FACULTY OF ENVIRONMENTAL STUDIES

York University

Final Report: GIS-based Analysis of a Solar Panel Implementation Project in the North York Region

ES/ENVS 4520 - Geographical Information Systems Applications in Environmental Studies (Advanced GIS)

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Introduction

Renewable technologies such as solar panels are clean energy alternatives that have much lower negative environmental impacts than conventional energy technologies. They contribute to mitigate the issue of global warming/climate change ("Why is renewable," 2015) and can help in the transition of our current conventional energy infrastructures into clean energy production systems. It is not only important to consider and analyze the solar potential ("The energy report," n.d.) that an area can generate, but also to understand the cost and benefits this solar energy can produce. The scenario of the North York region shows a trend of economic growth and increasing electrical demand ("York Region Solar," n.d.) which makes it a suitable candidate for the study area for this report.

Due to the increasing electrical demands in the North York region, there would be an increase in greenhouse gas emissions and further problems of shortage of electrical power supply and management during the winter storms and other weather events. Therefore, this report conducts a GIS-based analysis of the highest buildings in the proposed study area to calculate the solar potential that can be generated. This analysis through the GIS software allows for determination of the potential of urban solar energy implementation in the North York region and possibly in the entire city of Toronto.

Background: North York Region

The Region of North York is a municipality located in Toronto, Ontario, Canada. The North York area comprises of a population density of approximately 4,100 people per Km^2 and has a total population of 667,840 people. Around 300,500 or 45% of this population lives in apartment buildings with five or more stories (Statistics Canada, 2015). The North York area contains the North York Civic Center, Bayview Village, the Toronto District School Board, and encompasses commercial and financial centers such as Proctor and Gamble, Xerox, Nestle, Cadbury Adams and other offices.

Even though North York is a crucial business and a growing economic region of Toronto, its total land use area only contains approximately 176.87 Km^2 (Statistics Canada, 2015). Given the trend of increasing economic intensification, North York will have to increase its energy supply to meet the demands of its ongoing expansion. Therefore, this report conducts an analysis to obtain the solar potential of a small strip of the North York region which may allow us to understand the capacity of this area and its ability to incorporate a feasible solar energy project that is both profitable and promotes sustainability.

Hypothesis

The data acquired from the North York area will be analyzed to identify the tallest buildings in the study area selected. This report will calculate and show the solar potential that the proposed study area can attain using a standard solar panel module and GIS software. By using QGIS and ARCGIS we will be able to identify the most appropriate buildings with the highest solar potential to propose a solar panel installation. In addition, using the regulations and policies within Ontario's Feed-in Tariff (FIT) Program launched by Ontario's Green Energy and Economy Act (GEAEA) we hypothesize that the landlords of the selected buildings would decrease their energy bills and make profits from installing solar panels while taking advantage of the FIT program. We predict that these FIT calculations paired with solar insolation results will provide us with cost-effective benefits for North York region's potential solar panel implementation.

Data Acquisition

1. Study Area *Projection*

A common projection that was used for all data layers is WGS 84/UTM zone 17n EPSG:32617. The WGS 84 is used due to its 3D modeling preference, unlike NAD 83 which is based on a 2D datum (RMSI, 2010).

2. Data Requested and Acquired

Data was requested through the GAIA system form the York University Library and Geoportal Scholar. Janet Neate provided us with the data requested below.

1. Contours of the Greater Toronto Area

http://gaia.library.yorku.ca/uploads/attachment/file/115/Contours_GTA_05.zip

2) Data elevation files of the GTA, Greater Toronto Area, Ontario

http://gaia.library.yorku.ca/uploads/attachment/file/114/DEM_GTA_05.zip

3) Buildings, Places, DEM files for the North York Region

http://gaia.library.yorku.ca/uploads/attachment/file/113/NorthYork.zip

4) Digital Terrain files of North York, Toronto, Ontario

http://www.qgistutorials.com/en/docs/working_with_terrain.html

5) Annual mean daily global insolation for a South-facing surface with latitude tilt

http://pv.nrcan.gc.ca/index.php?lang=e&m=d

6) Photovoltaic (PV) potential (kWh/kW) and mean daily global insolation (MJ/m2 and kWh/m2) data for the region of North York by Natural Resources Canada.

http://pv.nrcan.gc.ca/index.php?lang=e

Metadata

Area: 3.6 Square Kilometres

Theme: Building Vectors, Clutter, DEM, Vector and Places data

Data Format & Resolution:

Format –ESRI Shape & Grid

Output Resolution – 5 meters

Projection System

Projection	UTM
Units	Meters
Zone	17
Hemisphere	N
Datum	WGS-84
Central meridian	81° W

Extent of the Data for North York city

Grid	Meters	Geographic
XMIN	626651.00	79° 25' 36.589872" W
YMIN	4845603.00	43° 45' 9.527616" N
XMAX	628661.00	79° 24' 2.772288" W
YMAX	4850203.00	43° 47' 37.326588" N

Vector Classes

Code	Class
1	Highways
2	Main Roads
3	Other Roads
4	Streets
5	Railways
6	Airstrip
7	Lakes
8	River

Clutter Classes

Clutter Code	Clutter Class
-9999	Unclassified
1	Inland Water
2	Open
3	Low tree density
4	High Tree density
5	Buildings < 5
6	Buildings < 10

7	Buildings < 15
8	Buildings < 20
9	Buildings < 30
10	Buildings < 40
11	Buildings < 50
12	Buildings > 50
13	Industrial area
14	Airstrip
15	River
16	Coast
17	Agriculture
18	Stadium / Play Ground

Data Organization:

\North_York\	Building, Clutter, Dem, Vector and Places.	Data Folders
\North_York\Esri\buildings	1 Building vector Shape file	Building vectors of North York city.
\North_York\Esri\Clutter	1 ESRI grid file.	Land use/land cover of North York city.
\North_York\Esri\dem	1 ESRI grid file.	Digital Elevation Model of North York city.
\North_York\Esri\vector	1 Vector shape file.	Road Network of North York city.
\North_York\Esri\Places	1 Places shape file.	Landmark of North York city.

(RMSI, 2010

GIS Analysis

The raw data acquired above is processed and displayed on four maps. Figure 1 below shows the general study area of interest located within the North York Region that is bounded by Finch Ave. East on the North, Sheppard Ave. East on the South, Doris Ave. on the East and Beecroft Road on the West. A map of this study area can be seen below in Figure 1. The raw data showing random buildings all over the region was clipped to only include the buildings in the proposed study area.

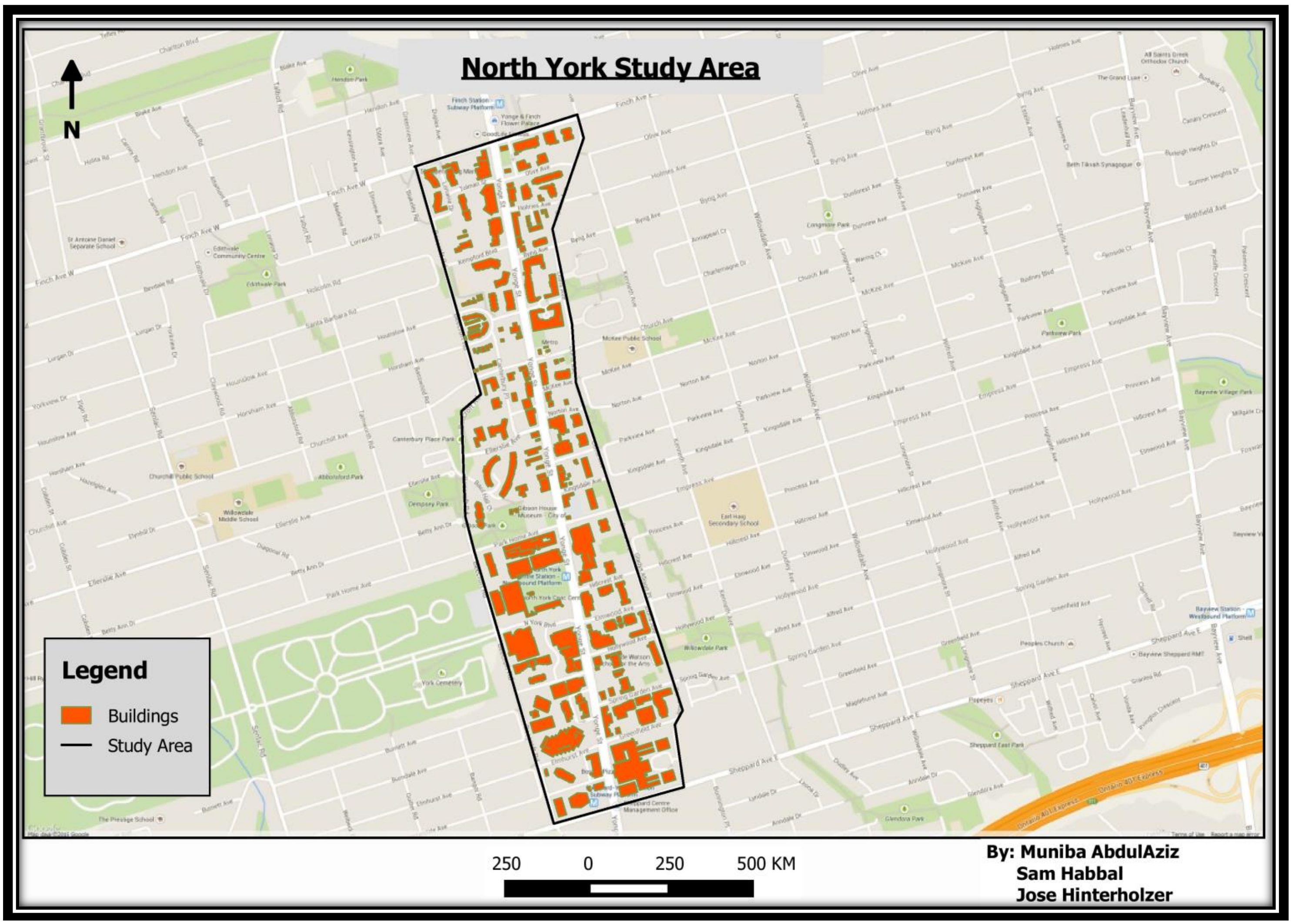

Figure 1. North York region's selected study area.

From the acquired data of North York, the shape files of places and buildings were overlapped and clipped to obtain a combined attribute shape file with the heights and areas of all buildings within the study area. As Figure 2 below shows, a map was created to illustrate a graduated legend of buildings with their relative heights.

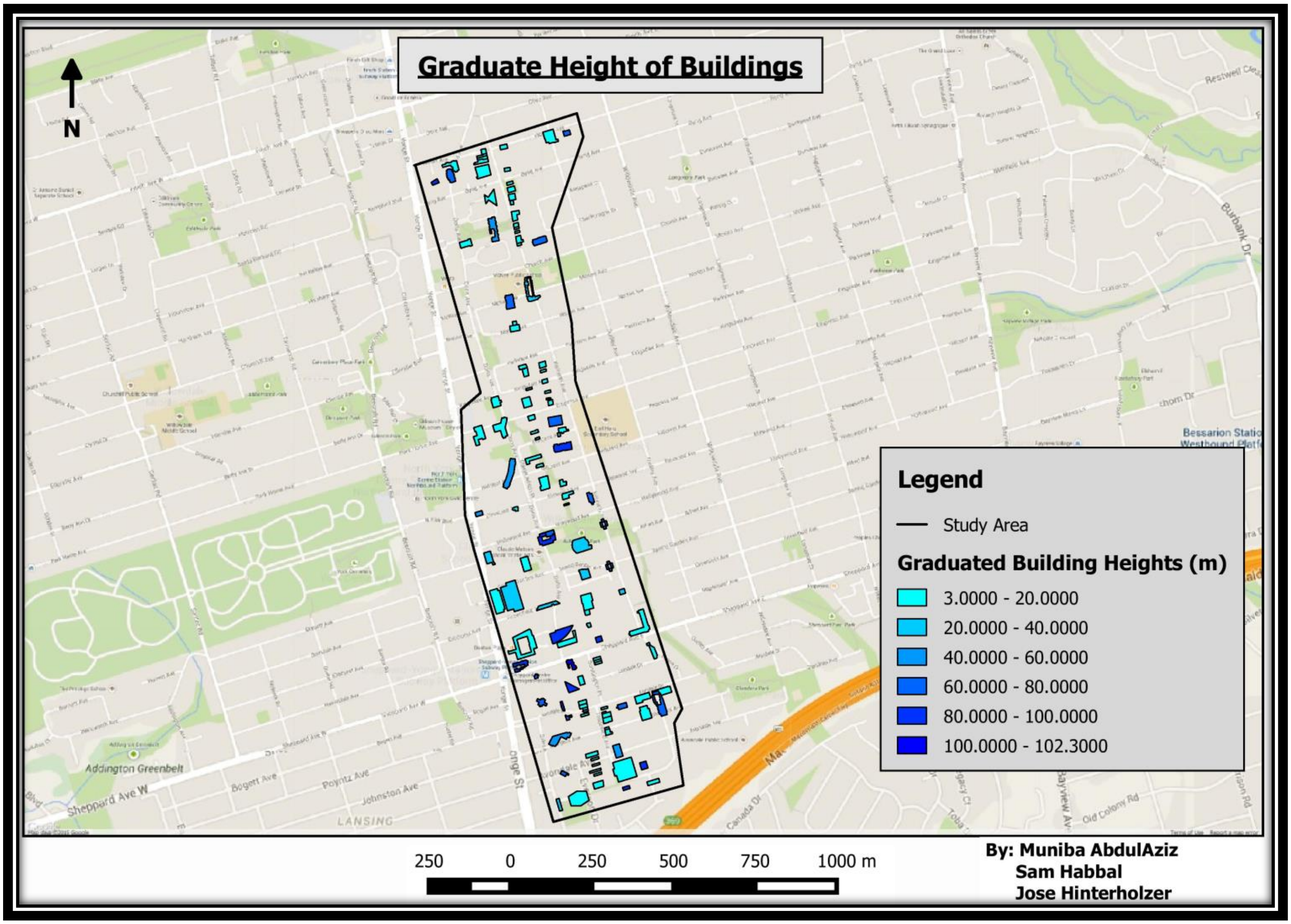

Figure 2. Graduated heights map of buildings in the study area.

This data is further analyzed by using only buildings that have a height greater than 80 meters. As Figure 3 below shows, a map was created to show a building classification based on the size of the rooftop areas. This helps recognize the quantity and location of buildings with the largest rooftop areas in the selected location.

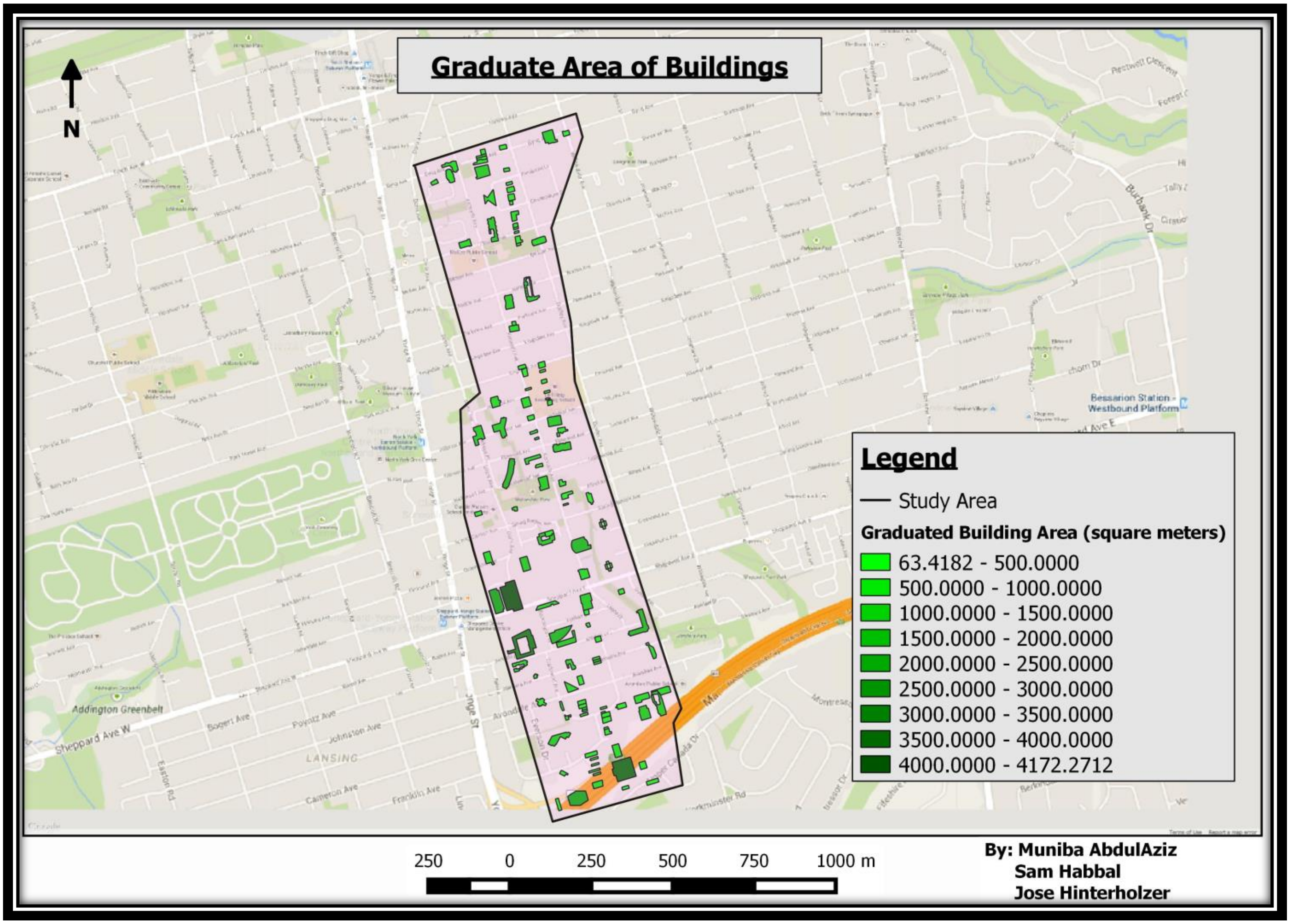

Figure 3. Graduated area map of buildings in the study area.

Figure 4 below was created using ArcGIS's solar radiation area tool. The shape files of the buildings with the largest heights and areas were converted from vector to raster format and processed with the solar radiation tool. Figure 4 illustrates the solar potential that can be gained with the proposed rooftops. It can be observed that some buildings closer to Finch Ave. East on the top of the map have some red bands and have a higher solar potential then some buildings closer to Spring Garden Ave. and Yonge St. that have blue bands and a relatively lower solar potential. The general trend of the buildings shows a sharp orange color illustrating that the solar potential for all these buildings is relatively high with the exception of a few buildings.

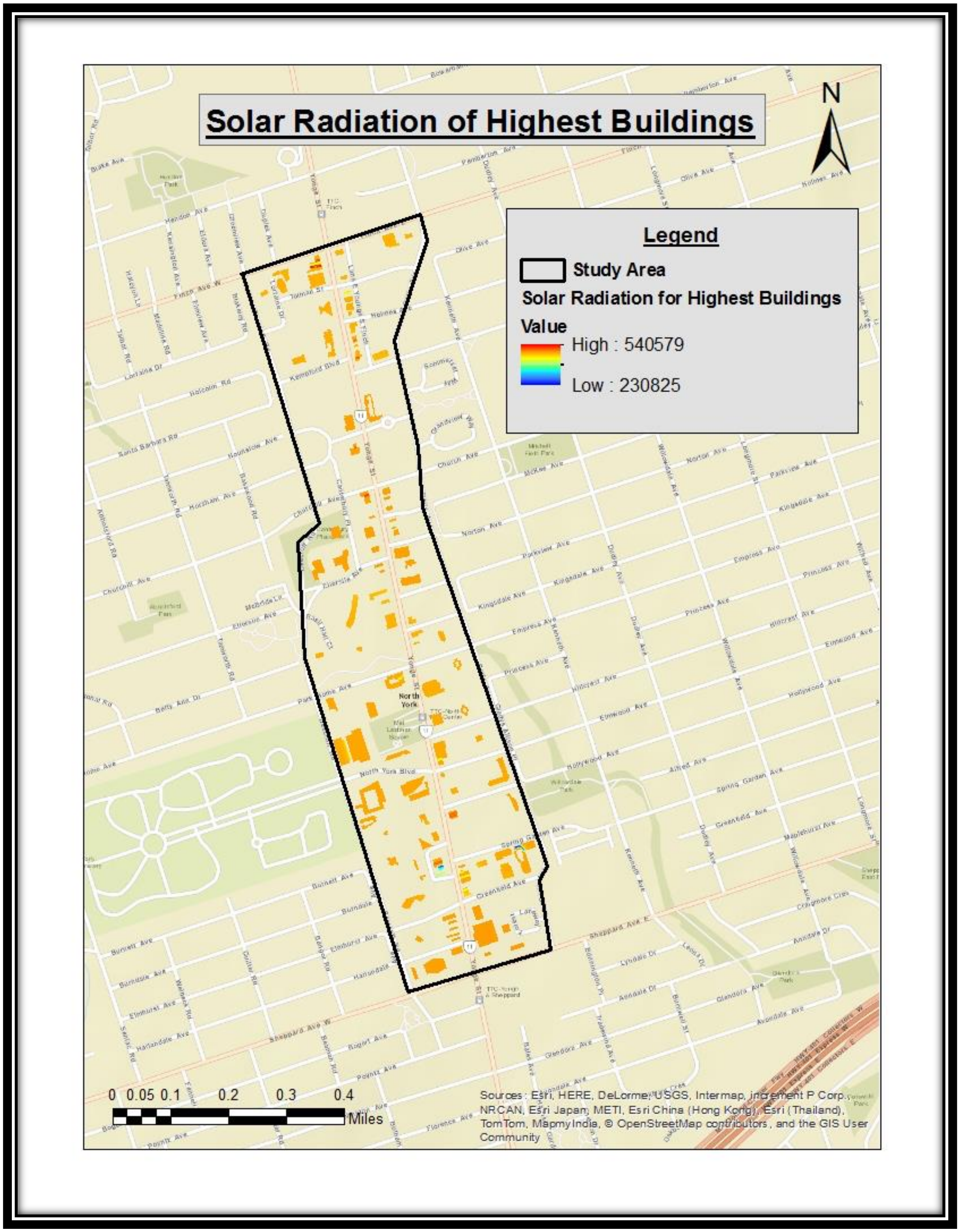

***Figure 4*.** Solar radiation of the highest buildings within the selected study area.

In order to understand the solar potential for the proposed study area, we require solar panel calculations that would show the amount of energy generated by the area available. The solar panel chosen for this project is a polycrystalline photovoltaic module called Solar SF160-24-P PV. It has an area of 62.2 inch x 31.8 inch or 1977.96 in^2 (1.28 m^2) and has a depth of 1.8 inches. The Solar SF 160-24-P PV Module was selected for this project due to its properties of anti-reflective coatings, high efficiency and long life cells. The manufacturing process of this PV panel includes a double oxidation coating making it resistant to the rugged Canadian weather conditions, guaranteeing long lasting quality under adverse weather events. Furthermore, this PV module has a bearing capacity against wind and snow of about 50lbs/sq ft, meeting the standards of ISO 9001 and ISO 14001 quality regulations that ensure quality and environmental expectations. This photovoltaic panel provides a warranty of performance of 80% of its energy production capacity after 25 years (Solar SF 160-24-P PV Modules – Schüco, n.d.). The maximum power generated ranges from 165 to 180 watts. For the purpose of solar potential calculations, 165 Watts will be used as the least power generated in the worst-case scenario.

Using data collected from Natural Resources Canada’s photovoltaic and solar maps, tabular data was examined and showed the mean daily global insolation in kWh/m^2 for the area of Toronto (Appendix B) . The insolation data collected by Natural Resources Canada used PV panels all facing south with different tilts including a 2-axis tracking PV panel (Appendix C). The solar panels are positioned south with different tilts because the testing methods used by Natural Resources Canada provided the best exposure and results when faced south. According to the data, when using a 2-axis tracking PV panel the mean annual average of insolation in the North York region contains a range from a minimum of 2900 W/m^2 to a maximum of 5900 W/m^2 of irradiance. We use the minimum irradiance for a worst case scenario analysis with the intention to show that future results could only improve from these numbers.

The chosen Solar SF 160 PV panel produces an output of 165W of power when tested under the irradiance of 1000 W/m^2. What this means for photovoltaic potential In the North York Region is that even if we took the lowest insolation results tested of 2900 W/m^2 the North York Region's insolation capacity will be well over the tested standard of 1000 W/m^2. For statistical assurance we are using the production of lowest 165W of power per panel although the actual solar insolation in the North York Region far surpasses the standard testing of 1000W/m^2.

$$\frac{1000\ \text{W/m}^2\ \text{irradiance}}{2900\ \text{W/m}^2\ \text{irradiance}} = \frac{165\ \text{Watts}}{\text{X Watts}} \qquad \text{X Watts} = 475\ \text{Watts generated at } 2900\text{W/m}^2\ \text{irradiance}$$

This demonstrates that the irradiance exposed in the North York region gives 475 Watts and is capable of being harnessed three times more power than what the Solar SF 160 panels are currently harnessing. This means future panels could be designed to harness the full potential of the irradiance exposed proving that results and benefits would increase with technological advancements, while still being profitable with the current technology.

For the purpose of this report, the solar potential calculations will include the buildings whose height is greater than 80 meters, since they are least affected by traffic pole shadows, building shadows and other shadow covers. However, there may be some systematic errors as certain rooftop areas may contain maintenance tanks or equipment, which may not allow the entire rooftop of the building to be used to place solar panels. The attribute data of these buildings is shown below in Table 1.

Table 1.

Attribute Table of Buildings With Height Greater Than 80 Meters

NAME	AREA (m^2)	HEIGHT (m)
HEWITT ASSOCIATES	440	97
CONTINENTAL CONDO	241	82
MINTO RADIANCE	431	105
NORTH YORK ACUPUNCTURE CLINIC	275	80
HEWITT ASSOCIATES TORONTO	203	81
CADBURY BUILDING	1810	86
SKYMARK CENTRE	749	102
NESTLE BUILDING	815	104
NORTH AMERICAN CENTRE	1784	89
SYNERGY TRAINING STUDIO	425	82
BROADWAY RESIDENCES	745	91
ULTIMA AT BROADWAY SOUTH TOWER	510	102
BOMBAY BHEL	293	93
MONET CONDO	846	90
THE MADISON	190	82
YORK COLLEGE OF BUSINESS	1121	82
NEVIAN CONSULTING & PLACEMENT SERVICES	613	85
MAJESTIC II	1196	81
Total Area (m^2)	**12687**	

As Table 1 shows, the buildings with height greater than 80 meters are selected in the North York Region for an estimated energy potential of buildings with high generation probability. Their total roof areas are summed to acquire the total area available to hold solar panels. This total area available is 12686.84 square meters and can hold 9912 solar polycrystalline panels. The amount of energy that 9912 panels can generate is 1,635 Kilowatts. This calculation is shown below.

To calculate the total watts generated:

$$\frac{12686.84\ m^2}{1.280\ \text{Panel Area}\ (m^2)} = 9911.59 \text{ or } 9912 \text{ Panels can be installed}$$

1 Panel Rated Power Given = 165 Watt/Hr (Appendix A)

9912 panels x 165 watts = 1,635,480 Watts or 1,635 Kilowatts

Therefore, all the panels of the buildings whose height is greater than 80 meters would generate 1,635 Kilowatts/Hr collectively. The cost of energy per watt from Schuco is approximately $2.30 to $2.55, however, $2.40 was used as an average for a commercial project in Canada (F. Cortese, personal communication, 2015).

9912 panels x $2.40 = $23,788.8 or $ 23,789

Collectively these buildings would have to spend about $23,789 to install these solar panels.

Feed-In Tariffs (FIT)

The Green Energy Act helps incorporate renewable energy into the electrical system by introducing the system of Feed-In Tariffs (FITs). Adopting the FIT program requires a contract between the interested party and the FIT organization for a period of 20 years (Renewable energy feed-in tariff program, n.d.), so it is highly important to select the PV panels that ensure energy production during the respective period.

The FIT program allows the PV panel users to make a profit when there is an excess of energy produced over the energy consumed, by feeding it back into the electrical grid. The FIT program is open to projects with a rated electricity generating capacity greater than 10 Kilowatts (KW) and up to 500 KW, which is suitable for this project. The FIT prices for Ontario are given at 0.316 cents for energy generated that is greater than 100 and less than 500 Kilowatts per project ("Renewable energy," n.d.). The total energy saved by using solar panels in the proposed region would be approximately 1,635 Kilowatt/Hr. The annual savings of the proposed buildings are calculated and shown below.

The FIT Ontario offers 0.316 cents per KW/Hr

Energy generated per day = 1,635 Kilowatt/ Hr x 0.316 cents per Kilowatt/Hr

= $516.66 Kilowatts/Hr

Energy Savings per day = $516.66 Kilowatts/Hr x 24 Hr

= $12,399.84 or $12,400 per day

Thus, the buildings higher than 80 meters in the North York region will generate profits of about $12,400 CAD by employing the FIT program. If this were extended to all buildings in the North York region, their owners would still make more profits while reducing their electricity bills and simultaneously reducing the greenhouse gas emission rates and mitigating climate change.

Cost Analysis

With the cost of $23,789 and the generation of energy of 1,635 kilowatts/Hr that gives a FIT benefit of about $ 12,400 per day or about $688 profit to each of the 18 buildings. After paying off costs such as installation fees, maintenance or repairs, each building will make a profit of about $20,640 per month.

These buildings can pay off their one-time cost of installing solar panels in about two days of energy generation and would keep getting profitable returns by feeding energy back into the collective grid. If this sample set provides benefits for the highest 18 buildings, doing further spatial analysis on other buildings can ensure profits for other buildings interested and many more that could manage a decent amount of solar radiation to generate the required capacity. Further, City of Toronto or private entrepreneurs could propose a solar panel plan or a by-law for collective buildings to transition the North York Region's conventional electricity sources into a renewable energy production and consumption system.

Environmental and Social Benefits

In addition to the economic benefits, this adaptation of renewable energy will not only produce eco-friendly energy, but also contribute to the social and environmental aspects of the community. Through the FIT program, renewable energy implementation can greatly reduce CO_2 emissions. Since PV modules generate electricity without producing air, noise and water pollution, these energy sources will have obvious advantages over conventional electricity supply options. Also, as renewable energy replaces the use of lead-acid batteries, the chances of their improper disposal, which is harmful to the environment, would be reduced.

If the North York area were to implement solar energy projects, it will create incentives for similar townships to follow suit in the adoption of solar energy as a sustainable source of energy, while socially demonstrating leadership in the region. Using solar energy would reduce fuel imports, as less natural gas would be used for electricity generation in the North York area. As our economy becomes less dependent on natural gas for fuel, the increase of livings costs due to the increasing fuel and energy prices would not make our society as vulnerable as it is today. As the practice of integration of solar energy becomes customary, the lower dependence on fuel and its world-price fluctuations can create a more stable economy for the North York region and Toronto as a whole.

Conclusion

In conclusion, after collecting raw data and processing it to analyze the solar potential of the North York region, calculations of the building areas and heights were made and the potential of solar radiation was obtained. The results from harnessing the solar radiation were employed to determine cost effectiveness and general feasibility for the project implementation in the North York Region. The buildings selected for the North York region generated 1,635 Kilowatts/Hr of energy and gained a $12,400 profit collectively. Overall, the results proved better than our hypothesis. As the North York region has three times the insolation capacity, a greater amount of energy and profits can be generated by future technologies more advanced than the Solar SF160 panel. This report can be used for further spatial and cost analysis pertaining to the solar renewable initiatives in the North York Region.

Recommendations

It is highly recommended for the building owners of the North York Region and other potential parties to invest in solar energy projects such as this, due to the long term benefits that are clearly stated in our study. As a growing financial district, the North York area will unavoidably increase its demographic density, thus, it would be more profitable to invest in a renewable energy initiative to meet the future electrical demands of the growing community while mitigating the problem of climate change and its detrimental effects on the environment.

References

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APPENDIX A

Technical Brochure of Solar SF 160-24-P PV Modules

Solarfun SF 160-24-P PV Modules

Polycrystalline Photovoltaic Modules

One of the few companies to meet Schüco's stringent quality standards, photovoltaic module manufacturer Solarfun Power is a trusted Schüco supplier. Solarfun Power's outstanding PV modules assure high-powered, reliable performance for solar projects both on- and off-grid.

Each PV cell features anti-reflective coatings, state-of-the-art silver front contacts, and full-coverage aluminum back contacts with a back surface field. Solarfun PV cells are meticulously manufactured in accordance with the highest technical standards, ensuring excellence at every stage of the production process and resulting in highly efficient, long-life cells.

The frames are constructed of aluminum alloy for maximum endurance in rugged weather conditions. They are also given a double oxidation coating for added protection against the elements, assuring impressive longevity even under adverse conditions. The load-bearing capacity for snow and wind loads is 50lbs/sq ft.

The modules fully adhere to Germany's stringent ISO 9001 and ISO 14001 quality and environmental standards. Every cell is individually inspected and power-matched to ensure consistent performance between the cells in the module array. Moreover, each PV cell is individually inspected and checked for current reversion, micro cracks, chipping, warping, and any uneven thickness.

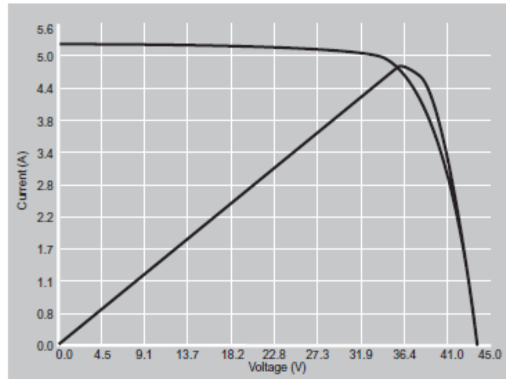
SCHÜCO

Technical Data

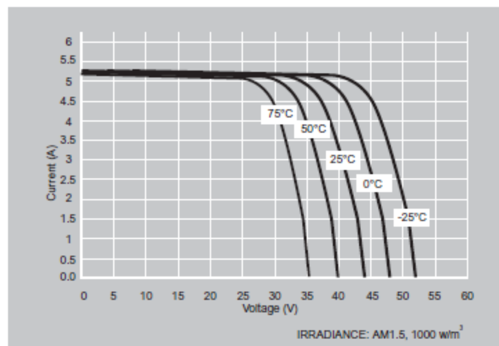
Electrical specifications				
Power output under standard test conditions (STC)*:	SF 160-24-P165	SF 160-24-P170	SF 160-24-P175	SF 160-24-P180
Rated power (P_{max})	165 W	170 W	175 W	180 W
Effective output tolerance(Δ Pmpp)	+/- 5%			
Rated voltage (V_{mp})	35.5 V	35.5 V	35.7 V	35.8 V
Rated current (I_{mp})	4.65 A	4.78 A	4.90 A	5.03 A
Open circuit voltage (V_{oc})	43,7 V	44,1 V	44,5 V	44,7 V
Short circuit current (I_{sc})	5.14 A	5.17 A	5.20 A	5.23 A
Module efficiency	12.9%	13.3%	13.7%	14.1%
Cell efficiency	14.8%	15.3%	15.8%	16.6%
Cell technology	Poly-Si			
Number of cells	72 (6 x 12)			
Temperature coefficient α (P_{mpp})	-0.48% / °C			
Temperature coefficient β (I_{sc})	+0.05% / °C			
Temperature coefficient χ (U_{oc})	-0.34% / °C			
Temperature coefficient δ (I_{mpp})	+0.05% / °C			
Temperature coefficient ε (U_{mpp})	-0.34% / °C			
Normal operating cell temperature (NOCT)**	45 °C +/- 2 °C			
Max. system voltage permitted	600 V			
Fuse rating	10 A			

Mechanical specifications	
Outer dimensions (L x W x H)	62.2 in x 31.8 in x 1.8 in
Aluminum frame	Aluminum-alloy
Weight	33 lbs
Connection system/diameter of cable	MC-T4/4 mm^2
Length of cable	35.4 in
Front/Encapsulant/Back	Tempered glass/EVA/backsheet

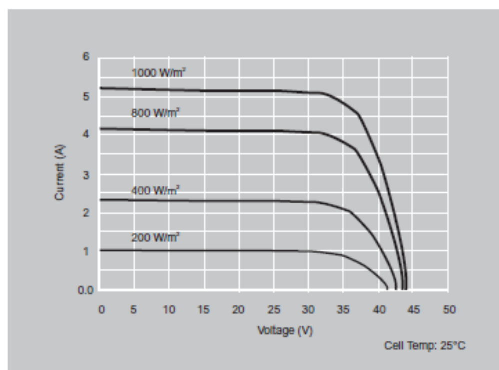
Qualification and warranty	
Product standard	UL 1703, CE, ISO 9001
Extended product warranty	3 years
Warranty of 90% performance P_{mpp} min	10 years
Warranty of 80% performance P_{mpp} min	25 years



IV Curves

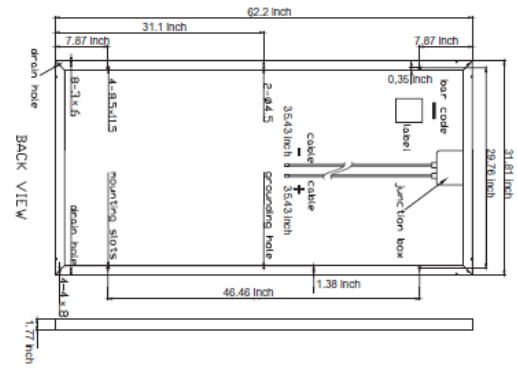


Various Temperatures



Various Irradiance Levels

Miscellaneous	
Schüco end clamps Type 41-1	256 327
Schüco intermediate clamps Type 41-2	256 328
Schüco Art.-No 165 W	232 426
Schüco Art.-No 170 W	232 369
Schüco Art.-No 175 W	232 427
Schüco Art.-No 180 W	232 442
Packing unit	4 modules



* Irradiance 1,000 W/m², air mass 1.5, cell temperature 25°C
** Irradiance 800 W/m², ambient temperature 20°C, wind speed 1 m/s
Photovoltaic modules show signs of electrical degradation. After they go into operation the degradation is initially degressive, and later it is linear.

Schüco USA L.P.
schuco-usa.com

P 3276/USA/05.09/Printed in Germany
Specifications subject to change without notice.

APPENDIX B

Solar Insolation Data

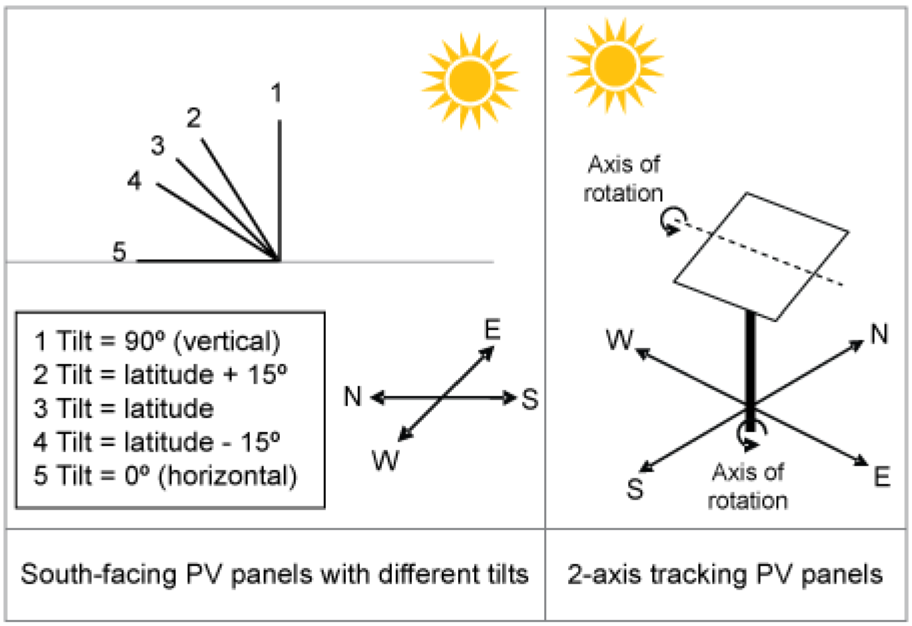
Mean daily global insolation (kWh/m²)

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=lat+15°	South-facing, tilt=lat-15°	Two-axis sun-tracking	Horizontal (tilt=0°)
January	2.9	2.8	3.0	2.5	3.5	1.6
February	3.7	3.9	4.0	3.6	4.8	2.6
March	3.7	4.6	4.6	4.5	6.0	3.7
April	3.1	5.0	4.6	5.2	7.1	4.6
May	2.7	5.3	4.6	5.7	7.9	5.5
June	2.6	5.5	4.7	6.0	8.9	6.2
July	2.7	5.5	4.8	6.1	9.0	6.2
August	2.9	5.2	4.7	5.5	7.7	5.2
September	3.2	4.6	4.4	4.6	6.2	3.9
October	3.2	3.8	3.8	3.6	4.8	2.6
November	2.3	2.5	2.6	2.2	3.0	1.4
December	2.3	2.2	2.4	2.0	2.6	1.2
Annual	2.9	4.3	4.0	4.3	5.9	3.7

Solar insolation data of the Toronto region collected by Natural Resources Canada, 2014

APPENDIX C

A visual diagram of the PV panels used to obtain global insolation (Natural Resources Canada, 2014)



Solar insolation data of the Toronto region collected by Natural Resources Canada, 2014