	74%
MAY	110	73%
JUN	110	73%
JUL	108	72%
AUG	105	70%
SEP	103	68%
OCT	95	63%
NOV	84	56%
DEC	67	44%

7.0 Research Study Results Applied to All Program Participants

Table 23 summarizes the statistics for all installations completed in Manitoba as part of the Solar Energy Program:

Table 23: Installation Totals for Manitoba

	No. Installations	Total DC kW*	Total AC kW**	DC-AC Ratio
Total installations in Manitoba	**1086**	**36,339**	**31,500**	**1.15**
Ground Installations	643	29,942	26,029	1.15
Rooftop Installations	443	6,397	5,471	1.17

* Totalized nameplate rating
** Totalized inverter rating

7.1 Annual Total Solar kWh Generation Estimate for Manitoba

The following annual estimates were derived using NREL PV-Watts® calculator using the applicable required losses and inputs in the advanced settings (refer to Appendix C), and the totalized nameplate values and ratios from the table in Section 6.0 above.

	Ground	Rooftop
Annual Solar kWh Gen	36,741,835	6,706,454
Total Annual kWh Gen	43,448,289	

7.2 Monthly Solar kWh Generation Estimate for Manitoba

Table 24 lists the monthly estimates derived using NREL PV-Watts® calculator with the applicable required loss inputs and correction factors from Appendix C, and the totalized nameplate values and ratios from the table in Section 6.0 above.

Table 24: Monthly Solar kWh Generation Estimates for Manitoba

Month	Solar Gen Total AC Output(kWh)		Total AC kWh O/P all 1,086 in Manitoba
	GROUND	ROOFTOP	
JAN	1,051,454	157,319	1,208,773
FEB	2,939,211	474,834	3,414,045
MAR	4,016,429	700,504	4,716,934
APR	3,681,186	684,082	4,365,268
MAY	4,423,669	877,335	5,301,003
JUN	3,803,850	772,678	4,576,528
JUL	4,524,009	909,022	5,433,031
AUG	4,070,961	774,533	4,845,494
SEP	3,035,182	540,477	3,575,658
OCT	2,392,124	392,952	2,785,077
NOV	1,556,806	238,959	1,795,765
DEC	1,246,954	183,758	1,430,711
Totals	36,741,835	6,706,454	43,448,289

7.3 Monthly Solar kWh Export Estimate for Manitoba

Table 25 lists monthly estimates derived using NREL PV-Watts® calculator with the applicable required loss inputs and correction factors from Appendix C, and the totalized nameplate values and ratios from the table in Section 6.0 above.

Table 25: Monthly Solar kWh Export Estimates for Manitoba

	Solar Export (kWh)		Total All 1,086 Solar	
Month	Ground*	Rooftop	**kWh EXPORT in Manitoba**	kWh to Customer Load*
JAN	130,847	20,451	151,298	1,057,475
FEB	1,056,502	154,064	1,210,566	2,203,480
MAR	1,569,926	322,391	1,892,317	2,824,617
APR	1,313,380	335,540	1,648,920	2,716,349
MAY	2,026,383	454,065	2,480,448	2,820,556
JUN	1,525,960	379,232	1,905,192	2,671,336
JUL	1,834,690	427,522	2,262,212	3,170,819
AUG	1,597,762	369,573	1,967,334	2,878,160
SEP	1,112,596	257,200	1,369,796	2,205,863
OCT	871,958	155,419	1,027,376	1,757,700
NOV	381,178	71,363	452,541	1,343,225
DEC	253,143	39,302	292,445	1,138,266
Totals	13,674,324	2,986,120	16,660,445	26,787,844
			38%	62%

*Export for ground installations and kWh-to-Customer-Load estimates were adjusted for communal living installations using the following method:

1. The totalized kW DC nameplate value for all ground installations in Manitoba, excluding communal colonies, was entered in PV-Watts®. The results are listed in the Solar-Export(kWh)-Ground* column.

2. The totalized kW DC nameplate value for all communal colony installations in Manitoba was entered in PV-Watts®. The results were added to the Total-all-1,086-kWh-to-Customer-Load* column.

7.4 Monthly Totalized Peak Solar kW AC Demand Output for Manitoba

The estimated values for the Graph 15 and Tables 26 and 27 below were derived by applying the statistical percent values from the actual sample group study results in Section 6.10 to the totalized DC nameplate values for Manitoba installations.

GRAPH 15

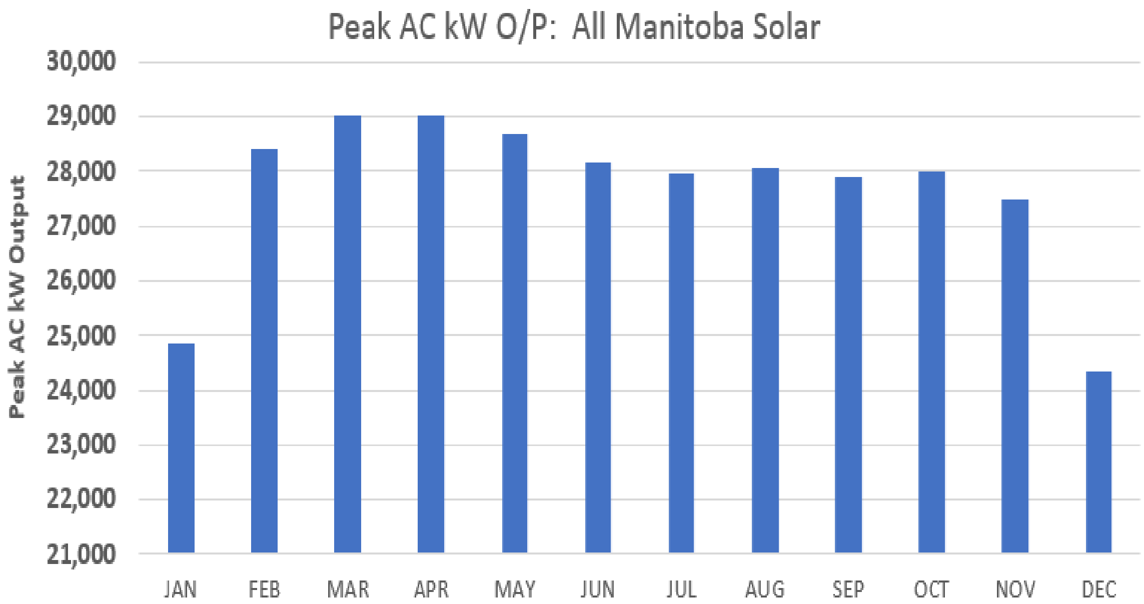


Table 26: Monthly Totalized Peak Solar kW AC Demand Output

Total DC Capacity = 36,321 kW

MONTH	Peak AC kW O/P: All Manitoba Solar	Percent of Capacity (Ground & rooftop Combined)
JAN	24,857	68%
FEB	28,416	78%
MAR	29,032	80%
APR	29,034	80%
MAY	28,694	79%
JUN	28,159	78%
JUL	27,962	77%
AUG	28,068	77%
SEP	27,897	77%
OCT	28,008	77%
NOV	27,469	76%
DEC	24,341	67%

Table 27: Monthly Totalized Peak Solar kW AC Demand Output – Ground vs. Rooftop

Total DC Capacity Ground =	29,933	kW
Total DC Capacity Rooftop=	6,388	kW

MONTH	GROUND Peak kW	Ground % of Total Capacity	ROOFTOP Peak kW	Rooftop % of Total Capacity
JAN	21,429	72%	3,137	49%
FEB	23,783	79%	4,520	71%
MAR	24,195	81%	4,753	74%
APR	24,199	81%	4,751	74%
MAY	23,933	80%	4,673	73%
JUN	23,436	78%	4,653	73%
JUL	23,302	78%	4,581	72%
AUG	23,502	79%	4,451	70%
SEP	23,420	78%	4,345	68%
OCT	23,785	79%	4,005	63%
NOV	23,599	79%	3,571	56%
DEC	21,160	71%	2,840	44%

8.0 Power Quality Considerations

Manitoba Hydro Corporate Policy P310: Maintaining Voltage Levels, defines the normal and extreme operating conditions for system voltage, shown in Table 28 below. This is a guideline for Manitoba Hydro to maintain voltage delivery within acceptable limits to help prevent power quality issues and damage to customer connected devices.

In the first few months after the initial solar installations, some customer complaints were directed at Manitoba Hydro for high voltage, flicker conditions and incidents of solar AC-inverters burning out.

8.1 Inverter Reactive Power Control

To assist the Power Quality Department and the Customer Energy Services Department with these complaints, the sample group data loggers were programmed to collect peak-voltage at the service entrance connection point over a period of one month. Investigation found that some inverters did not have their Reactive Power Control enabled when shipped from the manufacturer. Reactive Power Control is designed into the inverters to help control the voltage output and keep it within acceptable design limits. If RPC is not enabled, depending on the characteristics of the connected load, output voltage to the customer or the grid can get pushed up to over-voltage levels. Advising the customers and their contractors to enable the RPC mitigated the complaints.

Table 28: Manitoba Hydro Corporate Policy P310: Maintaining Voltage Levels

NORMAL SYSTEM VOLTAGES	EXTREME OPERATING CONDITIONS			
Single Phase		**Normal Operating Conditions**		
120/240 240 480 600	106/212 212 424 530	110/220 220 440 550	125/250 250 500 625	127/254 254 508 635
Three Phase 4-Conductor				
120/208Y 240/416Y 277/480Y 347/600Y	110/190 220/380 245/424 306/530	112/194 224/388 254/440 318/550	125/216 250/432 288/500 360/625	127/220 254/440 293/508 367/635
Three-Phase 3-Conductor				
240 480 600	212 424 530	220 440 550	250 500 625	254 508 635

8.2 Inverter Voltage Ramping

For a solar inverter to export power to the grid, it must put out a higher voltage than the grid to force it back. Solar inverters will ramp up, or boost, the voltage to slightly higher than line voltage. If line voltage is at the upper limit of normal operating conditions (Policy P310 Table 28), it is possible for solar inverters to ramp into the extreme operating conditions and affect the customer's connected load, and possibly other customers on the same distribution line.

If two or more solar installation are connected to the same distribution line, the voltage ramping condition may compound.

9.0 Best Practices and Notes for Solar Customers

The following suggestions may be offered to solar customers to help realize the most savings potential for their solar installations:

9.1 For installations equipped with *string inverters* (solar panels wired in series), if any part of a solar array (one or more single panels) is shadowed or blocked from the sun in any way, the kWh output and energy savings for the entire installation can be greatly affected. Even the slightest amount of snow, dirt or shading on a small section of the solar array can affect the kWh output. Customers should understand that their panels should be kept free of snow, dirt, or shadowing from tree cover, buildings, street signs and other sources occurring at certain times of the day.

9.2 Installations equipped with *microinverters* (one inverter for each solar panel) are less affected by shading losses. Although they may perform more efficiently than string inverters the overall installation costs are higher. One other disadvantage is with multiple inverters per installation, if one or a few inverters fail, it may be difficult to notice.

9.3 As presented in Sections 6.8 and 6.9 customers should plan to use large electrical loads at peak generation periods. For example: in the month of July, solar generation begins at approximately 6:30am, peaks at approximately 1:00pm-to-2pm, and ends at approximately 9:00pm. Using this guideline, the customer should plan to use large loads such as clothes dryers, dish washers or pool heaters in the 11:00am-to-3:00pm time range (for example) to gain the most dollar savings. If the customer is paying $0.0874/kWh to import vs. getting credited $0.03253/kWh (NUG rate) for exporting, it makes more sense to consume as much solar energy for domestic load vs. exporting at peak times.

9.4 Generally, ground installations produce more kWh annually and easier to perform maintenance, snow clearing and cleaning.

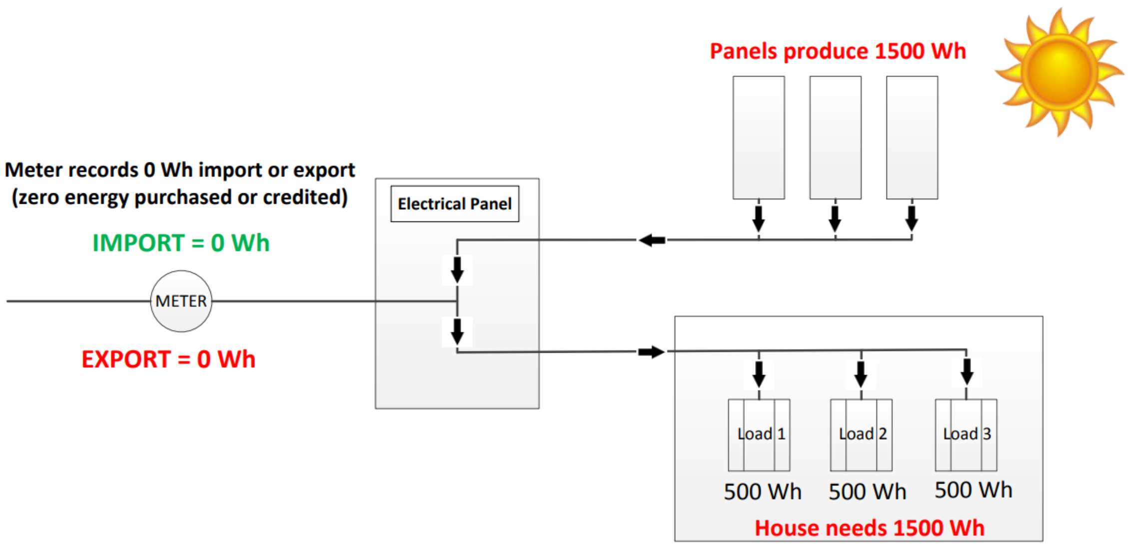
9.5 Limit the installation rating to serve domestic load vs. planning on savings from export (see point 2 above).

APPENDIX A

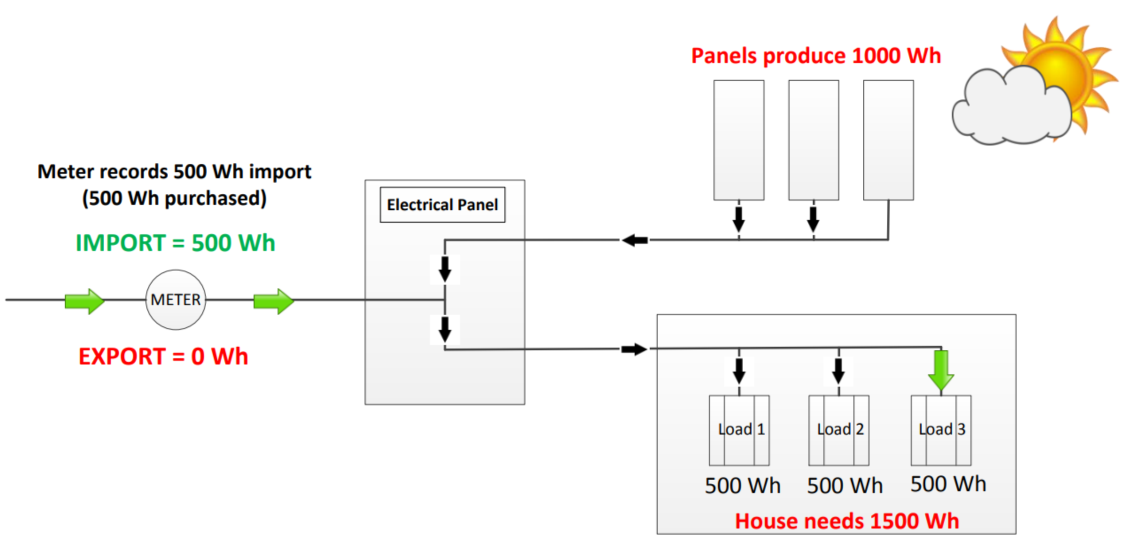
Revenue Metering Import/Export Energy Registers vs Total Solar output

Below are four possible scenarios demonstrating how the revenue meter does not record total solar generation or total residential consumption.

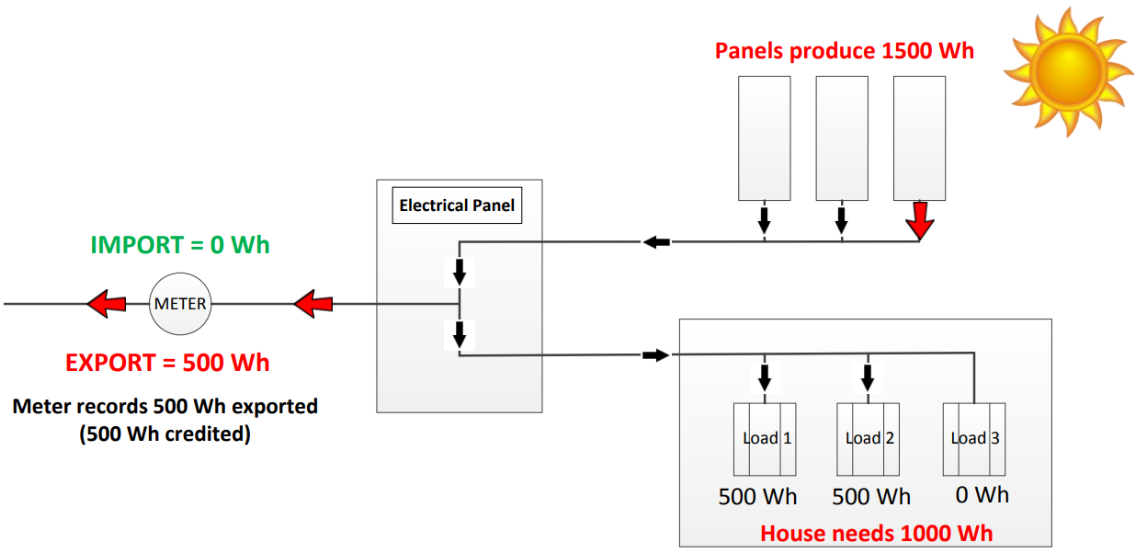
Scenario 1: Solar panels produce exactly what the house loads need. Note that the meter reads zero so the customer does not get credited for the 1500 Wh produced, but they also are not charged for the 1500 Wh they don't have to purchase from the grid. This is solar savings "unseen" by the meter.



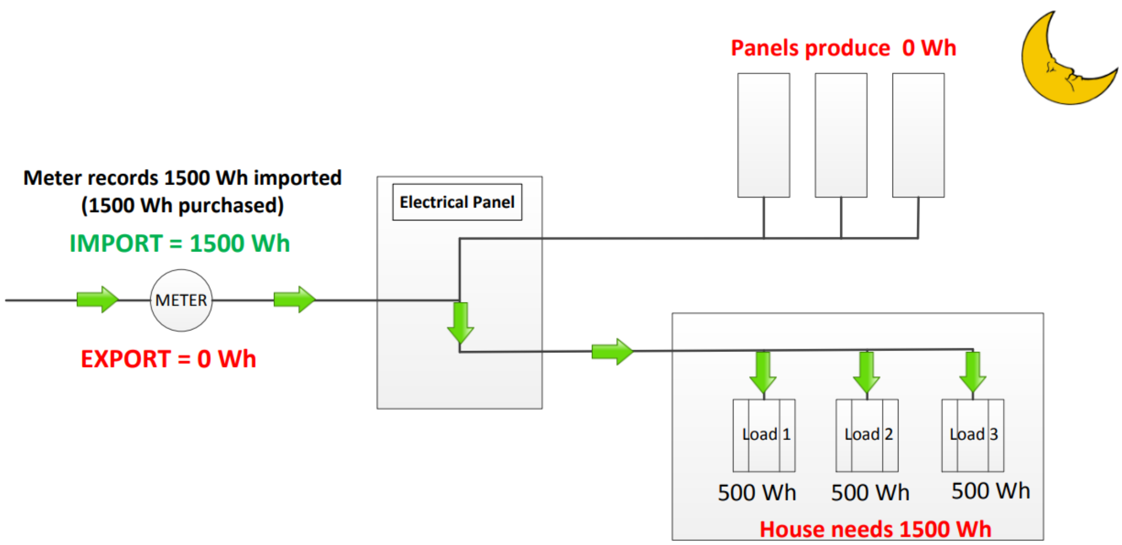
Scenario 2: Solar panels produce only part of the required house load so 500 Wh needs to be purchased from the grid. Note that the 1000 Wh of solar energy is not recorded by the meter and is "unseen" solar savings.



Scenario 3: Solar panels produce more than what the house load needs so 500 Wh is exported to the grid. The customer gets credited for the 500 Wh but 1000 Wh of solar savings (energy the customer didn't have to purchase) is "unseen" by the meter.



Scenario 4: Solar panels produce zero energy and all required energy is purchased from the grid.



Billing example using the four scenarios above:

	Wh Recorded by Meter		Wh Produced by Solar	Wh used by Customer
Scenario 1	**0**		**1500**	**1500**
Scenario 2	**500**	purchased	**1000**	**1500**
Scenario 3	**500**	credited	**1500**	**1000**
Scenario 4	**1500**	purchased	**0**	**1500**
Totals	**2000**	**purchased**	**4000**	**5500**
	500	**credited**		

The customer sees this on their bill:

- Billed for 2000 Wh
- Credited for 500 Wh

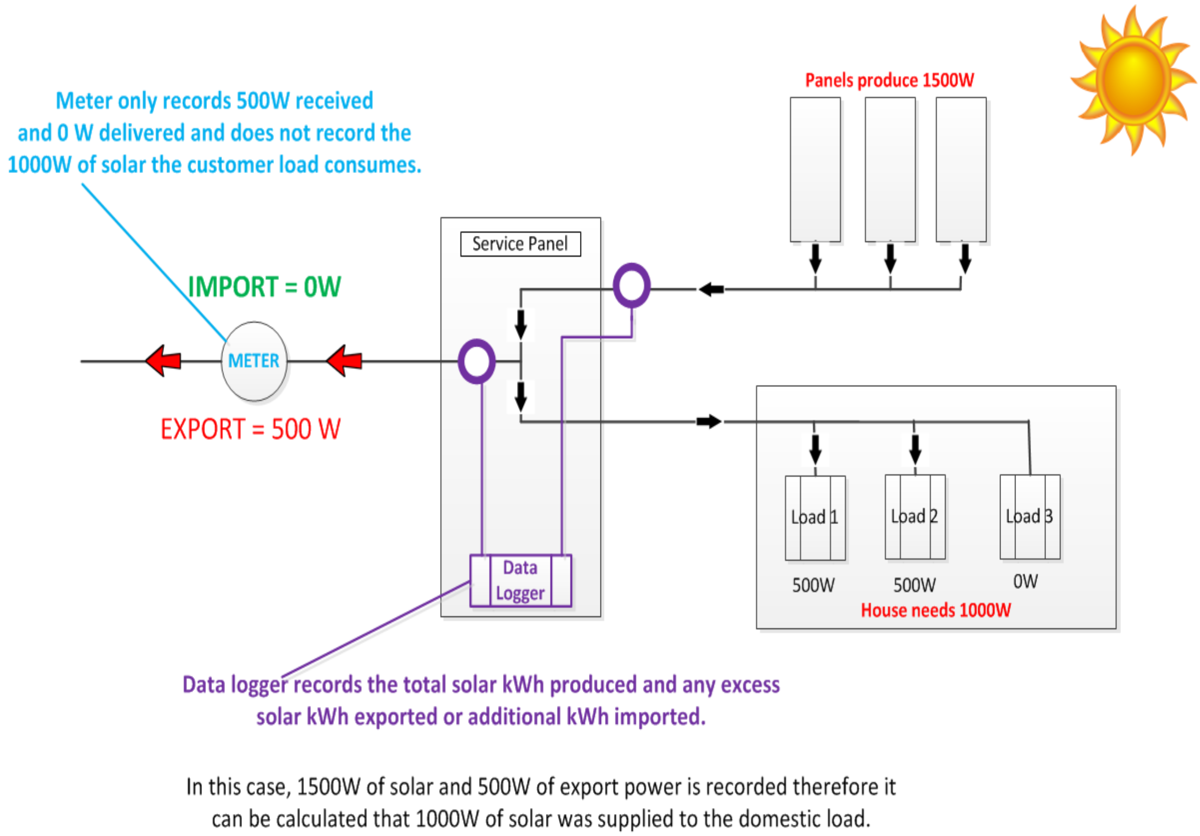
What the customer doesn't see is that without solar they would have been billed for 5500 Wh instead of 2000 Wh

The revenue meter can't provide the readings needed to show the customer that solar generation saved them from buying an extra 3500 Wh this month.

APPENDIX B

Research Data Logger Connection Points

The data logger records the same values the revenue meter measures
(kWh purchased and kWh credited), as well as the total solar kWh generated.
The total residential load can then be calculated.



APPENDIX C

NREL PV-WATTS® CALCULATOR Program Inputs

Online link: https://pvwatts.nrel.gov

NREL's PV-Watts® calculator is an online tool that allows homeowners, small building owners, installers and manufacturers to easily calculate estimated annual and monthly energy production of grid-connected PV energy systems throughout the world.

This calculator uses 30 years of historical solar irradiance and weather patterns.

NREL (National Reusable Energy Laboratory) is a national laboratory of the U.S. Department of Energy, Office of Energy and Renewable Energy operated by the Alliance for Sustainable Energy, LLC.

1. **PV-WATTS® Calculator System Information and Loss Inputs:**

   To have acceptable accuracy it is important to set up the calculator information boxes or drop-down window entries with the following inputs:

   SYSTEM INFO:

DC System Size:	Enter the DC nameplate rating
Module Type:	Standard
Array Type:	Fixed Open Rack or Fixed (roof mount)
System Losses:	Click on the "Loss Calculator" icon and use the following inputs:

Soiling:	2
Shading:	0 (or the applicable value)
Snow:	10% Ground or 20% Rooftop
Mismatch:	2
Wiring:	2
Connections:	0.5
Light Ind Deg:	1.5
Nameplate rtg:	1
Age:	2 (or applicable)
Availability:	3

Tilt (deg):	Enter tilt degrees angle if known or if not known, 41° for GROUND or 23° for ROOFTOP
Azimuth:	180° (or other if known)
Advanced Parameters:	Click on the drop-down window:

DC to AC Size Ratio:	as applicable
Inverter Efficiency:	as applicable
Ground Coverage:	leave at default value

2. Correction Factors for PV-Watts® Monthly kWh Output Estimates:

The PV-Watts® Calculator will produce monthly and annual kWh output estimates.
When calculating the monthly output for single installations or for totalized groups, the correction factors in the table below should be applied.

When comparing the PV-Watts® per-month values to the values found from the research group, it was found that PV-Watts® slightly overestimated or underestimated the outputs for Manitoba based installations. These correction factors used the results from the research sample group, normalized to the NASA Research Laboratory 30-year average.

Example: If the PV-Watts® Calculator estimates that an installation will produce 10,000 kWh in December, a more accurate value for that month would be:

$$10{,}000 \times 0.776 = 7{,}776 \text{ kWh}$$

PV-Watts® CORRECTION FACTOR	
Normalized to NASA 30 YR AVG	
JAN	0.548
FEB	1.443
MAR	1.177
APR	0.864
MAY	1.267
JUN	1.138
JUL	1.207
AUG	1.082
SEP	0.986
OCT	0.925
NOV	0.862
DEC	0.776

3. Tilt Angle Average for Ground and Rooftop Installations:

A very important input value for the accuracy of the PV-Watts® estimates is the tilt-angle of the installation. If the tilt angle is not known, the following statistical averages will produce results with reasonable accuracy:

Ground Type (fixed)Tilt Angle: **41º**

Rooftop Type (fixed) Tilt Angle: **23º**

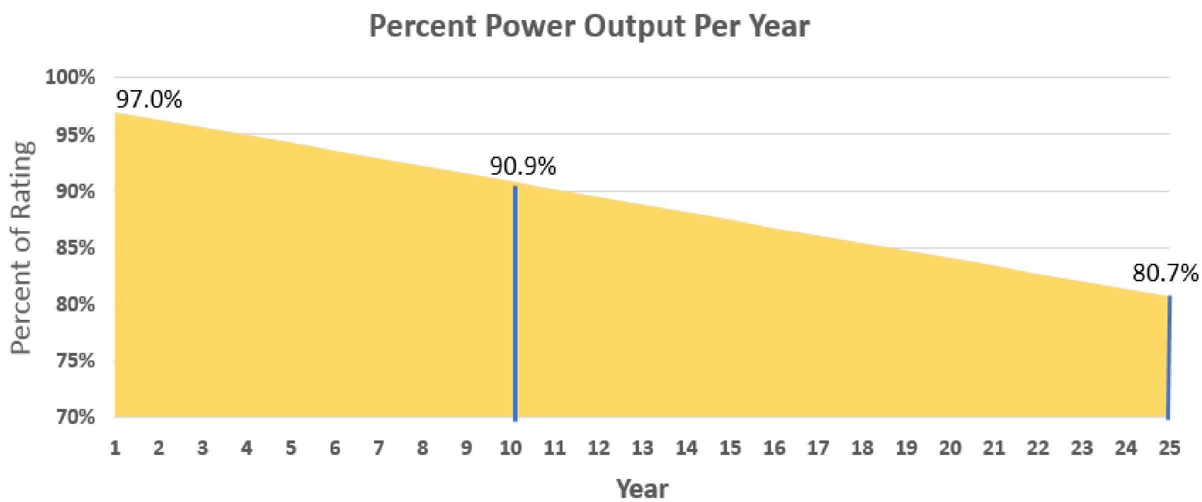
APPENDIX D

Declining Solar PV Performance Over Time

When calculating solar output, export and savings estimates it is important to consider the solar output decline over time.

A 2012 study by the National Renewable Energy Laboratory (NREL) found that, on average, solar panel output falls by 0.8 percent each year. This rate of decline is called solar panel degradation rate and is caused from thermal cycling, damp heat, humidity freeze and UV exposure. Thermal cycling is dramatic extremes in high/low temperatures impacting solder connections and component stress and fatigue. Damp heat is long term exposure to humidity and high temperature which can cause the material that insulates the cells to separate. Humidity freeze id the effects of trapped humidity freezing and damaging components. UV exposure to the solar back-sheet (the side of the panels facing away from the sun), can reduce its ability to protect the photovoltaic cells and electrical components from external stresses.

Graph 17



DC-AC Ratio vs. Declining Solar Output Performance

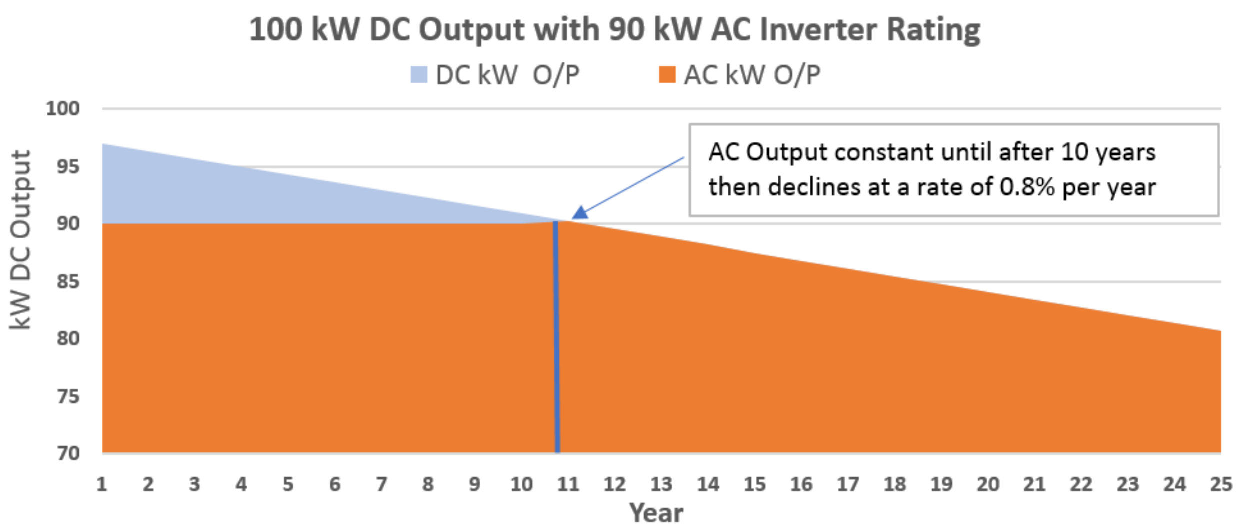
Most solar installations, for various design reasons, have more DC kW solar PV capacity installed than the AC kW inverter output rating. For example, an installation may have 100 kW DC of solar panels with inverter output of 90 kW AC. This means that even though the panels can potentially produce 100 kW of DC power, the AC output is clipped at 90 kW AC, and the DC-AC ratio for this installation is 1.11.

The DC-AC ratio vs. declining output performance should be considered when calculating solar output, export and savings estimates. A high DC-AC ratio means the declining DC output won't affect a decline in AC output until time (years) has passed.

Example:

Graph 18 demonstrates an installation with 100 kW DC of peak PV panel capacity with 90 kW AC peak inverter output capacity. It will take 10 years of PV panel performance decline before it has an effect on the AC output.

GRAPH 18



APPENDIX E

NASA POWER Data Access Viewer

https://power.larc.nasa.gov/data-access-viewer/

The NASA POWER Data Access Viewer is an online tool that provides solar and meteorological **data** sets from **NASA** research for support of renewable energy, building energy efficiency and agricultural needs.

A 30year-averaged solar radiance data (kWh/m^2/day) for Manitoba was used to normalize the Year 2020 research study data.

The data below was collected from the NASA POWER Data Access Viewer

NASA/POWER SRB/FLASHFlux/MERRA2/GEOS 5.12.4 (FP-IT) 0.5 x 0.5 Degree Interannual Averages/Sums
Dates (month/day/year): 01/01/1981 through 12/31/2019
Location: Latitude 49.9177   Longitude -97.177
Elevation from MERRA-2: Average for 1/2x1/2 degree lat/lon region = 245.87 meters   Site = na
Climate zone: na (reference Briggs et al: http://www.energycodes.gov)
Value for missing model data cannot be computed or out of model availability range: -999
Parameter(s):

ALLSKY_SFC_SW_DWN SRB/FLASHFlux 1/2x1/2 All Sky Insolation Incident on a Horizontal Surface (kW-hr/m^2/day)

YEAR	Annual Avg
1991	3.51
1992	3.35
1993	3.33
1994	3.46
1995	3.53
1996	3.6
1997	3.63
1998	3.67
1999	3.5
2000	3.5
2001	3.57
2002	3.58
2003	3.59
2004	3.39
2005	3.48

Year	Annual Avg
2006	3.64
2007	3.49
2008	3.78
2009	3.61
2010	3.63
2011	3.78
2012	3.64
2013	3.42
2014	3.42
2015	3.77
2016	3.57
2017	3.63
2018	3.7
2019	3.52
2020	3.71

Year 2020 Normalized Data

NASA POWER Access Viewer 30-year annual average solar radiance = 3.57 $kWh/m^2/day$

Year 2020 annual average solar radiance = 3.71 $kWh/m^2/day$

Normalization Factor = 3.57 ÷ 3.71 = 0.962

Section 5.1 summarized the Year 2020 study group findings as follows:

Ground type installations = 1247 kWh / kW DC nameplate rating

Rooftop type installations = 1058 kWh / kW DC nameplate rating

These values were normalizing to the 30-year average in Section 5.3:

Ground type installations = (1247 x 0.962) kWh / kW DC nameplate rating

= 1200 kWh / kW DC nameplate rating

Rooftop type installations = (1058 x 0.962) kWh / kW DC nameplate rating

= 1020 kWh / kW DC nameplate rating

APPENDIX F

Annual Hourly Solar Generation and Solar to Customer Load Profiles

Graph 18 compares the annual hourly solar kW generation output and the annual hourly solar supplied to the domestic load average for the twenty installations in this study. The blue-grey shaded data displays the total solar kW generation output and the orange shaded data displays the portion of the total solar generation supplied directly to the customer load. These two profiles cannot be derived from the revenue meter readings and described as "behind-the-meter" values.

Note the decline in solar generation performance from October, November, December and January.

GRAPH 18