

UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

**Roof Solar Potential at UBC: Assessing Suitability of Campus' Building Roofs
for Solar Energy Capture**

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ROOF SOLAR POTENTIAL AT UBC

Assessing Suitability of Campus' Building Roofs for Solar Energy Capture



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1. Executive Summary

When implemented in the right location, solar energy provides many benefits. UBC, Vancouver campus, has extensive roof area that could be used for implementation of solar energy facilities such as Photovoltaic solar arrays. However, whether it is beneficial to implement these facilities depends on a variety of influencing factors. This study provides an assessment of UBC campus and its spatial, architectural, and geographical attributes to determine the suitability of UBC rooftops for implementation of solar energy capture facilities. The first part of this study, the roof suitability study, provides a brief analysis of suitability of UBC roofs for PV solar arrays by taking into consideration the urban form of UBC campus only. The second part of the study, the solar suitability study, consists of a simulation of the sun's behavior over UBC in generally clear sky conditions, calculating solar radiation for each m² of campus area for the year of 2018. UBC's urban form, its geographical location and geoclimatic zone, atmospheric conditions, and monthly changes in the sun's behavior are taken into consideration. Solar radiation maps are provided as well as estimates of total yearly solar radiation that could potentially be captured by UBC's roof area. Finally, the study provides a solar suitability index, ranking all 537 UBC roofs from most suitable for solar energy facilities to least suitable for solar energy facilities.

2. Context

In recent years, UBC has made significant efforts to meet sustainability standards. This is reflected by several of UBC's campus policies and guidelines such as the Energy Management Plan, the Green Building Plan (anticipated to be completed in Fall 2018), and Climate Action Plan (UBC Campus + Community Planning, 2010). In 2010, UBC identified clear targets for its emission reductions: 67% emission reductions by 2020, and 100% reductions by 2050 (UBC Campus + Community Planning, 2010). In order to meet these targets UBC campus will have to implement more environmentally-friendly, low-emissions technologies to source its energy and fuel its vibrant student life. One type of renewable energy source that UBC has yet to implement at a larger scale are photovoltaic (PV) solar panel arrays. Implementation of solar power on UBC campus is attractive for two reasons: cost of solar energy is decreasing fast; solar energy provides long-term pay off and requires little maintenance (International Energy Agency, 2017). The purpose of this project is to evaluate the technical potential of solar energy on UBC campus, given the total available rooftop area. In this context, the study aims at providing a better understanding of which rooftop areas are most relevant and suitable for implementation of PV solar panel arrays; and an estimate of how much energy can be captured by those areas.

3. Methodology

The study consisted of a spatial analysis of UBC Campus focusing on how urban form, geographical location, and atmospheric conditions affect solar potential. It was done in two parts: a roof suitability analysis, and a solar suitability study. In this study, LiDAR point cloud datasets of UBC campus for 2015, and a shapefile of UBC's building footprints from 2015 were used. These datasets are described in Table 1.

Table 1. Data used for study of solar potential

Data	Source
UBC LiDAR datasets for 2015	http://dvn.library.ubc.ca.ezproxy.library.ubc.ca
UBC building footprints shapefile	http://dvn.library.ubc.ca.ezproxy.library.ubc.ca

3.1. Roof Suitability Analysis

A number of PV Solar Panel requirements were taken into consideration.

- First, suitable roof surfaces must be at an angle that is between 0° and 49°, the latter being equal to the latitude of Vancouver's geographical location (49.2827° N) (Brakels, 2018).
- Second, suitable roof surfaces must not be North facing, and South facing surfaces must be considered optimal. Though less relevant, East and West facing surfaces must be considered as well (EnergySage, 2018).
- Third, suitable roof surfaces must be at least 100m². This zone represents the area required for a 10kW solar PV system, which is the average minimum installed capacity for commercial buildings (Hong et al., 2016; Hois, 2013, SunergySystems, 2018).

These requirements were used for the roof suitability analysis, the first phase in evaluating technical potential of solar energy on UBC campus. This was an initial sweep intended at providing a general idea of solar suitability at UBC considering building form only.

Using ESRI's ArcMap's model builder and a Digital Surface Model (DSM), created from the LiDAR datasets, slope and aspect raster datasets were derived. These were computed using the "Slope" (Data management toolbox), and "Aspect" (Data management toolbox) tools. Using the "Reclassify" tool and "Raster Calculator" tool, all south, east and west facing surfaces were extracted and ranked. South facing surfaces were ranked as class 1, and East/West facing surfaces as class 2. Similarly, all the surfaces falling between 0° and 50° angles, were extracted and ranked. Surfaces at angles between 25° and 50° were ranked as class 1 and lower angles as class two. Apart the efficiency decrease mentioned above, another reason why flat and low angle roofs were ranked as class 2 is that although PV solar panels can be mounted on tilted frames on flat roofs, this solution has downsides. Mainly, costs increase by around 200\$ to 300\$ per system, and fewer panels can be fitted on roof space if they are tilted. This is because they have to be mounted with

more space between panels, in order to avoid one row casting a shadow on the row below it (Brakels 2018; Ibrahim, 2015).

From the buildings footprints shapefile, all roof areas greater or equal to 100m² were extracted. Finally, using the “Raster Calculator” tool, ranked aspect, ranked slope, and minimum required roof areas were combined together to create a final roof solar potential suitability map (Figure 1).

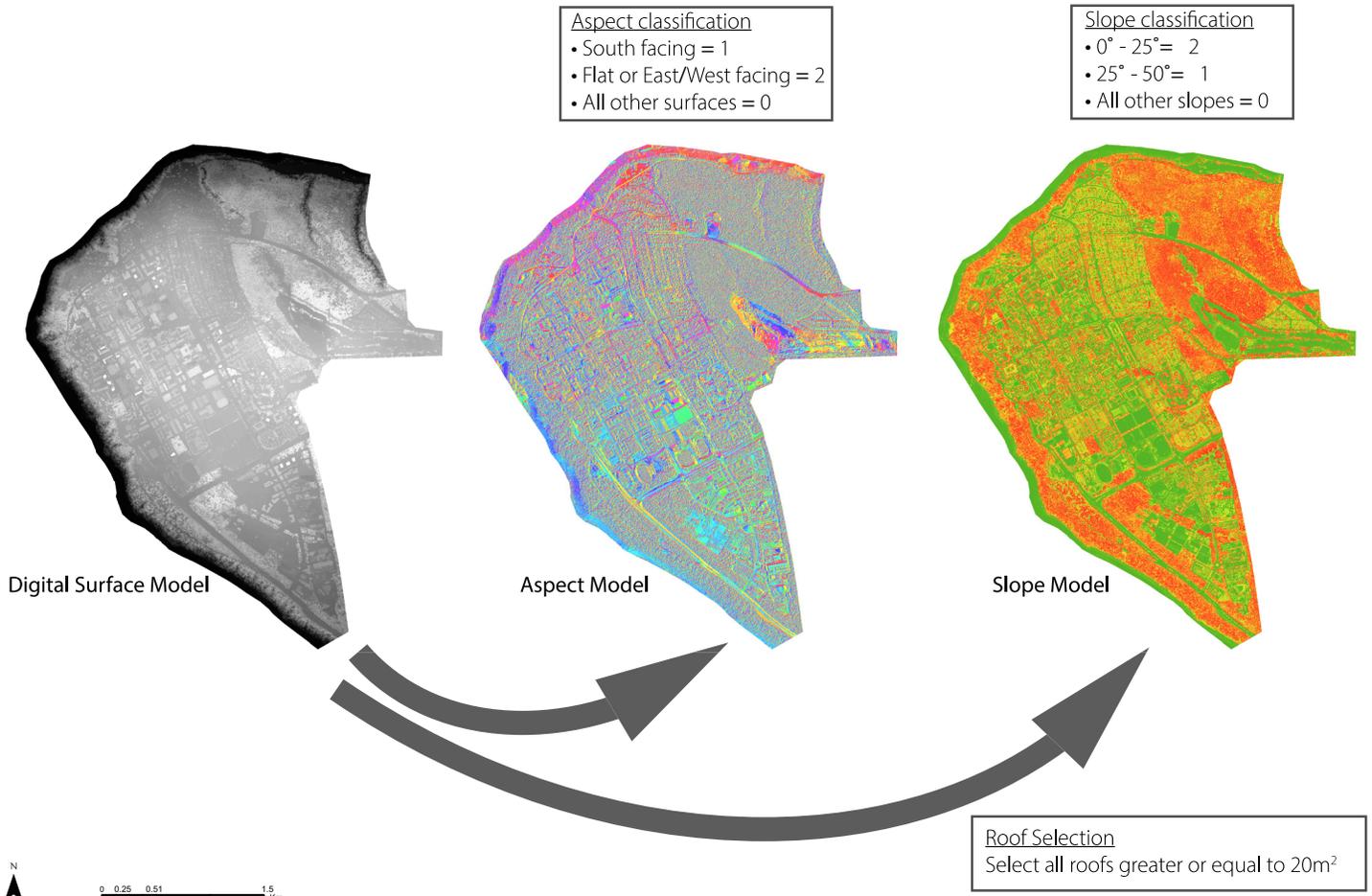


Figure 1. Aspect Classification, Slope Classification, and Roof Selection.

3.2. Solar Suitability Study

The second part of the analysis, the Solar Suitability Study, was intended at providing a much more extensive analysis of solar energy potential on campus. It consisted of simulating the trajectory of the sun over UBC campus for each month of the year (Figure 6). This was done using the “Area Solar Radiation” tool in ArcMap. For a given day of the year and hourly interval, and with the Digital Surface Model (DSM) as an input, “Global Radiation” (a combination of direct, diffuse, and global insolation) is calculated in Wh/m², across the UBC campus geographical area. This tool uses Methods from the hemispherical viewshed algorithm developed by Rich et al. (1994), and returns “global radiation” as the total amount of radiation calculated for a specific geographical area. “Global radiation (Global_{tot}) is calculated as the sum of direct (Dir_{tot}) and diffuse (Dif_{tot}) radiation of all sun map and sky map sectors, respectively:

$$\text{Global}_{\text{tot}} = \text{Dir}_{\text{tot}} + \text{Dif}_{\text{tot}}$$

See appendix 1 for a detailed description of the “Area solar radiation” tool.

“Area solar radiation” has been widely used to calculate solar energy in a number of instances. For example, the “Min-

nesota Solar Suitability Analysis” was an ambitious project completed by students at University of Minnesota in which the entire state of Minnesota was mapped for solar suitability using the “area solar radiation” tool in ArcGIS (University of Minnesota, 2010). At UBC, former PhD student Rory Tooke used this tool to map solar suitability for the Metro Vancouver area, and created the online interactive map “Community Energy Explorer” (CALP, 2010).

For estimating solar potential on UBC campus, the “area solar radiation” tool was run for the 15th of each month of 2018 at 1 hour intervals, during the interval representing hours of sunlight for each of those days. These intervals were taken from timeanddate.com predictions (TimeAndDate, 2018) and can be viewed in Table 2. For each of those intervals, global solar radiation in Wh/m² was obtained for each hour of sunlight as a raster. Next, using the “raster calculator” tool, each of those rasters representing 1 hour worth of solar radiation were added together to calculate daily solar irradiance in Wh/m² as a raster layer. This process was repeated for the 15th of each month. Finally, each 15th day raster layer was multiplied by the number of day in each given month using the “raster calculator” to estimate monthly solar irradiance as a raster dataset. All raster datasets representing a month’s worth of solar radiation were then added together using “raster calculator” to obtain a final raster representing yearly solar irradiance in Wh/m² (Figure 2). These values were divided by 1000 to convert them into kWh/m².

Table 2. Sunlight intervals used for each day, from timeanddate.com (TimeAndDate, 2018).

Month	Year	Day	Sunrise time	Sunset time	Length of day
January	2018	15th	8:02	16:42	8:40
February	2018	15th	7:21	17:32	10:11
March	2018	15th	7:25	19:17	11:52
April	2018	15th	6:20	20:05	13:44
May	2018	15th	5:29	20:49	15:20
June	2018	15th	5:06	21:19	16:13
July	2018	15th	5:23	21:12	15:49
August	2018	15th	6:04	20:28	14:24
September	2018	15th	6:49	19:25	12:36
October	2018	15th	7:33	18:21	10:48
November	2018	15th	7:23	16:30	9:07
December	2018	15th	8:01	16:14	8:12

Below are the equations used for calculation of solar radiation. For each month:

$$\text{Solar}_{\text{Daily}} = \sum \text{solar radiation}_{\text{1st hour of sunlight, n hour of sunlight}}$$

Where n = # of hours of sunlight

$$\text{Solar}_{\text{Monthly}} = \text{Solar}_{\text{Daily}} * (\# \text{ of days/month})$$

For estimation of yearly solar radiation:

$$\text{Solar}_{\text{Yearly}} = \sum \text{Solar}_{\text{Monthly (january, december)}}$$

Where solar radiation is measured in Wh/m².

Using the “raster calculator” tool, the yearly solar radiation raster was multiplied by the UBC roofs layer. This allowed to quantify solar radiation for UBC roofs at a yearly scale (Figure 7). The “Zonal statistics as table” tool was used to calculate the total potential amount of solar radiation reaching UBC roofs yearly. Considering average efficiency of 15% for PV solar cells (Green et al., 2011; Solar by Empire, 2018; Murmson, 2017), the potential total amount of primary energy was multiplied by 0.15 to estimate the potential total amount of secondary energy convertible by PV solar cells from UBC roofs. Finally, this number was converted to GJ using the kWh to GJ conversion factor of 0.0036 as shown below:

1 kWh = 0.0036 GJ

Additionally, the “Zonal Statistics as Table” tool was used to combine building data from the UBC buildings footprints shapefile and solar radiation data from the yearly solar radiation raster. This process allowed to generate a variety of solar radiation statistics (min; max; mean; range; standard deviation; sum) for each UBC building. Using the “table to excel” tool, these statistics were exported to Microsoft Excel format and were used to calculate the potential total amount of primary energy reaching UBC roofs. In Excel, a Suitability Index was created by assigning a suitability rating to each building between 0 and 1. This rating was calculated by the following equation:

$$\text{Suitability} = (Y_i - Y_{\min}) / (Y_{\max} - Y_{\min}) * (X_i - X_{\min}) / (X_{\max} - X_{\min})$$

Where:

- Y — Roof area in m²
- X — Average solar radiation in kWh/m²
- i — A given UBC building

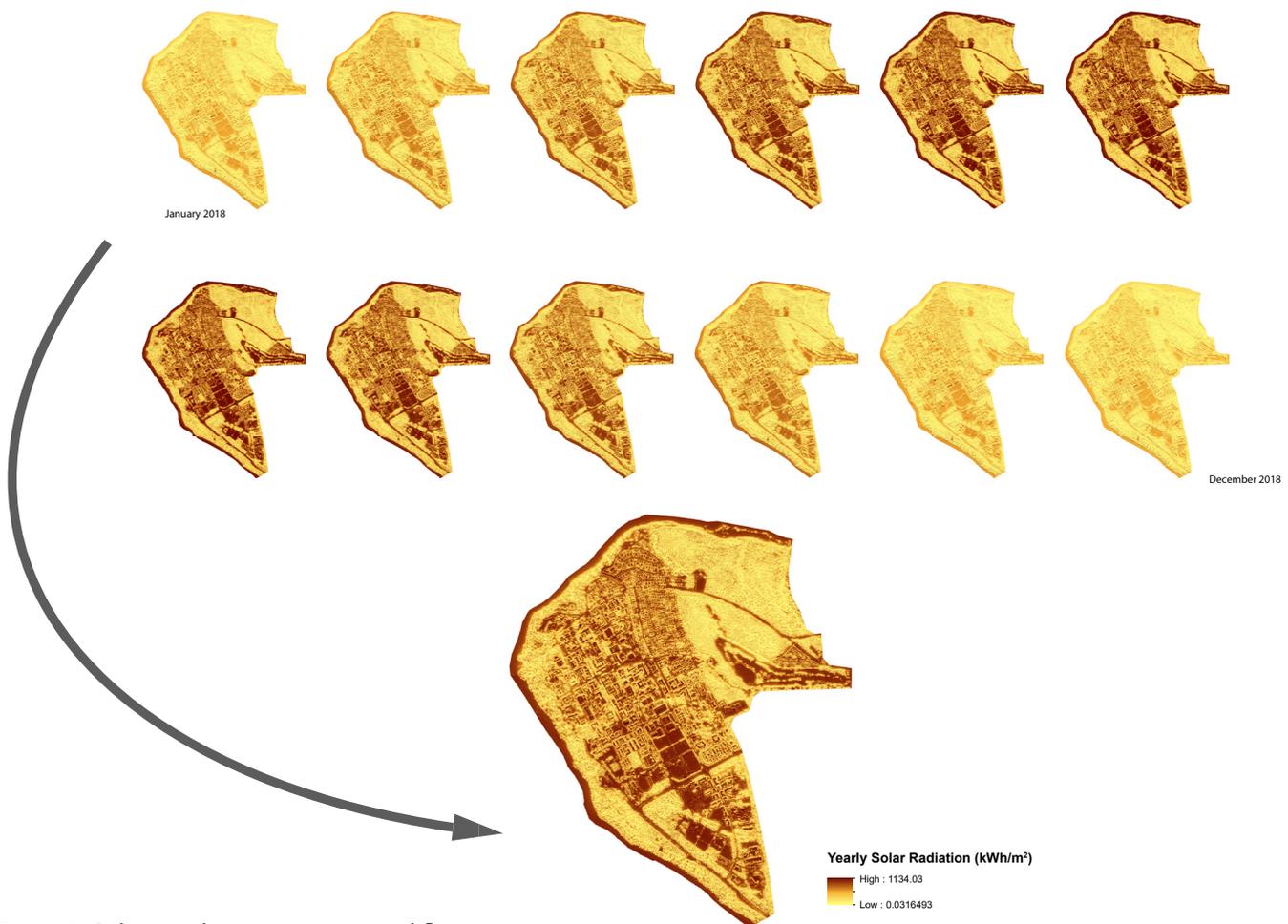


Figure 2. Solar simulation mapping workflow.

4. Results

Figure 3 illustrates the result of the roof suitability analysis. As observed, several roofs seem to be suitable for solar energy in terms of their aspect, slope and size. Out of 642,211 m² of roof area, 47% meets the slope, size, and aspect suitability requirements described in “Section 1: Methodology” (Figure 3).

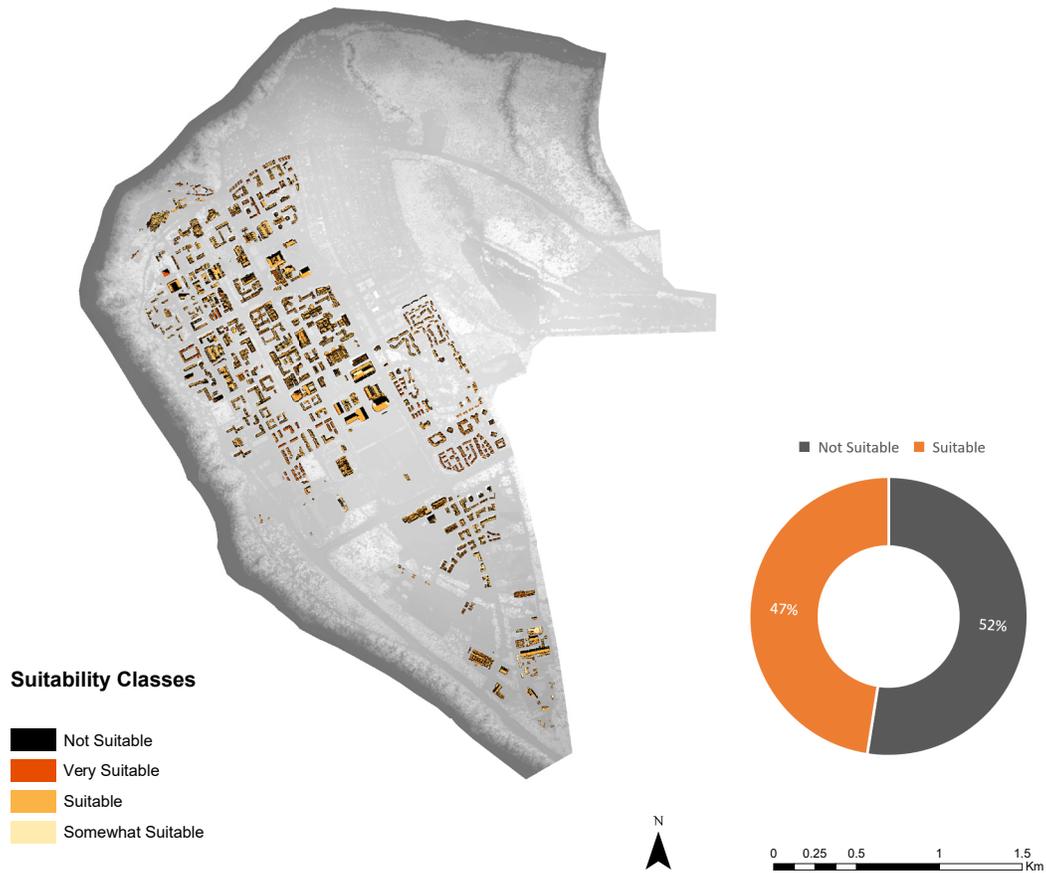


Figure 3. Roof Suitability Map.

Total yearly solar radiation for UBC and UBC roofs in kWh/m² can be observed in Figure 4. For UBC's total roof area of 642,211 m², the total yearly solar radiation potential, in generally clear sky conditions, is of 490,707,543 kWh. UBC's total roof area receives on average 767 kWh/m² of solar radiation yearly, with radiation values ranging from 0.03 kWh/m² to 1134 kWh/m². Monthly averages in solar radiation greatly vary between seasons, with highest monthly average in June of 132 kWh/m² and lowest monthly average in December of 5.5 kWh/m².

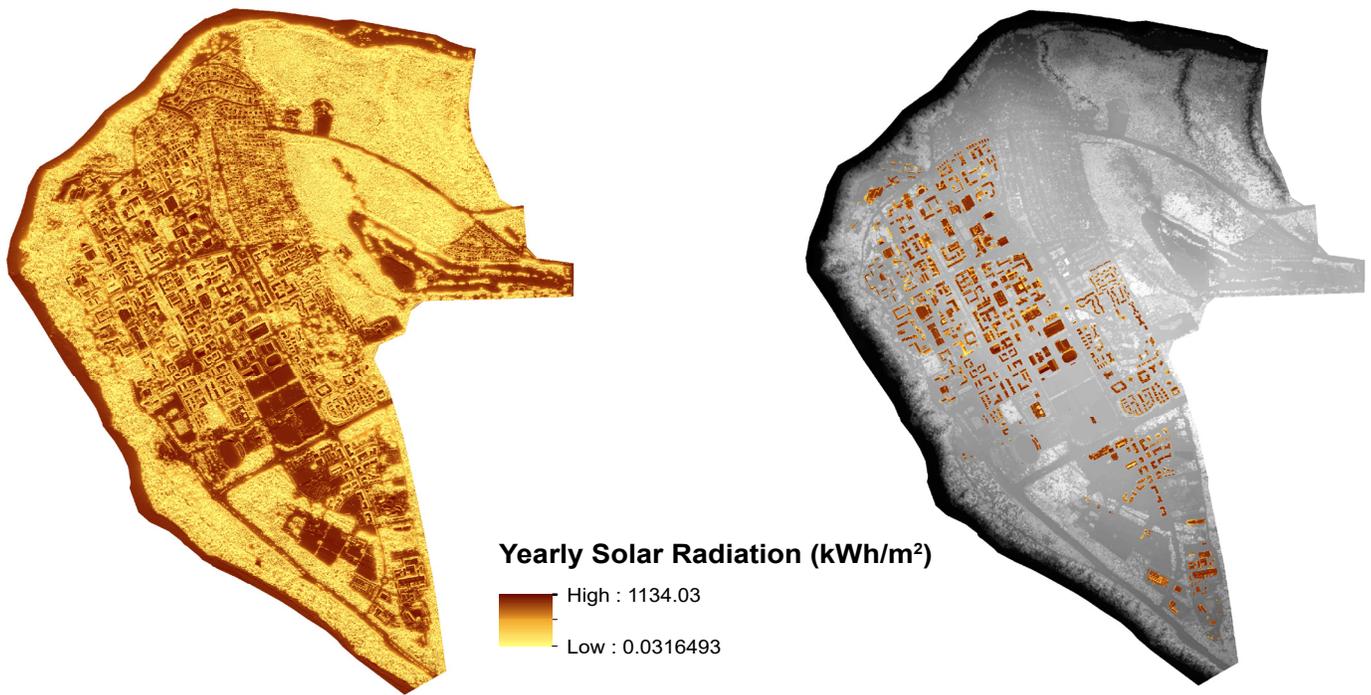


Figure 4. UBC Yearly Solar Radiation (left), UBC Roof Yearly Solar Radiation (right) Maps.

Zonal statistics performed on yearly solar radiation at UBC revealed results indicative of solar potential for each individual building. Of UBC's 537 buildings, the 20 buildings with highest yearly total solar radiation potential (kWh) are shown in Figure 5. Among those, the Forest Sciences Center has the potential of receiving 6.8 Million kWh worth of solar radiation yearly, and the Doug Mitchell Thunderbird Sport Center has the potential of receiving 12.2 Million kWh worth of solar radiation yearly. While these buildings' rooftops receive very high amounts of solar radiation, installing PV cells on them is not necessarily the most efficient solution. This is because they may have a large roof surface area but a low solar energy to roof area ratio (kWh/m²). For example, "Hampton Place Lot 3 - Thames Court" has the potential of receiving 3.8 Million kWh worth of solar radiation yearly. However, on average, "Hampton Place Lot 3 - Thames Court" only receives 710 kWh of solar radiation per m². This indicates that a portion of the roof area on "Hampton Place Lot 3 - Thames Court" is likely characterized by less optimal conditions for solar radiation collection.

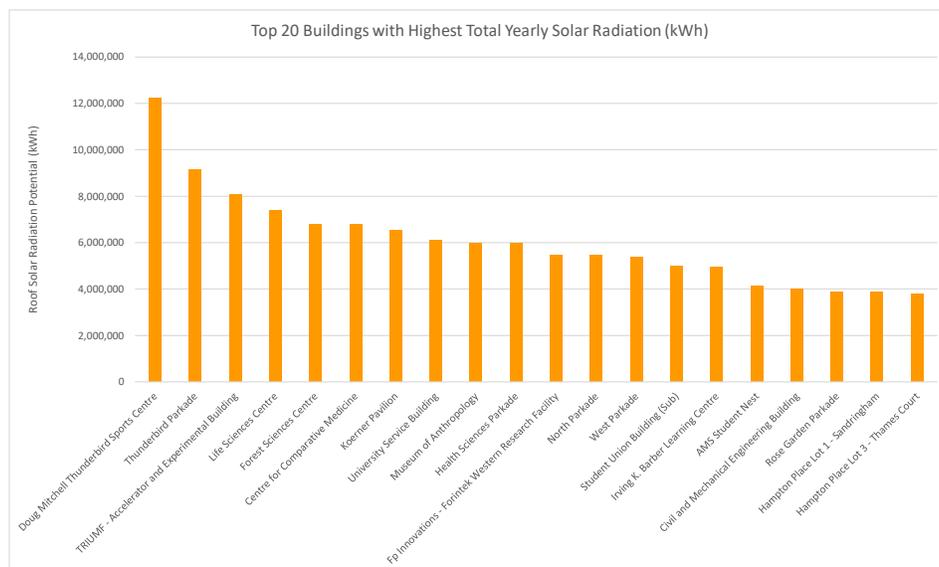


Figure 5. Top 20 Buildings with Highest Yearly Total Solar Radiation Potential (kWh).

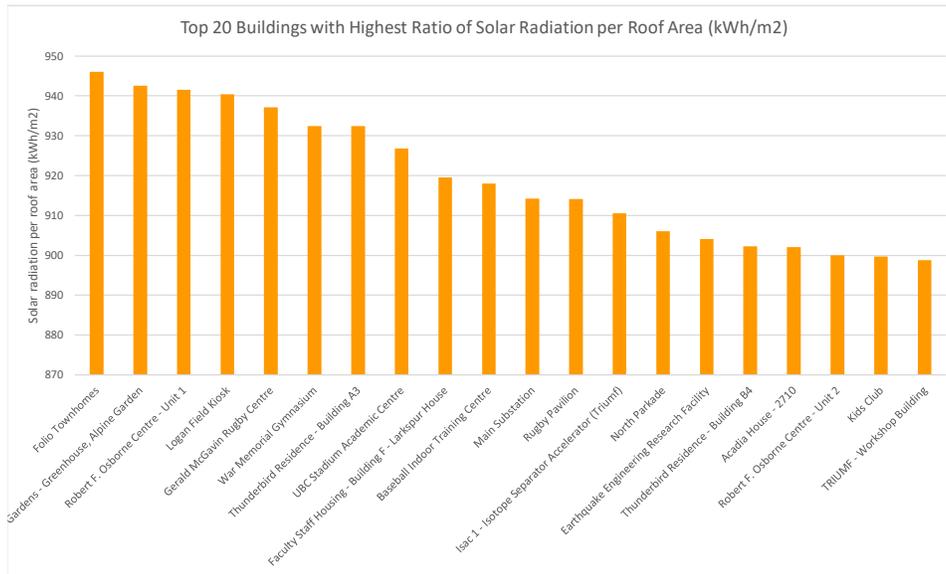


Figure 6. Top 20 Buildings with Highest Yearly Total Solar Radiation Potential (kWh).

In this light, Figure 6 illustrates the 20 buildings with highest ratio of solar radiation per roof area (kWh/m²) at UBC (Figure 6). Among these buildings, the “Robert F. Osborne Centre - Unit 1” building has the potential of receiving 2.3 Million kWh worth of solar radiation at 942 kWh/m². While these buildings may have very high ratio of solar radiation per roof area (kWh/m²), the installation of PV solar arrays on them is not necessarily the most impactful solution either. In fact, kWh of solar radiation per m² is not the sole indicator of solar energy potential. If a roof has a high kWh of solar radiation per m² but a small surface area, installation of PV solar arrays may not translate into significant energy production.

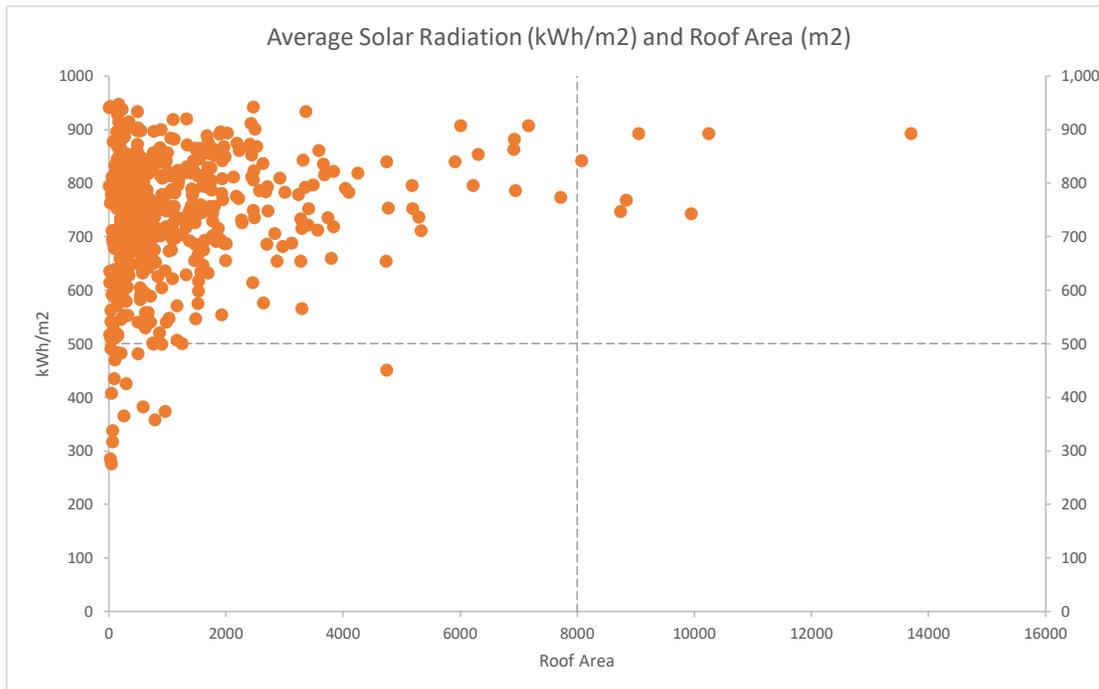


Figure 7. Average Solar Radiation (kWh/m²) and Roof Area (m²)

The distribution of roof sizes (m²) and solar radiation per roof area (kWh/m²) is illustrated in Figure 7. As depicted in Figure 7, UBC has a large quantity of small roofs that are intervariable in kWh of solar radiation per m² potential. Figure 7 also indicates that UBC has a significant quantity of medium sized roofs with a generally high potential of kWh of solar radiation per m². Lastly, Figure 7 illustrates that UBC has a small amount of very large roofs with high potential of solar radiation per roof area (kWh/m²). Roofs located within the upper right quadrant of Figure 7 are the most ideal roofs for implementation of PV solar arrays, for they would allow the harnessing of maximum solar energy with highest efficiency. Conversely, roofs located within the lower left quadrant of Figure 7 are the least ideal roofs for

implementation of PV solar arrays, for they would allow the harnessing of minimal amounts of solar energy with low efficiency.

As both roof area (m²) and solar radiation per roof area (kWh/m²) must be high for good suitability, the solar suitability index combines both these parameters for each roof, and ranks all UBC roofs from most suitable to least suitable for solar energy capture. The 40 most suitable buildings for solar energy capture can be observed in Figure 8 (see Appendix 2 for the entire suitability index). Together, rooftops for those 40 buildings account for 37% of all solar radiation reaching UBC roofs (Table 10). The top 5 buildings that scored the highest on the solar suitability index are the Doug Mitchell Thunderbird Sports Centre, the Thunderbird Parkade, the TRIUMF - Accelerator and Experimental Building, the Life Sciences Centre, and the Forest Science Center (Figure 8). Please see Figure 9 for a 1:800 solar map of each of these buildings, and Table 10 for a summary of the results from this study.

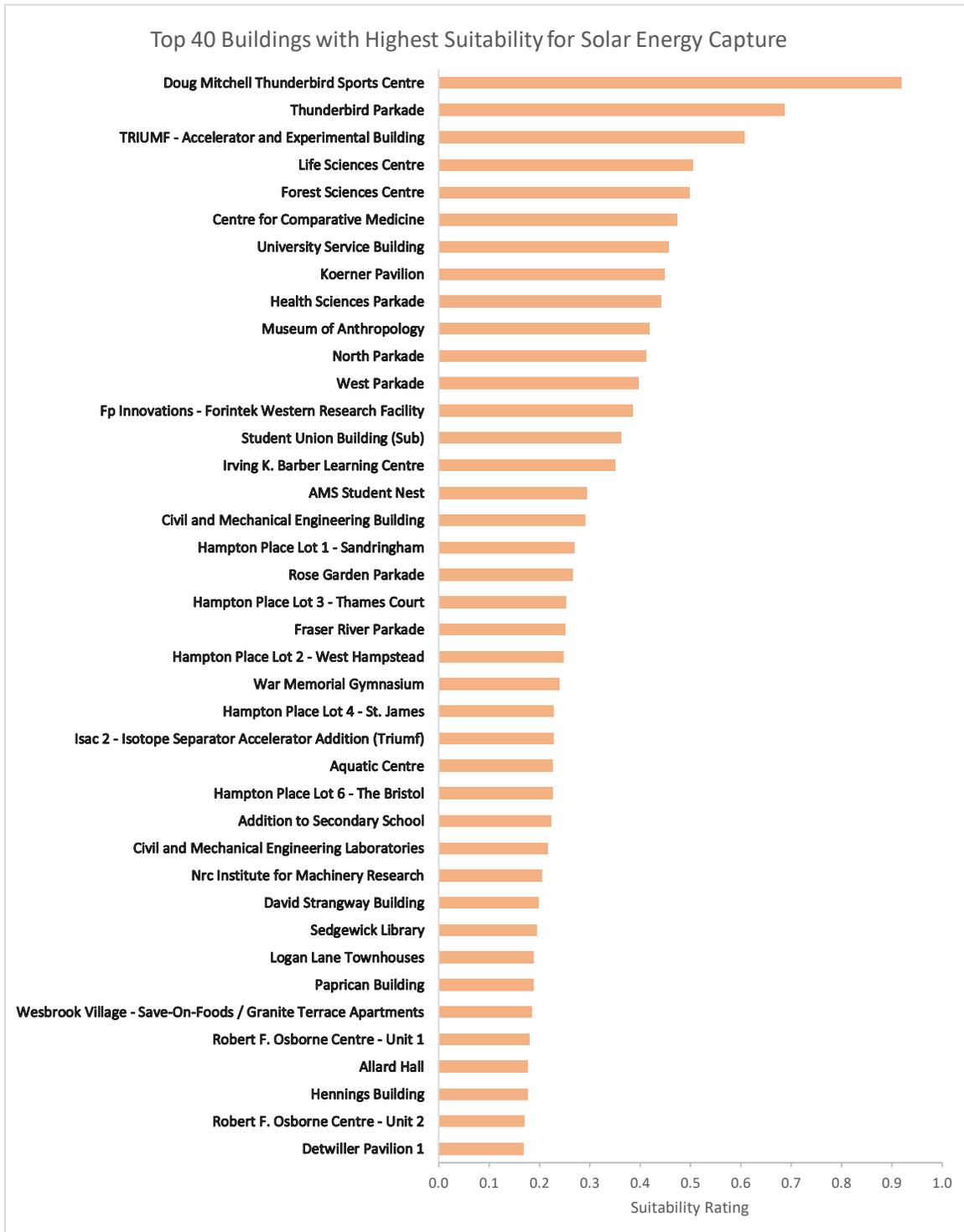
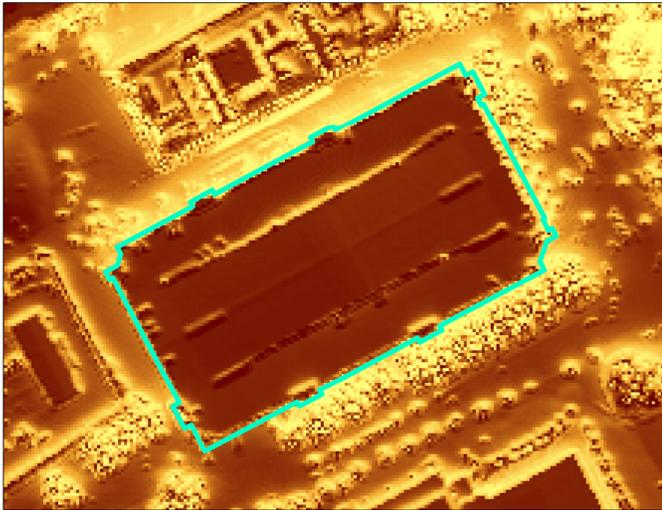
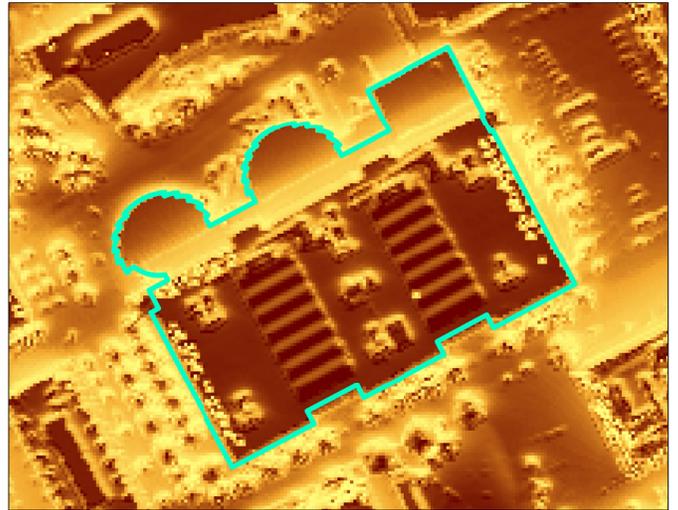


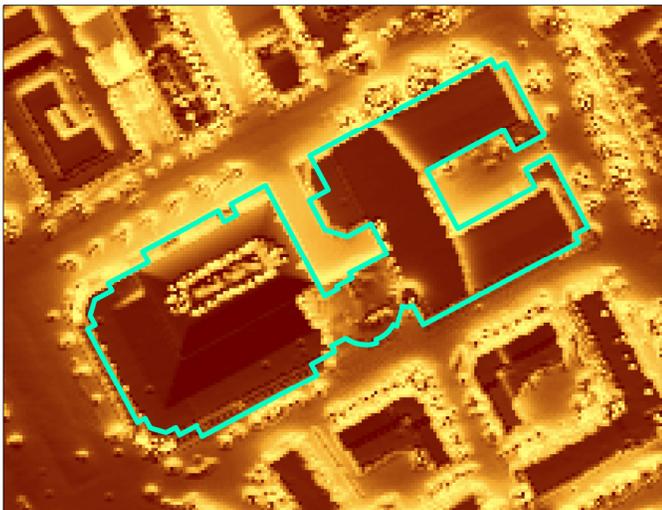
Figure 8. Top 40 Buildings with Highest Suitability for Solar Energy Capture



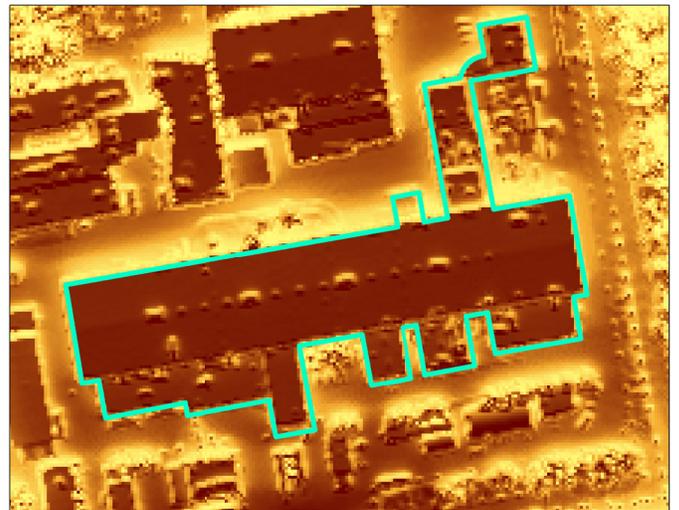
Thunderbird Parkade



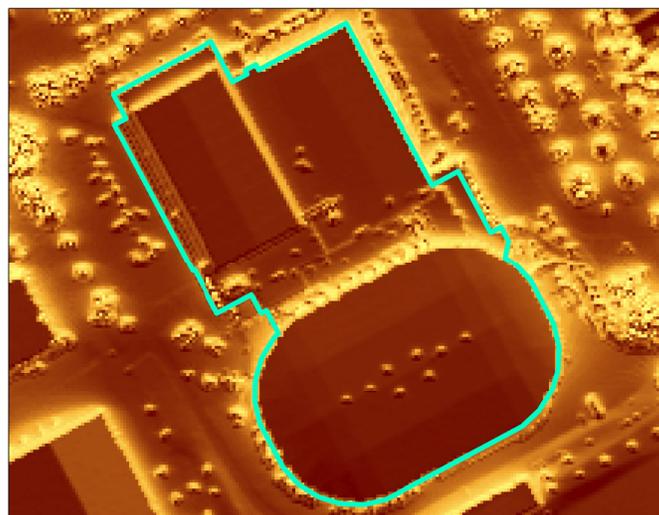
Life Sciences Center



Forest Sciences Center



TRIUMF - Accelerator and Experimental Building



Doug Mitchell Thunderbird Sports Centre

— Building footprint

Yearly Solar Radiation (kWh/m²)



0 5 10 20 30 40 Meters

Figure 9. Top 5 Buildings with Highest Suitability for Solar Energy Capture

Table 10. Results Summary (Yearly)

Results Summary (Yearly)	
UBC TOTAL ROOF AREA (m ²)	642,211
Energy Totals and Potential Savings	
POTENTIAL TOTAL PRIMARY ENERGY FROM SOLAR (kwh)	490,707,544
POTENTIAL TOTAL SECONDARY ENERGY FROM 15% EFFICIENCY PV (kwh)	73,606,131.54
POTENTIAL TOTAL SECONDARY ENERGY FROM 15% EFFICIENCY PV (GJ)	264,982
POTENTIAL ENERGY SAVINGS FROM USE OF SOLAR FOR ELECTRICITY (%)	51%
POTENTIAL ENERGY SAVINGS FROM USE OF SOLAR FOR DISTRICT ENERGY (%)	62%
Potential Emission Reductions	
POTENTIAL EMISSION REDUCTIONS FROM USE OF SOLAR FOR ELECTRICITY (tCO ₂ e)	795
POTENTIAL EMISSION REDUCTIONS FROM USE OF SOLAR FOR DISTRICT ENERGY (tCO ₂ e)	13,132
Top 40 Energy Totals	
TOTAL ENERGY FROM TOP 40 MOST SUITABLE BUILDINGS (kWh)	182,895,965
TOTAL ENERGY FROM TOP 40 MOST SUITABLE BUILDINGS (%)	37%

5. Discussion and Recommendations

As reported on the “UBC Vancouver Campus – 2016 Greenhouse Gas Emissions Inventory”, UBC is emitting about 40,536 tCO₂e of greenhouse gas (GHG) emissions yearly and consuming 145,313,732 kWh of high voltage electricity purchased from BC hydro (University of British Columbia, 2016). As seen previously, the potential yearly total solar radiation reaching UBC roofs in generally clear sky conditions is 490,707,543 kWh (Figure 10). At 15% efficiency, UBC rooftops coupled with PV solar arrays have the potential of producing 73,606,131 kWh in electricity, which is slightly more than half the total consumption of electricity at UBC. Thus, solar energy could be used to replace a significant portion of purchased electricity from BC hydro. However, while electricity savings would be substantial, carbon emission reductions would be less important given the low emission factor of BC hydro electricity (BC Hydro, 2015; University of British Columbia, 2016; Table 10). In this scenario, it would be difficult to make a convincing business case for switching to solar energy at UBC, for little money would be saved on offset costs.

Instead, solar energy at UBC could be used to replace other types of energy consumption that account for more substantial amounts of GHG emissions. More than half of UBC’s carbon emissions originate from the burning of natural gas dedicated to district energy usage (University of British Columbia, 2016). If electricity from solar energy could be used for solar water heating at the building level, high GHG emission reductions could result from district energy usage (Table 10)(Solar Water Heaters, 2018). Converting potential energy produced from solar into GJ yields 264,982 GJ. This represents 62% of UBC’s current usage for district energy of 424,697 GJ, and a potential GHG emissions reduction of more than half the current levels (University of British Columbia, 2016; Table 10). Thus, it seems that the argument for solar energy at UBC rests upon the possibility of transitioning from other forms of energy consumption to solar produced electricity. Future research could look at the feasibility of such scenario, and the associated net benefits of a solar energy transition.

While this study provides an appropriate assessment of atmospheric, geographic, spatial, and architectural characteristics that influence PV solar array implementation potential on UBC Vancouver campus, it does not consider a number of elements which fall outside of the scope of this study. These include, but are not limited to, structural integrity, accessibility of roofs, presence of other mechanical equipment on roofs, and type of roof material. The suitability index provided in this study is intended to be used as a tool for identifying roofs that would be most suitable in terms of energy production and production efficiency from solar. Before starting a solar project, experts must further assess other roof conditions such as those suggested above. Regarding the data used for this study, one limitation must be highlighted. The most recently available LiDAR datasets were of 2015, which imposed some constraints on the study. Many buildings that were under construction in 2015 could not be included as part of the study, and technical potential for solar energy on those buildings could not be estimated. In addition, the study assumes that no trees have been removed from UBC campus since 2015. If trees have been removed, the calculation of solar roof radiation and the

results of the solar suitability analysis could be affected.

If UBC wishes to implement PV solar arrays on select buildings, it is recommended to refer to the solar suitability index provided by this study (Appendix 2). Highly suitable buildings in this index have the potential to provide maximum returns in energy production and highest conversion efficiency from solar. Focusing on buildings with highest suitability ratings (see 40 buildings identified in Figure 8) for implementation of PV solar arrays would provide the maximum benefits in terms of solar energy efficiency.

Finally, it is important to consider that the solar study was carried out simulating generally clear sky conditions. The main reason for this limitation was the timeframe provided to complete the study. Solar radiation values are thus likely to be most accurate for spring and summer months, and inflated for the winter and fall months. Given Vancouver's typical overcast conditions in the winter, it is highly recommended that this study is repeated simulating realistic cloud cover in winter and fall months. This additional research would prove crucial and necessary to be combined with the results of this study. Such extension of this study would improve the utility of the solar suitability index for buildings on UBC campus.

6. Appendix 1: Area Solar Radiation Tool

The solar radiation analysis tools calculate insolation across a landscape or for specific locations, based on methods from the hemispherical viewshed algorithm developed by Rich et al. (Rich 1990, Rich et al. 1994) and further developed by Fu and Rich (2000, 2002).

The total amount of radiation calculated for a particular location or area is given as global radiation. The calculation of direct, diffuse, and global insolation are repeated for each feature location or every location on the topographic surface, producing insolation maps for an entire geographic area.

SOLAR RADIATION EQUATIONS

Global radiation calculation

Global radiation ($Global_{tot}$) is calculated as the sum of direct (Dir_{tot}) and diffuse (Dif_{tot}) radiation of all sun map and sky map sectors, respectively.

$$Global_{tot} = Dir_{tot} + Dif_{tot}$$

Direct solar radiation

Total direct insolation (Dir_{tot}) for a given location is the sum of the direct insolation ($Dir_{\theta,\alpha}$) from all sun map sectors:

$$Dir_{tot} = \sum Dir_{\theta,\alpha} \quad (1)$$

The direct insolation from the sun map sector ($Dir_{\theta,\alpha}$) with a centroid at zenith angle (θ) and azimuth angle (α) is calculated using the following equation:

$$Dir_{\theta,\alpha} = S_{Const} * \beta^{m(\theta)} * SunDur_{\theta,\alpha} * SunGap_{\theta,\alpha} * \cos(AngIn_{\theta,\alpha}) \quad (2)$$

where:

- S_{Const} — The solar flux outside the atmosphere at the mean earth-sun distance, known as solar constant. The solar constant used in the analysis is 1367 W/m². This is consistent with the World Radiation Center (WRC) solar constant.
- β — The transmissivity of the atmosphere (averaged over all wavelengths) for the shortest path (in the direction of the zenith).
- $m(\theta)$ — The relative optical path length, measured as a proportion relative to the zenith path length (see equation 3 below).
- $SunDur_{\theta,\alpha}$ — The time duration represented by the sky sector. For most sectors, it is equal to the day interval (for example, a month) multiplied by the hour interval (for example, a half hour). For partial sectors (near the horizon), the duration is calculated using spherical geometry.

- $\text{SunGap}_{\theta,\alpha}$ — The gap fraction for the sun map sector.
- $\text{Angln}_{\theta,\alpha}$ — The angle of incidence between the centroid of the sky sector and the axis normal to the surface (see equation 4 below).

Relative optical length, $m(\theta)$, is determined by the solar zenith angle and elevation above sea level. For zenith angles less than 80° , it can be calculated using the following equation:

$$m(\theta) = \text{EXP}(-0.000118 * \text{Elev} - 1.638 * 10^{-9} * \text{Elev}^2) / \cos(\theta) \quad (3)$$

where:

- θ — The solar zenith angle.
- Elev — The elevation above sea level in meters.

The effect of surface orientation is taken into account by multiplying by the cosine of the angle of incidence. Angle of incidence ($\text{AnglnSky}_{\theta,\alpha}$) between the intercepting surface and a given sky sector with a centroid at zenith angle and azimuth angle is calculated using the following equation:

$$\text{Angln}_{\theta,\alpha} = \text{acos}(\text{Cos}(\theta) * \text{Cos}(G_z) + \text{Sin}(\theta) * \text{Sin}(G_z) * \text{Cos}(\alpha - G_a)) \quad (4)$$

where:

- G_z — The surface zenith angle.

Note that for zenith angles greater than 80° , refraction is important.

- G_a — The surface azimuth angle.

Diffuse radiation calculation

For each sky sector, the diffuse radiation at its centroid (Dif) is calculated, integrated over the time interval, and corrected by the gap fraction and angle of incidence using the following equation:

$$\text{Dif}_{\theta,\alpha} = R_{g_{lb}} * P_{dif} * \text{Dur} * \text{SkyGap}_{\theta,\alpha} * \text{Weight}_{\theta,\alpha} * \cos(\text{Angln}_{\theta,\alpha}) \quad (5)$$

where:

- $R_{g_{lb}}$ — The global normal radiation (see equation 6 below).
- P_{dif} — The proportion of global normal radiation flux that is diffused. Typically it is approximately 0.2 for very clear sky conditions and 0.7 for very cloudy sky conditions.
- Dur — The time interval for analysis.
- $\text{SkyGap}_{\theta,\alpha}$ — The gap fraction (proportion of visible sky) for the sky sector.
- $\text{Weight}_{\theta,\alpha}$ — The proportion of diffuse radiation originating in a given sky sector relative to all sectors (see equations 7 and 8 below).
- $\text{Angln}_{\theta,\alpha}$ — The angle of incidence between the centroid of the sky sector and the intercepting surface.

The global normal radiation ($R_{g_{lb}}$) can be calculated by summing the direct radiation from every sector (including obstructed sectors) without correction for angle of incidence, then correcting for proportion of direct radiation, which equals $1 - P_{dif}$:

$$R_{g_{lb}} = (S_{\text{const}} \sum(\beta^{m(\theta)})) / (1 - P_{dif}) \quad (6)$$

For the uniform sky diffuse model, $\text{Weight}_{\theta,\alpha}$ is calculated as follows:

$$\text{Weight}_{\theta,\alpha} = (\cos\theta_2 - \cos\theta_1) / \text{Div}_{azi} \quad (7)$$

where:

- θ_1 and θ_2 — The bounding zenith angles of the sky sector.
- Div_{azi} — The number of azimuthal divisions in the sky map.

For the standard overcast sky model, $Weight_{\theta,\alpha}$ is calculated as follows:

$$Weight_{\theta,\alpha} = (2\cos\theta_2 + \cos2\theta_2 - 2\cos\theta_1 - \cos2\theta_1) / 4 * Div_{azi} \quad (8)$$

Total diffuse solar radiation for the location (Dif_{tot}) is calculated as the sum of the diffuse solar radiation (Dif) from all the sky map sectors:

$$Dif_{tot} = \sum Dif_{\theta,\alpha} \quad (9)$$

(ESRI, 2018).

7. Appendix 2: Yearly Solar Radiation Statistics and Solar Suitability Index for UBC Buildings Rooftops

Yearly Solar Radiation Statistics and Solar Suitability Index for UBC Buildings Rooftops					
NAME	Zone Code	Roof Area (m ²)	Average Solar Radiation (kWh/m ²)	Total Yearly Solar Radiation (kWh)	Suitability Index for Solar
Doug Mitchell Thunderbird Sports Centre	408	13,707	891	12,219,579	0.919
Thunderbird Parkade	407	10,253	891	9,137,817	0.687
TRIUMF - Accelerator and Experimental Building	519	9,062	892	8,080,053	0.607
Life Sciences Centre	235	9,959	742	7,384,967	0.505
Forest Sciences Centre	360	8,082	841	6,798,953	0.497
Centre for Comparative Medicine	185	8,846	767	6,786,231	0.473
University Service Building	294	6,933	882	6,111,569	0.457
Koerner Pavilion	442	8,751	746	6,527,514	0.448
Health Sciences Parkade	60	6,926	862	5,968,163	0.441
Museum of Anthropology	390	7,730	772	5,970,748	0.418
North Parkade	271	6,015	906	5,450,146	0.412
West Parkade	295	6,316	853	5,384,458	0.396
Fp Innovations - Forintek Western Research Facility	400	6,950	785	5,456,362	0.385
Student Union Building (Sub)	261	5,926	838	4,968,720	0.363
Iving K. Barber Learning Centre	439	6,230	794	4,949,674	0.352
AMS Student Nest	276	5,189	795	4,124,677	0.293
Civil and Mechanical Engineering Building	239	4,752	839	3,988,966	0.291
Hampton Place Lot 1 - Sandringham	335	5,193	751	3,900,881	0.289
Rose Garden Parkade	230	5,305	736	3,903,750	0.285
Hampton Place Lot 3 - Thames Court	337	5,342	710	3,792,066	0.252
Fraser River Parkade	215	4,263	818	3,486,550	0.251
Hampton Place Lot 2 - West Hampstead	336	4,783	752	3,598,266	0.248
War Memorial Gymnasium	323	3,372	932	3,144,052	0.240
Hampton Place Lot 4 - St. James	306	3,849	821	3,160,692	0.228
Isac 2 - Isotope Separator Accelerator Addition (Triumf)	259	3,593	860	3,088,717	0.228
Aquatic Centre	226	4,107	782	3,212,123	0.226
Hampton Place Lot 6 - The Bristol	317	4,049	789	3,194,174	0.226
Addition to Secondary School	389	3,669	834	3,060,722	0.223
Civil and Mechanical Engineering Laboratories	66	3,689	814	3,004,450	0.216
Nrc Institute for Machinery Research	34	3,327	842	2,800,797	0.204
David Strangway Building	437	3,498	796	2,784,526	0.198
Sedgewick Library	99	4,742	654	3,098,945	0.195
Logan Lane Townhouses	288	3,359	791	2,658,536	0.188
Paprican Building	92	3,745	735	2,751,926	0.187
Wesbrook Village - Save-On-Foods / Granite Terrace A	250	3,849	718	2,762,050	0.185
Robert F. Osborne Centre - Unit 1	89	2,478	942	2,333,112	0.179
Allard Hall	459	3,252	778	2,529,479	0.177
Hennings Building	440	3,418	751	2,566,815	0.176
Robert F. Osborne Centre - Unit 2	272	2,501	900	2,250,942	0.169
Detwiller Pavilion 1	242	2,926	809	2,365,910	0.169
H. R. Macmillan Building	62	3,575	711	2,542,366	0.169
Isac 1 - Isotope Separator Accelerator (Triumf)	260	2,437	911	2,218,952	0.168
Nrc Institute for Fuel Cell Innovation	281	3,014	783	2,358,552	0.166
Somerset	453	3,409	721	2,458,792	0.165
Earth Sciences Building	441	3,285	733	2,406,321	0.163
Student Recreation Centre	450	2,537	867	2,199,915	0.163
Geography Building	224	2,644	836	2,209,258	0.161
P. A. Woodward Instructional Resources Centre	380	3,811	659	2,510,438	0.159
Chan Centre for The Performing Arts	1	3,301	714	2,357,023	0.157
Coquihalla Common Block	419	2,416	872	2,106,736	0.156
UBC Tennis Centre	57	2,422	866	2,098,360	0.155
J. B. Macdonald Building	406	2,443	851	2,079,452	0.152
Greenwood Commons - Rental Housing	7	2,718	792	2,153,164	0.152
Beaty Biodiversity Centre	431	2,691	783	2,107,246	0.148
Westchester Townhouses	289	2,485	823	2,044,032	0.147
Michael Smith Laboratories	356	2,580	786	2,026,679	0.143
Tapestry At Wesbrook Village, UBC - North Building	428	2,479	806	1,997,390	0.142
Earth and Ocean Sciences - Main	64	2,450	812	1,988,742	0.142
Journey	23	2,193	874	1,916,734	0.142
Reflections	20	2,235	860	1,921,219	0.141
Chemical & Biological Engineering Building	343	3,128	687	2,149,984	0.140
Purdy Pavilion	338	2,722	747	2,033,457	0.139
Keenleyside	249	2,032	893	1,813,820	0.136
Djavad Mowafaghian Centre for Brain Health	443	3,282	654	2,145,639	0.135
Institute for Computing, Information and Cognitive Sys	370	2,847	705	2,007,136	0.133
The Fred Kaiser Building	376	2,982	681	2,031,426	0.131
Faculty Staff Housing - Building E - Tamarack House	467	1,913	895	1,712,095	0.128
Douglas Kenny Building	97	2,479	748	1,855,258	0.127
Thunderbird Stadium	344	1,975	868	1,714,189	0.127
Brockhouse Community Centre	367	1,898	891	1,691,183	0.126
The Brimacombe Building	212	2,499	734	1,835,176	0.124
Pacific - Adera	277	2,140	811	1,735,395	0.124
Library PARC	377	1,995	849	1,693,320	0.124
Brock Hall - East Wing	513	1,947	857	1,669,514	0.123
Bookstore	405	2,707	685	1,853,694	0.120
Legacy Apartments	455	1,944	843	1,639,682	0.119
Wesbrook Building	420	2,228	770	1,715,832	0.119

Yearly Solar Radiation Statistics and Solar Suitability Index for UBC Buildings Rooftops						
NAME	Zone Code	Roof Area (m2)	Average Solar Radiation (kWh/m2)	Total Yearly Solar Radiation (kWh)	Suitability Index for Solar	
TRIUMF - Offices, Laboratory & Workshops	520	1,940	841	1,631,656	0.119	
Marine Drive Residence - Building #6	449	2,190	775	1,697,265	0.118	
Prodigy	418	2,877	653	1,879,372	0.118	
Public Safety Building	312	1,847	858	1,584,966	0.116	
Sopron House	314	1,788	863	1,543,571	0.114	
Woodward Library	221	1,810	850	1,539,284	0.113	
The Leonard S. Klinck Building	218	1,948	807	1,572,426	0.112	
St. John's College Phase 2 & 3	399	2,269	731	1,657,820	0.112	
Clement's Green	283	1,768	860	1,519,744	0.112	
Ritsumeikan-UBC House	95	2,287	725	1,657,809	0.111	
South Campus Warehouse	363	1,682	888	1,493,099	0.111	
Buchanan Building Block D	258	1,707	875	1,492,987	0.111	
School of Population & Public Health	273	1,718	854	1,467,970	0.108	
Mews	401	1,936	780	1,509,183	0.106	
Macleod Building	369	1,749	827	1,446,994	0.104	
Lower Mall Research Station	2	1,957	768	1,503,211	0.104	
Pharmaceutical Sciences Building	103	3,309	565	1,869,845	0.104	
Pathways I (West)	457	1,630	862	1,404,608	0.103	
Nobel House	421	1,707	828	1,413,736	0.102	
Biological Sciences Building - West Wing	268	1,766	804	1,419,506	0.101	
Place Vanier Residence - Gordon Shrum Common E	284	1,562	864	1,349,504	0.099	
Walter H. Gage Residence - Apartments	233	1,759	786	1,382,801	0.097	
Folio Apartment Building	430	1,562	844	1,318,062	0.096	
Mathematics Building	39	1,486	865	1,285,030	0.095	
Point Grey Apartments (Osoyoos Housing)	315	1,806	756	1,364,540	0.094	
Buchanan Building Block A	372	1,610	813	1,309,604	0.094	
Faculty Staff Housing - Building F - Larkspur House	120	1,341	920	1,233,093	0.093	
Buchanan Building Block B	516	1,652	793	1,309,374	0.092	
Orchard Commons	528	4,758	450	2,141,627	0.091	
Yu - Modern Green	361	2,467	613	1,513,122	0.090	
Biological Sciences Building	93	1,610	793	1,277,065	0.090	
West Mall Swing Space Building	296	1,734	755	1,309,627	0.090	
Totem Park Residence - Dene House/Nootka House	214	1,776	743	1,318,816	0.090	
Hampton Place Lot 10 - Pemberley	32	2,008	686	1,377,222	0.089	
Technology Enterprise Facility 3 (Tef3)	322	1,877	714	1,340,712	0.089	
Hampton Place Lot 7-2 - Wyndham Hall	149	1,532	813	1,244,889	0.089	
Neville Scarfe Building - Classroom Block	484	1,452	841	1,221,773	0.089	
Chemistry D Block, Centre Wing	132	1,980	686	1,357,914	0.088	
Marine Drive Residence - Building #2	125	1,446	836	1,208,561	0.087	
Totem Park Residence - Kwakiutl House/Shuswap H	352	1,780	729	1,296,777	0.087	
Dahlia House - Building 2	388	1,350	870	1,175,048	0.087	
St. John's College Phase 1	121	1,907	694	1,324,215	0.086	
Ponderosa Commons	527	2,646	575	1,522,246	0.086	
Faculty Staff Housing - Building D - Gardenia House	21	1,471	818	1,202,751	0.086	
Chancellor House (Apartments)	238	1,452	824	1,195,812	0.086	
Spirit - Adera	415	1,412	818	1,155,566	0.083	
Neville Scarfe Building - Lecture Block	425	1,582	758	1,199,772	0.083	
Henry Angus Building	384	1,837	691	1,268,761	0.083	
Walter H. Gage Residence - Common Block	515	2,001	654	1,309,346	0.082	
Totem Park Residence - Haida House/Salish House	210	1,779	701	1,246,879	0.082	
Continuing Studies Building	359	1,595	744	1,186,490	0.081	
Food, Nutrition and Health Building	339	1,340	829	1,111,128	0.080	
Chancellor Hall (Apartments)	424	1,453	784	1,139,234	0.080	
Marine Drive Residence - Building #3	445	1,349	819	1,104,284	0.079	
Music Building	234	1,420	788	1,118,816	0.079	
Biological Sciences Building - North Wing	267	1,431	777	1,111,891	0.077	
Brock Hall - West Wing	231	1,514	748	1,133,114	0.077	
Baseball Indoor Training Centre	187	1,109	918	1,018,083	0.077	
Totem Park Residence - Hemelesem House	303	1,642	693	1,137,475	0.074	
St. John Hospice	410	1,129	881	994,212	0.074	
Power House	98	1,481	735	1,088,420	0.073	
Campus Energy Centre	526	1,410	756	1,066,308	0.073	
Coast Apartment East	265	1,482	725	1,075,130	0.072	
Aquatic Ecosystems Research Laboratory	285	1,387	748	1,038,003	0.071	
Thunderbird Residence - Building A2	302	1,191	824	980,862	0.070	
Chemistry A Block, Chemistry Physics Building	334	1,624	675	1,096,152	0.070	
Thunderbird Residence - Building A1	298	1,187	822	975,449	0.070	
Magnolia House - Building 1	460	1,063	883	939,110	0.070	
Thunderbird Residence - Building B2	279	1,185	815	965,783	0.069	
Ultima	522	1,393	731	1,018,507	0.069	
Thunderbird Residence - Building C1	305	1,198	805	964,037	0.068	
Pathways II (East)	190	1,195	804	961,371	0.068	
Chemistry B Block, South Wing	500	1,353	734	993,291	0.067	
Thunderbird Residence - Building B1	287	1,194	796	950,146	0.067	
Pulp and Paper Centre	213	1,483	685	1,015,845	0.066	
David Lam Management Research Centre	211	1,704	631	1,075,653	0.066	
Centre for Interactive Research in Sustainability (CIR	368	1,620	646	1,047,049	0.065	
Westpoint	340	1,308	735	961,806	0.065	
SAIL 1	523	1,311	732	959,058	0.065	
Leon and Thea Koerner University Centre	392	1,315	730	959,805	0.064	

Yearly Solar Radiation Statistics and Solar Suitability Index for UBC Buildings Rooftops						
NAME	Zone Code	Roof Area (m2)	Average Solar Radiation (kWh/m2)	Total Yearly Solar Radiation (kWh)	Suitability Index for Solar	
Ponderosa Commons West	292	1,528	665	1,016,191	0.064	
TRIUMF - Ariel Building	525	1,096	813	890,607	0.063	
Hebb Building	225	1,327	717	951,047	0.063	
Old Administration Building	46	1,004	855	858,898	0.063	
Asian Centre	274	1,384	691	956,518	0.062	
Plant Operations Nursery	413	1,135	781	885,975	0.062	
Horticulture Building	79	1,577	634	999,090	0.061	
MBA House	402	1,048	817	855,820	0.061	
Frederic Lasserre Building	366	1,050	813	853,923	0.061	
Fraser Hall - Student Rental Housing	122	990	841	833,044	0.060	
TRIUMF - Workshop Building	521	900	899	808,895	0.060	
Berwick Memorial Centre	130	1,469	655	961,818	0.060	
Friedman Building	94	1,021	821	837,758	0.060	
Anthropology and Sociology Building	50	1,084	787	853,362	0.060	
Frank Forward Building	63	1,264	703	888,826	0.058	
First Nations Longhouse	404	1,932	554	1,069,620	0.058	
Neville Scarfe Building - Library	358	963	838	807,052	0.058	
Dorothy Somerset Studios	69	1,124	756	849,900	0.058	
Donald Rix Building	59	1,177	731	860,403	0.058	
Old Auditorium	396	1,160	735	852,915	0.057	
Institute for Computing, Information and Cognitive Sy	378	1,544	617	952,515	0.057	
Child Care Services Administration Building	311	1,146	732	838,479	0.056	
Alumni Centre	333	973	812	789,780	0.056	
Auditorium Annex Offices A	223	884	866	765,332	0.056	
Faculty Staff Housing - Building B - Cascara House	28	887	847	751,310	0.054	
Walter H. Gage Residence - Court	505	997	779	776,672	0.054	
SAIL 2	414	1,044	756	789,121	0.054	
Vancouver School of Theology - Iona Building	423	1,538	598	919,434	0.054	
Fp Innovations - Feric - Forest Engineering Research	243	921	809	744,835	0.053	
Biological Sciences Building - South Wing	502	1,094	723	790,528	0.053	
Mathematics Annex	222	868	839	728,593	0.053	
Biomedical Research Centre	324	1,145	697	798,197	0.052	
Tapestry At Wesbrook Village, UBC - South Building	456	1,098	713	782,759	0.052	
TRIUMF - Trailer	534	777	896	696,413	0.052	
Frederic Wood Theatre	351	1,014	749	758,983	0.052	
Somerville House	341	887	813	721,294	0.051	
Wesbrook Residential Tower	422	1,326	628	832,837	0.050	
Argyll House West	282	1,067	714	761,987	0.050	
Carey Centre	427	993	747	741,863	0.050	
Bioenergy Research and Demonstration Facility	448	1,526	575	876,816	0.049	
Coast Apartment West	248	1,091	695	757,834	0.049	
Student Union Building (Sub) - Addition 2	14	1,082	698	754,881	0.049	
D.H. Copp Building	219	912	777	708,868	0.049	
Morris and Helen Belkin Art Gallery	47	915	772	706,023	0.049	
Faculty Staff Housing - Building C - Sumac House	29	784	849	665,622	0.048	
B.C. Binning Studios	398	900	769	692,226	0.048	
Hawthorn Green	24	763	856	653,285	0.047	
Gerald McGavin Building	229	992	714	707,991	0.047	
Acadia Family Housing Phase III - Unit 5	158	982	718	705,091	0.047	
Argyll House East	429	1,074	675	724,430	0.046	
Thunderbird Residence - Building C2	304	760	824	626,349	0.045	
Esse (Townhouses)	280	869	754	655,293	0.045	
Henry Angus Building Addition	382	1,037	673	697,633	0.044	
Walter C. Koerner Library	462	1,490	546	813,423	0.044	
Panhellenic Sorority House	31	837	748	626,210	0.042	
Vanier Korea House	321	832	750	624,169	0.042	
Chemistry C Block, East Wing	501	690	844	582,223	0.042	
Totem Park Residence - Qellexen House	297	1,099	621	682,036	0.041	
Stirling House	350	889	701	623,444	0.041	
Plant Operations Exterior Storage Shed	96	680	817	555,730	0.039	
Nine On The Park	468	792	737	583,437	0.039	
Coal and Mineral Processing Laboratory	65	757	757	573,399	0.039	
Engineering Student Centre	371	662	824	545,430	0.039	
Buchanan Tower	241	812	716	581,041	0.038	
Henry Angus Building Classroom Addition	9	970	636	616,883	0.038	
Marine Drive Residence - Building #4	447	1,177	570	671,288	0.037	
Wayne and William White Engineering Design Centr	244	695	771	535,538	0.037	
Faculty Staff Housing - Building A - Azalea House	27	615	835	513,631	0.037	
Hampton Place Lot 7-1 - The Stratford	148	723	749	541,288	0.037	
Acadia House - 2720	18	554	897	496,667	0.037	
Granite Terrace III	461	663	786	521,180	0.036	
Brock Hall Annex	512	769	707	543,504	0.036	
Acadia Community Centre	91	781	697	544,473	0.035	
Acadia Family Housing Phase III - Unit 7	156	662	775	512,770	0.035	
D.H. Copp Building Addition	438	760	707	537,518	0.035	
Thunderbird Residence - Building A3	300	494	932	460,596	0.034	
Old Barn Community Centre	269	650	769	499,576	0.034	
Jack Bell Building for The School of Social Work	446	742	705	523,378	0.034	
Acadia Family Housing Phase III - Unit 6	157	603	802	483,885	0.034	
Anthropology and Sociology Building - Anne Wesbro	518	584	819	478,569	0.034	

Yearly Solar Radiation Statistics and Solar Suitability Index for UBC Buildings Rooftops						
NAME	Zone Code	Roof Area (m2)	Average Solar Radiation (kWh/m2)	Total Yearly Solar Radiation (kWh)	Suitability Index for Solar	
Anthropology and Sociology Building - Isabel Macinn	517	556	847	471,075	0.034	
Thunderbird Residence - Building B4	286	508	902	458,339	0.034	
Hampton Place Lot 9 - The Balmoral	33	790	674	532,610	0.034	
Detwiller Pavilion 2	11	565	828	467,549	0.033	
Thunderbird Residence - Building A4	299	501	897	449,270	0.033	
Wesbrook Building Annex	186	727	695	505,009	0.033	
Promontory Tower	454	683	722	493,114	0.033	
Acadia Family Housing Phase III - Unit 8	155	574	808	463,901	0.033	
Acadia Family Housing Phase III - Unit 9	109	600	782	469,115	0.032	
Acadia Family Housing Phase II - Unit 19	107	802	651	522,426	0.032	
Hampton Place Lot 5 - The Chatham	313	911	604	550,050	0.032	
Mary Bollert Hall	83	547	823	450,112	0.032	
Marine Drive Residence - Simon K.Y. Lee Hku-UBC	466	842	625	526,088	0.032	
Place Vanier - Tec De Monterrey	318	785	650	510,178	0.032	
Thunderbird Residence - Building B3	278	495	872	431,611	0.031	
TRIUMF - Plan Services Building	533	569	791	450,025	0.031	
Acadia Family Housing Phase II - Unit 13	117	757	656	496,302	0.031	
The Leonard S. Klinck Building Addition	12	499	853	425,675	0.031	
Ponderosa Commons East	291	1,262	500	630,456	0.031	
Academy	496	1,042	547	570,074	0.031	
Biological Archive Centre	246	494	857	423,550	0.030	
Thea Koerner House Addition	510	707	675	477,072	0.030	
Kids Club	316	457	900	411,186	0.030	
Civil and Mechanical Engineering Structures Lab	451	509	831	423,069	0.030	
Acadia Family Housing Phase II - Unit 12	118	747	649	484,829	0.030	
TRIUMF - Plant Storage Shed	532	492	848	416,993	0.030	
George Cunningham Building (Pharmaceutical Scie	364	600	739	443,698	0.030	
D.H. Copp Building Addition 2	106	600	733	439,813	0.029	
Corus Apartment Building	426	1,170	506	592,001	0.029	
Sing Tao Building	395	466	857	399,509	0.029	
Acadia House - 2700	19	549	759	416,769	0.028	
West Mall Annex	494	987	539	532,324	0.028	
Thea Koerner House	90	633	687	435,062	0.028	
St. Andrew's Hall Residence - Block B - Walker Hous	100	676	660	446,293	0.028	
Medical Sciences Block C	220	590	712	419,922	0.027	
Cecil Green Park House	74	553	733	405,395	0.027	
Buchanan Building Block C	374	681	640	436,090	0.027	
Neville Scarfe Building - Office Block	145	573	709	406,262	0.026	
Spirit Park Apartments - 2725	15	587	696	408,833	0.026	
Friedman Building Addition	507	504	765	385,308	0.026	
Ponderosa Office Annex B	482	484	776	375,794	0.026	
George Cunningham Building Addition (Pharmaceut	123	502	751	376,948	0.025	
Botanical Gardens - Workshop	473	496	756	374,869	0.025	
Ponderosa Office Annex E	485	525	725	380,590	0.025	
Place Vanier Residence - Aldyen Hamber House	493	451	799	360,420	0.025	
St. Mark's College	228	484	760	367,912	0.025	
Hennings Building Penthouse Addition	13	417	833	347,249	0.025	
Place Vanier Residence - Dorothy Mawdsley House	463	445	796	354,183	0.024	
St. Mark's College Chapel	102	455	782	355,921	0.024	
Place Vanier Residence - Phyllis Ross House	465	446	787	351,190	0.024	
International House	49	437	796	347,636	0.024	
Koerner Gallery	188	716	588	421,212	0.024	
Rugby Pavilion	56	356	914	325,432	0.024	
Spirit Park Apartments - 2705	16	583	658	383,613	0.024	
Campus & Community Planning 1	58	474	748	354,469	0.024	
Place Vanier Residence - Sherwood Lett House	4	447	775	346,463	0.024	
Hugh Dempster Pavilion	403	567	659	373,617	0.023	
Earthquake Engineering Research Facility	452	349	904	315,542	0.023	
Chemistry E Block, North Wing	498	541	674	364,739	0.023	
Place Vanier Residence - Robson House	216	449	758	340,370	0.023	
Sitka	387	870	520	452,228	0.023	
Child Care Services - Building 5	43	530	680	360,528	0.023	
Child Care Services Building 2	346	476	724	344,428	0.023	
Child Care Services Building 1	354	478	720	344,106	0.023	
Acadia Family Housing Phase II - Unit 14	167	462	735	339,364	0.022	
Buchanan Building Block E	373	481	714	343,420	0.022	
St. Andrew's Hall Residence - Block A - Ross House	232	584	632	368,818	0.022	
Anthropology and Sociology Building - Mary Murrin H	509	383	824	315,661	0.022	
St. Andrew's Hall Residence - Block C - Lennox Hous	240	559	645	360,403	0.022	
Marine Drive Residence - Building #5	444	913	498	455,050	0.022	
Acadia House - 2710	8	334	902	301,284	0.022	
Earth and Ocean Sciences - South	492	456	726	331,275	0.022	
Place Vanier Residence - Okanagan House	217	446	736	328,340	0.022	
Fraternity Village - House - 4	332	409	779	318,713	0.022	
Ponderosa Office Annex F	487	383	814	311,633	0.022	
Acadia Faculty Row Housing - Unit 1	474	364	840	305,769	0.022	
Vancouver School of Theology - Chancellor Building	266	369	821	303,121	0.021	
Coast Townhouses	247	426	743	316,607	0.021	
Wesbrook Village - Office / Bank	251	488	681	332,500	0.021	
Place Vanier Residence - Cariboo House	6	443	723	320,476	0.021	

Yearly Solar Radiation Statistics and Solar Suitability Index for UBC Buildings Rooftops					
NAME	Zone Code	Roof Area (m2)	Average Solar Radiation (kWh/m2)	Total Yearly Solar Radiation (kWh)	Suitability Index for Solar
Acadia Family Housing Phase II - Unit 15	166	532	646	343,773	0.021
Sage Townhouses	416	610	595	363,173	0.021
Green College - Building A South	342	455	708	322,020	0.021
Leon and Thea Koerner University Centre Addition 1	391	681	558	379,903	0.021
Folio Duplex 2	434	356	824	293,433	0.021
Acadia Park Highrise	184	718	539	387,022	0.020
Place Vanier Residence - Tweedsmuir House	5	444	705	313,055	0.020
Spirit Park Apartments - 2715	17	381	774	294,735	0.020
Fraternity Village - House - 8	36	371	786	291,721	0.020
Vista	495	664	555	368,520	0.020
Folio Duplex 3	435	353	809	285,664	0.020
Norman Mackenzie House (President's Residence)	71	460	681	313,106	0.020
TRIUMF - Stores Building	262	344	821	282,378	0.020
Acadia Faculty Row Housing - Unit 2	476	364	783	284,939	0.019
Acadia Family Housing Phase II - Unit 8	139	404	730	294,907	0.019
Place Vanier Residence - Kootenay House	3	446	684	305,181	0.019
Green College - Graham House, Green Commons, c	301	565	594	335,584	0.019
Walter H. Gage Residence - East Tower	506	547	604	330,286	0.019
Sage Tower	458	635	557	353,717	0.019
Place Vanier Residence - Margaret Mackenzie House	464	449	675	303,226	0.019
Acadia Family Housing Phase II - Unit 10	108	415	709	294,126	0.019
Auditorium Annex Offices B	499	317	840	266,429	0.019
Green College - Building B East	84	385	731	281,357	0.018
Child Care Services - Building 3	45	375	742	278,175	0.018
Frederic Wood Theatre Addition	189	349	777	271,279	0.018
Hampton Place Lot 8 - The Regency	42	768	498	382,650	0.018
Empire Pool	227	757	500	378,872	0.018
Carey Theological College Addition	511	310	839	260,240	0.018
Walter H. Gage Residence - North Tower	514	543	589	319,921	0.018
Acadia Family Housing Phase II - Unit 17	164	423	677	286,576	0.018
Walter H. Gage Residence - South Tower	504	541	581	314,492	0.018
Plant Science Garage	30	292	855	249,655	0.018
Fraternity Village - House - 1	330	348	754	262,282	0.017
Acadia Faculty Row Housing - Unit 3	475	362	731	264,487	0.017
Botanical Garden Centre - Reception and Education	479	272	885	240,774	0.017
Axis - Concert highrise	383	631	529	333,969	0.017
Child Care Services - Building 2	38	372	693	257,678	0.016
Gerald McGavin Rugby Centre	379	237	937	222,108	0.016
In-Vessel Composting Facility	22	288	812	233,842	0.016
St. Mark's Duplex 7	127	277	830	229,985	0.016
Folio Duplex 1	433	355	700	248,571	0.016
Totem Field Studios	349	262	851	223,015	0.016
St. Mark's Duplex 6	128	279	813	226,822	0.016
Botanical Garden Centre - Campbell Building	478	304	762	231,799	0.015
Fraternity Village - House - 7	37	336	710	238,664	0.015
Fraternity Village - House - 2	40	367	670	245,720	0.015
Folio Duplex 4	124	312	736	229,690	0.015
Research Station Annex 3	412	337	695	234,235	0.015
TRIUMF - Compressor Building	524	289	765	221,147	0.015
St. Mark's Duplex 8	375	266	806	214,504	0.015
Abdul Latha Science Student Centre	275	286	767	219,451	0.015
Fairview Crescent Student Housing - Unit 7	175	250	839	209,758	0.015
Child Care Services - Building 1	310	369	650	239,674	0.015
Fraternity Village - House - 6	331	351	669	234,674	0.014
St. Mark's Duplex 5	129	275	781	214,685	0.014
Fairview Crescent Student Housing - Unit 21	206	253	819	207,326	0.014
Fairview Crescent Student Housing - Unit 28	191	253	819	207,323	0.014
Botanical Gardens - Greenhouse	490	502	539	270,819	0.014
Fraternity Village - House - 5	41	357	647	230,935	0.014
Fairview Crescent Student Housing - Unit 16	169	247	817	201,845	0.014
Acadia Family Housing Phase II - Unit 7	140	304	706	214,484	0.014
Food, Nutrition and Health Building - Addition	357	266	769	204,464	0.014
Ponderosa Office Annex C	483	321	671	215,373	0.013
Fairview Crescent Student Housing - Unit 31	198	245	800	195,986	0.013
Child Care Services Building 3	355	236	817	192,828	0.013
Biological Sciences Building - Workshop	503	355	627	222,756	0.013
Campus & Community Planning 2	80	341	642	219,081	0.013
St. Andrews Hall	381	332	647	214,850	0.013
Coal & Mineral Processing Laboratory Addition	131	255	760	193,755	0.013
Peter Wall Institute for Advanced Studies	393	260	750	194,956	0.013
Hillel House - The Diamond Foundation Centre for J	104	337	633	213,377	0.013
Ponderosa Office Annex A	486	297	683	202,740	0.013
Acadia Family Housing Phase III - Unit 2	110	229	811	185,618	0.013
P. A. Woodward Instructional Resources Centre Lect	61	286	696	198,924	0.012
Child Care Services - Building 4	44	263	734	193,112	0.012
Fairview Crescent Student Housing - Unit 11	173	259	742	192,067	0.012
Chancellor Row (Duplex) - 2	345	251	754	189,369	0.012
Fairview Crescent Student Housing - Unit 34	195	214	842	180,201	0.012
Lower Mall Header House	491	280	701	196,349	0.012
Carey Theological College	327	204	864	176,344	0.012

Yearly Solar Radiation Statistics and Solar Suitability Index for UBC Buildings Rooftops						
NAME	Zone Code	Roof Area (m2)	Average Solar Radiation (kWh/m2)	Total Yearly Solar Radiation (kWh)	Suitability Index for Solar	
Coast Duplex 1	257	265	722	191,205	0.012	
Plant Science Field Building	320	200	875	174,989	0.012	
Folio Townhomes	432	180	946	170,285	0.012	
Crescent West Block 5	134	276	699	192,920	0.012	
Chancellor Row (Duplex) - 3	309	233	773	180,134	0.012	
Acadia Family Housing Phase III - Unit 3	159	231	777	179,495	0.012	
Acadia Family Housing Phase II - Unit 1	144	308	641	197,560	0.012	
Fairview Crescent Student Housing - Unit 4	178	237	757	179,452	0.012	
Fairview Crescent Student Housing - Unit 26	201	274	688	188,402	0.012	
Acadia Family Housing Phase III - Unit 1	160	227	778	176,596	0.012	
Old Fire Hall	67	288	666	191,776	0.012	
Fairview Crescent Student Housing - Unit 13	172	255	712	181,658	0.012	
Main Substation	270	178	914	162,728	0.011	
Gas Gun Facility	55	193	852	164,427	0.011	
Fairview Crescent Student Housing - Unit 32	197	213	794	169,139	0.011	
Theatre-Film Production Building	68	327	605	197,831	0.011	
Coast Duplex 4	254	232	746	173,013	0.011	
Acadia Family Housing Phase II - Unit 9	113	228	751	171,289	0.011	
Fairview Crescent Student Housing - Unit 3	181	214	780	166,846	0.011	
Botanical Gardens - Shade House	489	503	480	241,681	0.011	
Coast Duplex 5	353	234	731	171,017	0.011	
Ambulance Station	88	212	781	165,500	0.011	
Stores Road Annex	77	275	659	181,194	0.011	
Fairview Crescent Student Housing - Unit 33	196	210	786	164,992	0.011	
Acadia Family Housing Phase III - Unit 10	154	225	746	167,868	0.011	
Coast Duplex 3	255	231	733	169,300	0.011	
Acadia Family Housing Phase II - Unit 11	119	258	679	175,098	0.011	
Fairview Crescent Student Housing - Unit 23	204	257	679	174,514	0.011	
Fairview Crescent Student Housing - Unit 2	182	216	760	164,174	0.011	
Acadia Family Housing Phase III - Unit 4	126	225	734	165,176	0.011	
UBC Stadium Academic Centre	386	161	927	149,218	0.010	
Chancellor Row (Duplex) - 1	347	230	719	165,413	0.010	
Main Substation Addition	10	180	848	152,649	0.010	
Fairview Crescent Student Housing - Unit 24	203	253	673	170,339	0.010	
Fairview Crescent Student Housing - Unit 12	161	253	672	170,139	0.010	
Crescent West Block 2	136	274	637	174,608	0.010	
Fairview Crescent Student Housing - Unit 8	180	207	760	157,362	0.010	
C. K. Choi Building for The Institute of Asian Research	394	969	373	361,482	0.010	
Coast Duplex 2	256	231	705	162,951	0.010	
Fairview Crescent Student Housing - Unit 27	192	211	746	157,415	0.010	
Environmental Services Facility - Chemical Waste Pr	469	239	675	161,389	0.010	
AYO Demonstration Smart Home	537	186	795	147,900	0.010	
Crescent West	252	208	733	152,432	0.010	
Fairview Crescent Student Housing - Unit 1	183	223	699	155,945	0.010	
Acadia Family Housing Phase II - Unit 16	165	210	727	152,738	0.010	
Wood Products Laboratory	78	198	755	149,576	0.010	
Fairview Crescent Student Housing - Unit 9	179	211	722	152,372	0.010	
Triumf House	26	331	552	182,847	0.010	
TRIUMF- Trailer T06	529	302	579	174,778	0.010	
Crescent West Block 6	135	273	605	165,204	0.009	
Acadia Family Housing Phase II - Unit 26	150	210	711	149,210	0.009	
Fairview Crescent Student Housing - Unit 30	199	157	866	136,025	0.009	
Acadia Family Housing Phase II - Unit 24	152	211	701	147,814	0.009	
Acadia Family Housing Phase II - Unit 6	111	227	661	150,046	0.009	
Landscape Architecture Annex	264	246	628	154,519	0.009	
Fairview Crescent Student Housing - Unit 19	208	160	825	132,054	0.009	
Botany Greenhouse 2	146	142	895	127,030	0.009	
Botanical Garden Centre - Gate House and Shop-In-	308	153	844	129,198	0.009	
Acadia Family Housing Phase II - Unit 23	115	224	652	146,110	0.009	
Fairview Crescent Student Housing - Unit 15	170	204	691	140,960	0.009	
Fairview Crescent Student Housing - Unit 35	194	145	873	126,618	0.009	
Totem Field Studios Addition	193	151	833	125,732	0.008	
Fairview Crescent Student Housing - Unit 29	200	156	813	126,828	0.008	
Fairview Crescent Student Housing - Unit 20	207	155	805	124,781	0.008	
Fairview Crescent Student Housing - Unit 17	168	153	812	124,174	0.008	
Acadia Family Housing Phase II - Unit 22	151	212	645	136,697	0.008	
Staging Research Centre	417	220	628	138,099	0.008	
Fairview Crescent Student Housing - Unit 5	177	150	803	120,380	0.008	
TRIUMF - Trailer A	536	146	816	119,087	0.008	
Acadia Family Housing Phase II - Unit 21	114	226	606	137,069	0.008	
Acadia Family Housing Phase II - Unit 18	163	222	612	135,961	0.008	
Acadia Family Housing Phase II - Unit 25	116	237	589	139,547	0.008	
Acadia Family Housing Phase II - Unit 2	112	234	591	138,379	0.008	
Fairview Crescent Student Housing - Unit 25	202	265	552	146,245	0.008	
Fairview Crescent Student Housing - Unit 6	176	147	794	116,684	0.008	
The Barn	76	194	658	127,719	0.008	
Acadia Family Housing Phase II - Unit 5	141	212	623	131,997	0.008	
Fairview Crescent Student Housing - Unit 18	209	154	755	116,203	0.007	
Crescent West Block 1	133	207	616	127,427	0.007	
Crescent West Block 3	137	209	607	126,841	0.007	

Yearly Solar Radiation Statistics and Solar Suitability Index for UBC Buildings Rooftops					
NAME	Zone Code	Roof Area (m2)	Average Solar Radiation (kWh/m2)	Total Yearly Solar Radiation (kWh)	Suitability Index for Solar
Liu Institute for Global Issues	48	798	357	284,618	0.007
Cecil Green Park Coach House	73	135	792	106,910	0.007
Crescent West Block 7	138	206	600	123,622	0.007
Ponderosa Office Annex G	293	594	381	226,514	0.007
Forestry Field House South Campus	35	239	548	131,011	0.007
Fairview Crescent Student Housing - Unit 10	174	142	752	106,842	0.007
Medical Sciences Block C Addition	508	161	676	108,768	0.006
Green College - Principal's Residence - Building C	362	199	591	117,532	0.006
Chancellor Hall (Townhouses)	365	119	820	97,559	0.006
Fairview Crescent Student Housing - Unit 14	171	145	711	103,117	0.006
Botanical Gardens Workshop (Trailer)	290	125	785	98,147	0.006
Neville Scarfe Building - Teacher Education Office	153	218	545	118,703	0.006
Botany Greenhouse 1	147	106	833	88,313	0.006
Acadia Family Housing Phase II - Unit 4	142	307	425	130,343	0.005
TRIUMF- Trailer T04	530	221	482	106,509	0.005
Fairview Crescent Student Housing - Unit 22	205	152	571	86,782	0.004
TRIUMF - Hazmat	535	81	877	71,067	0.004
Botanical Garden - Garden Pavilion	307	118	635	74,960	0.004
Theatre-Film Production Building Annex	480	131	590	77,248	0.004
Norman Mackenzie House (President's Residence -	488	85	783	66,528	0.004
Environmental Services Facility - Incinerator	52	102	678	69,120	0.004
Forestry Green House	497	117	619	72,368	0.004
Engineering High Head Room Laboratory	328	158	518	81,820	0.004
Acadia Family Housing Phase II - Unit 20	162	159	514	81,739	0.004
Botanical Gardens Scholars' Retreat	54	121	587	71,068	0.004
Plant Science Field Station	263	76	800	60,771	0.004
Townhouse Attached To Chancellor House - 4	237	89	703	62,609	0.004
Acadia Family Housing Phase II - Unit 3	143	104	611	63,553	0.003
Green College - Administration -Building F	85	107	586	62,675	0.003
Green College - Building E	82	83	687	57,028	0.003
Rodney Graham Millennium Sculpture Pavillion	25	79	711	56,149	0.003
Haida House	325	150	482	72,368	0.003
Chancellor House Cityhomes	436	87	637	55,449	0.003
Botanical Gardens - Greenhouse and Workshop	471	62	810	50,244	0.003
Environmental Services Facility - Pcb Equipment Stor	105	120	510	61,191	0.003
UBC Farm Yurt	409	67	711	47,624	0.003
Townhouse Attached To Chancellor House - 3	236	69	694	47,889	0.003
Green College - Building A North	86	264	365	96,244	0.002
Botanical Gardens - Lunchroom	472	54	778	41,998	0.002
Cecil Green Park Squash Court	72	84	534	44,860	0.002
Telus Hub	253	106	469	49,662	0.002
Townhouse Attached To Chancellor House - 2	101	67	591	39,616	0.002
Power House - Meter Station	385	104	434	45,125	0.002
Botanical Gardens - Greenhouse, Alpine Garden	75	33	943	31,105	0.001
Mortuary House	326	42	561	23,567	0.001
Natural Gas Storage	411	30	762	22,868	0.001
Research Ponds	319	40	541	21,639	0.001
TRIUMF - Badge Room	531	46	490	22,535	0.001
Environmental Services Facility - Solvent & Silver Red	51	39	509	19,856	0.001
Green College - Kitchen / Laundry	87	51	406	20,715	0.001
Ladner Clock Tower	397	26	613	15,943	0.000
Botanical Garden Centre - Lookout Tower	477	25	634	15,860	0.000
Chemistry Storage	81	76	337	25,646	0.000
Biological Sciences - Paper Recycling/Flammable St	481	28	516	14,458	0.000
Japanese Tea House - Nitobe Gardens	348	76	316	23,988	0.000
Material Recovery Facility	53	15	794	11,903	0.000
Environmental Services Facility - Office	470	29	284	8,246	0.000
Vanier Pump Station	70	53	275	14,550	0.000
Logan Field Kiosk	329	13	940	12,225	0.000

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