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Potential energy output from horizontally inclined rooftop solar power systems in relation to electricity consumption. A case study of Sørhellinga.

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Renewable Energy

Preface

This thesis was written in the final semester of a two-year master's degree in renewable energy at the Norwegian University of Life Sciences. The topic for the thesis was decided in February 2023. The decision to write about solar power was further strengthened throughout the spring semester of 2023 as I found the subject of solar power very interesting. I was particularly interested in building integrated solar power due to its implementation on already existing structures which negate the area use, possibly vital for future land use problems.

I would like to thank my classmates for two years of a great learning environment. I would also like to specifically thank my supervisor Muyiwa Samuel Adaramola for his help and support writing this thesis.

Abstract

This thesis investigates the potential energy output of rooftop solar power systems in relation to electricity consumption. The aim was to quantify the impact a horizontally inclined rooftop solar power system could have on covering the electricity consumption of a building. For a future with increased electricity demand it is important to study the potential energy output of different power generating technologies.

The chosen site was Sørhellinga and the potential energy output was calculated using solar equations in an excel spreadsheet. Two scenarios of solar power systems were outlined, an average quality system and a high-quality system. In the third scenario the area required to fully cover the energy consumption of the building was investigated.

The study found that the two proposed solar power systems had an energy output of 117 679.49 kWh/year and 140 888.58 kWh/year for an average and high-quality system, respectively. Sørhellinga's estimated annual electricity consumption was 1 479 000 kWh. The solar power systems were shown to cover 7.96% and 9.53% of the electricity consumption. The area required for energy output to equal electricity consumption was found to be 12.2 and 9.9 times as large as the suitable roof area. Rooftop solar power systems are a good supplement to a building's electricity consumption but would need to work in conjunction with other power generating technologies to satisfy future electricity demands.

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1.0 Introduction

There has been increased global warming as an effect of increased greenhouse gas emissions since the industrial revolution, leading to climate change (Agency, 2024). Climate change poses a major threat to life on Earth. Changes in weather patterns and more destructive weather causes ice melting, rising sea levels, increased drought and loss of species (Nations, u.å.-b). Some locations on Earth may become uninhabitable due to rising sea levels. Drought may lead to agricultural losses and reduced food production, causing famine in the most vulnerable places on the planet. To combat climate change international environmental agreements have been set. Per the Paris agreement all parties involved must contribute to limiting global warming to a maximum of 2ºC, with a true goal staying within 1.5ºC (Nations, u.å.-c). Reduction of greenhouse gas emissions is the primary focus of the agreement. Norway has as a current goal to reduce emissions by 50 to 55 percent within 2030 (miljødepartementet, 2023). Reducing emissions will require fossil fuels to be phased out and electrification of several industries.

The United Nations has developed 17 sustainable development goals (Nations, u.å.-a). The goals range from social and gender equality, no poverty and zero hunger to economic growth, conservation of life and climate action. The goals were set as a framework to strive for so that the world's development can sustain current needs without jeopardizing the needs of future generations (FN-Sambandet, 2023). Goal seven is affordable and clean energy for everyone. This goal covers providing clean electricity for developing countries. The goal also covers the adjustment of energy systems in developed countries to a more renewable energy mix.

The Norwegian share of renewable electricity production was in 2023 98.3% (sentralbyrå, 2023b). The electricity balance from 2023 can be seen in table 1, using data from Statistisk sentralbyrå. Norway is a mountainous country with large hydrological resources. Development of hydropower plants over the course of the 20th century resulted in an almost exclusive production of electricity from hydropower, at 89.2% for 2023. Increased hydropower production is limited by availability of resources and conservation of waterways. NVE estimates that the potential for upgrading existing hydropower is 6-8 TWh (NVE, 2009) With an increasing demand for electricity in the future and a need for electricity to be produced from renewable sources, wind and solar are prime candidates for expansion. Wind power has been steadily expanding in Norway over the past 20 years. Solar power is rapidly increasing its expansion but is still only 0.11% of the total production of electricity. In 2023 over 300MW of grid connected solar power was installed, effectively doubling the total installed capacity (NVE, 2019b).

Table 1: Total electricity production and share of electricity producing technologies in Norway.

Total production (TWh)	Hydropower (TWh)	Wind power (TWh)	Solar Power (TWh)	Thermal (TWh)
153.98	137.33	13.96	0.16	2.52
100.00%	89.19%	9.07%	0.11%	1.64%

Large utility-scale solar power plants provide half the production in Norway (NVE, 2019b). The solar modules can be optimally tilted and directionally aligned to produce electricity efficiently. However, large utility-scale solar power plants require a surface area that is relatively flat. With an increased expansion of wind and solar power in Norway an issue that arises is area use. Area use leads to habitat loss for species in that area. Habitat loss is one of the major threats to biodiversity (WWF, u.å.). Norway has 4957 species on the red list for threatened species as of 2021 (Artsdatabanken, 2021). The expansion of large utility-scale solar power plants and wind power must be carefully considered depending on threatened species in the area.

Integrating power generating technologies in existing infrastructure or buildings solves the issue of habitat loss. However, roughly 95% of solar power facilities are already installed on roofs for personal consumption, but only account for half the energy output (NVE, 2019b). The structure of houses may not always be optimal for solar modules. The alignment of the solar modules could be off due to the roof not facing south, receiving too little sunlight. Shading from nearby trees or other buildings could limit production. The slant of the roof could also provide an issue for optimal production.

The focus of this thesis is to calculate the potential electricity output from horizontally inclined rooftop solar modules installed on Sørhellinga, NMBU. The potential electricity output will be compared to the estimated electricity consumption of the building. Using this comparison to gain insight into how much of a building’s electricity consumption a rooftop solar power system can cover.

2.0 Literature Review

This chapter is meant to explain the research in literature that has assisted in answering the questions regarding the thesis. The literature involves statistics and estimations for energy consumption and production and potential for roof mounted solar power.

2.1 Future energy consumption and production

Anthropogenic climate change is driving the inevitable change of our energy systems, albeit it is a slow process. Carbon dioxide emissions from fossil fuels need to be reduced, but phasing out fossil fuels requires replacements. Most of the world's population relies on fossil fuels for electricity production or for transport. Replacing fossil fuels in the energy system requires changes in infrastructure and technology, as well as economic incentives. There is not one singular fuel or resource that can replace fossil fuels. Several different resources need to be utilized. Biofuel, hydropower, wind power, solar power and potentially hydrogen are some of the resources that will replace fossil fuels. The advantage of fossil fuels is their flexibility. A thermal power plant can change its production to match the electrical load. Dispatchable hydropower, a hydropower plant with a water reservoir, has the same advantage as fossil fuel. Solar and wind power are variable energy sources and can produce power only when the conditions allow it (Birkelund et al., 2021). A combination of different renewable energy sources is needed to meet the demand that fossil fuels have satisfied.

There has historically been an increasing demand for electricity, as an effect of technological

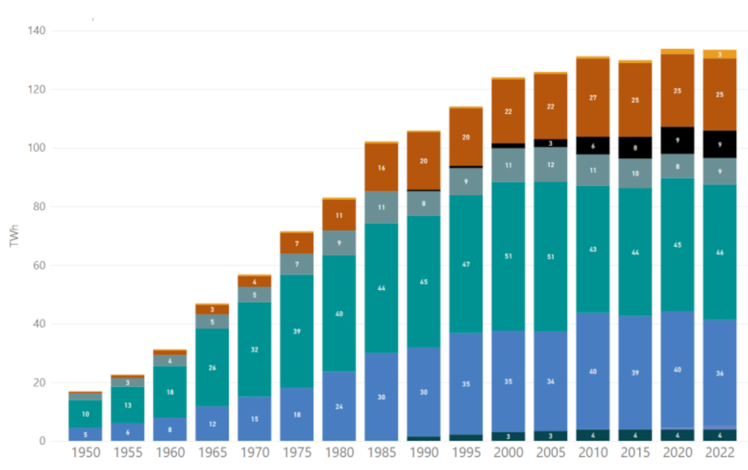

Figure 1: Yearly electricity consumption for last 70 years in Norway, by industry (NVE, 2019a).

advancements, population growth, politics, and energy system changes. Electricity consumption in Norway over the last 70 years is shown in figure 1.

Environmental politics is deciding the development of increased CO_2-prices in the future. This results in increased electricity prices. Increased prices result in it being more profitable to invest and expand in renewable energy. More growth of renewable energy will in turn result in reduced electricity prices. Increasing exchange capacity has exposed the Norwegian electricity prices to Europe's and caused electricity prices in Norway to depend on the electricity prices in Europe (Birkelund et al., 2021). Electricity production is expected to be higher than consumption, as shown in figure 2.

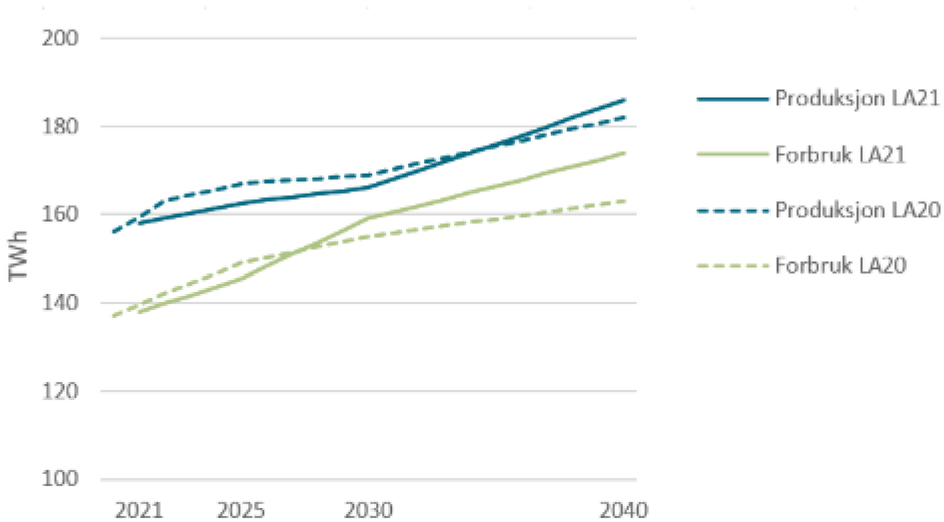

Figure 2: Estimated increase in production and consumption of electricity in Norway from 2021-2040 (Birkelund et al., 2021).

Further electrification of the transport industry, petroleum industry and introduction of new industry, like hydrogen from electrolysis, will increase the electricity demand. Therefore, the development of the production and consumption in the future is highly dependent on political choices in Norway as well as the climate politics in Europe and technological advancement.

2.2 Energy consumption in buildings

To quantify energy use in buildings without having specific information about a specific building, estimations can be made based on Enova building statistics (Enova, 2017). Energy consumption is reported to Enova from owners of buildings around the country. The energy consumption is corrected for temperature and location which results in the values for energy use having smaller geographical and temperature related differences.

The buildings with the highest energy use weighted by area are grocery stores and the lowest are blocks of flats as shown in table 2. University and college buildings have an energy consumption in the upper middle part of the building categories, but the energy consumption is still less than half of grocery stores (Enova, 2017).

Table 2: Table of energy use in kWh/m² for different building categories in Norway (Enova, 2017).

Alle bygninger		**Alder**		**Oppvarmet areal (bra)**		**Temperatur- og stedskorrigert spesifikk energibruk (kWh/m2)**		**Virkelig spesifikk energibruk (kWh/m2)**
Type bygg	**Antall bygg**	**Gj.snitt alder (år)**	**Gj.snitt byggeår**	**Gj.snitt areal (m2)**	**Totalt areal (m2)**	**Gj. snitt**	**Areal-vektet**	**Areal-vektet**
Barnehage	172	26	1991	719	123 687	195	**181**	173
Boligblokk	40	28	1989	4 180	167 181	143	**143**	136
Dagligvarebutikk	1272	16	2001	1 119	1 422 804	617	**540**	510
Forretningsbygg, eks. dagligvarebutikk	247	27	1990	10 612	2 621 148	259	**235**	219
Hoteller	87	42	1975	7 630	663 771	304	**272**	262
Idrettsbygg	98	26	1991	3 502	343 189	219	**237**	231
Kontorbygg	416	39	1978	8 125	3 380 058	180	**179**	171
Kulturbygg	235	140	1877	1 600	375 922	217	**190**	182
Lett industri, verksteder	172	32	1985	8 574	1 474 792	327	**269**	259
Skolebygg	380	36	1981	5 629	2 138 935	156	**140**	133
Småhus	22	40	1977	1 148	25 261	158	**166**	160
Sykehjem	179	28	1989	4 371	782 410	222	**224**	212
Sykehus	36	32	1985	18 080	650 880	298	**310**	309
Universitet- og høgskolebygg	79	61	1956	8 779	693 552	284	**261**	244
TOTALT	**3435**	**35**	**1982**	**4 327**	**14 863 590**	**365**	**244**	**232**

2.3 Potential for rooftop solar

To meet the future electricity demands more power generating technologies need to be invested in. The integration of roof mounted solar power plants will help supply future electricity demands, but the potential of solar power needs to be examined. In a study done in 2018 a 1-year real life performance assessment was conducted (Ates & Singh, 2021). The solar power plant was installed on the roof of Köprübaşı Vocational School at Manisa Celal Bayar University, Turkey. The university is located at 38.7º North (Ates & Singh, 2021). Solar modules used in the study had a module efficiency of 16%. The solar power plant installed had a rated power of 30 kW and the panels were tilted at an incline of 12°, oriented at -20º azimuth angle (Ates & Singh, 2021). The study conducted measurements of predicted output which gave a performance ratio of 83.61%. The solar radiation at the site was 1 818kWh/m^2/year (Ates & Singh, 2021). The final results of the study showed that the system had an output of 45 591 kWh which gave the system a capacity factor of 17.35% (Ates & Singh, 2021). The study concluded that the performance of the system would be a good indicator of the potential of roof mounted solar power systems that are not cleaned regularly and operate in areas with grid fluctuations.

3.0 Method

The method chapter is meant to display the procedure for the calculations done in this thesis. The data used in these calculations is also explained, and where the data has been collected. In addition to explaining the different scenarios chosen.

Many factors must be considered to calculate the potential output of solar power in a location. Some factors can be determined without the use of advanced equipment, such as the latitude and day of the year. Other factors, like solar radiation, can be measured with advanced equipment, such as a pyranometer, or calculated with solar equations. In this thesis no advanced equipment has been used. Latitude has been determined with google earth (Google, u.å.). Temperature data has been collected from Yr (Yr, 2023a). The same for wind data (Yr, 2023b). Calculating the potential solar radiation will not provide as accurate results as using advanced equipment would. However, as there was no access to advanced equipment for this thesis, all measurements have been calculated.

For the potential solar power output of building integrated solar modules at Sørhellinga, solar radiation has been calculated for every hour of the year 2023 using excel. Data for temperature and wind that have been used are daily mean temperature and wind data for the year 2023. Temperature data was taken from the weather station in Ås. This weather station did not have data for wind, so the data was taken from the weather station in Blindern, Oslo. This could provide some inaccuracy as temperature and wind can fluctuate and vary between years, and a historical data set over several years could have been more accurate. Yet, with increasing global temperatures using the most recent year could prove to be a more accurate representation of the future (Organization, 2023).

It was not possible to get accurate data for the electricity consumption of Sørhellinga. Electricity consumption was instead calculated using Enova's statistics for energy use in buildings (Enova, 2017). The statistics for energy use in buildings are given per year for different building types. This data was further used in combination with SSB's data for general electricity consumption, which does not include consumption of industry that requires a lot of electricity, to estimate energy use per month (sentralbyrå, 2023a). The data from SSB was used to weight energy consumption per month in percentages, and the data from Enova could then be multiplied with the percentages to get an estimate for energy use at Sørhellinga per month.

3.1 Sørhellinga

Sørhellinga is a university building that is a part of the Norwegian University of Life Sciences, located in Ås. The building has five floors and a total area of 10 200 m^2 (Byggeindustrien, 2008).

3.2 Latitude & roof area

Latitude and roof area have been estimated using google earth. Latitude shown on google earth is very accurate and is measured to 59.66º north. The measuring tool on google earth allows for measuring distances between two points in meters. The distances measured using google earth are shown in figure 3. The lengths shown in red color display the actual breadth and length of Sørhellingas roof, and the area within the green lines display the area where solar modules will be installed. The area below the green could potentially be used for solar modules as well, specifically on the south side of the roof. However, the uneven surface in addition to roof windows and ventilation result in a small area for solar modules and potential for shading. Therefore, the area highlighted in green is the only area that will be used for this thesis.

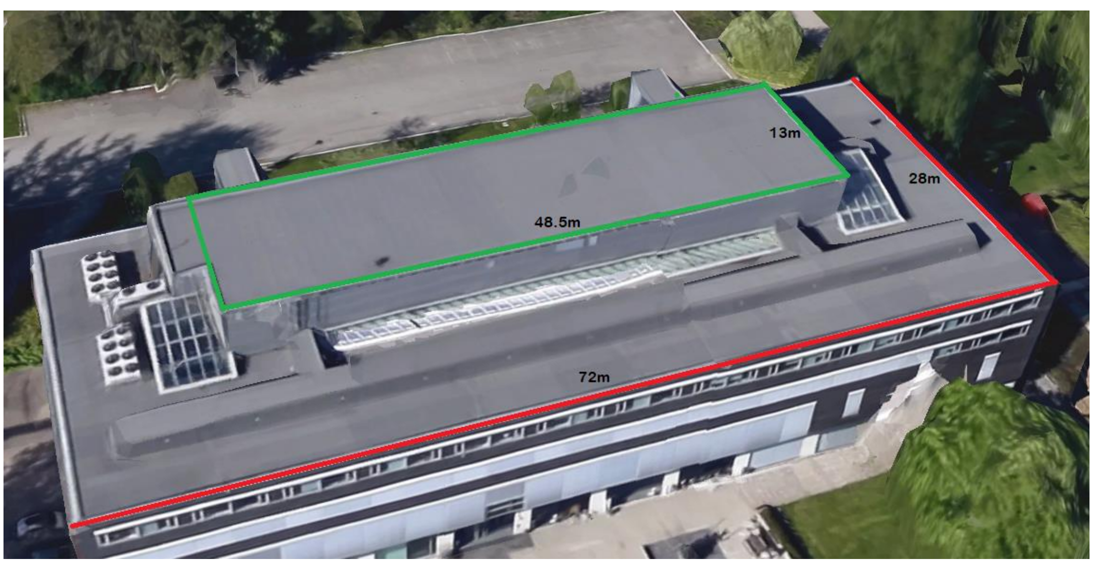

Figure 3: Rooftop depiction of Sørhellinga including measurements and proposed area for installment of solar modules (Google, u.å.).

3.3 Declination angle

Declination angle describes the angle between the equatorial plane and a line between the center of the sun and earth. The declination angle fluctuates between 23.45º on the summer solstice and -23.45º on the winter solstice, in the northern hemisphere. Declination is symbolized with δ and calculated using equation 1 (Adaramola, 2023a).

$$[1]\ \delta = 23.45 * \sin\left(\frac{360}{365}*(284+N)\right),$$

Where N is the day of the year.

3.4 Hour angle

The hour angle represents the degrees the earth must rotate for the sun to be at the center of the local meridian. The sun will be in the center of the local meridian at solar noon, which is at 12:00. The hour angle does not change over the course of the year, it is constant for the different hours of the day, changing by 15º every hour. The hour angle is calculated with equation 2 (Adaramola, 2023a).

$$[2]\ H = 15^{o} * (12 - ST),$$

Where ST is the local time.

3.5 Altitude angle

The altitude angle is the angle between a chosen point on the earth's surface, represented on a flat plane, and the sun. As seen in figure 4 the altitude angle effectively depicts the height of the sun in the sky. The altitude angle is symbolized with ß and is calculated with equation 3 (Adaramola, 2023a).

$$[3]\ ß = \sin^{-1}(\cos(L) * \cos(\delta) * \cos(H) + \sin(L) * \sin(\delta)),$$

Where L is the latitude, δ is the declination angle and H is the hour angle.

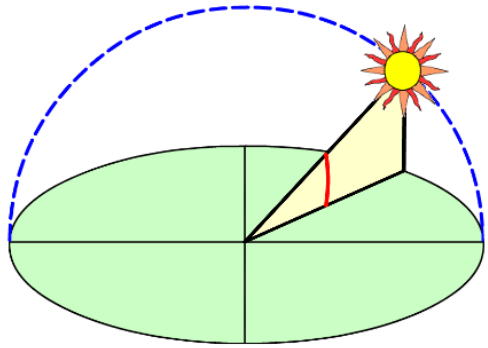

Figure 4: Altitude angle shown visually. (Honsberg & Bowden, 2019)

3.6 Azimuth angle

The azimuth angle is the angle between a line drawn in the north to south direction and the direction the rays of sunlight are coming from, displayed in figure 5. Figure 5 depicts the sun in the southern hemisphere, in Norway the azimuth angle would be measured from the southern compass direction. The azimuth angle is measured on the horizontal plane. In the northern hemisphere the azimuth angle is 0º when the sun is due south, which occurs at 12:00. The azimuth angle is symbolized by φ and is calculated with equation 4 (Adaramola, 2023a).

$$[4]\ \varphi = \sin^{-1}\left(\frac{\cos(\delta) * \sin(H)}{\cos(ß)}\right),$$

Where δ is the declination angle, H is the hour angle and ß is the altitude angle.

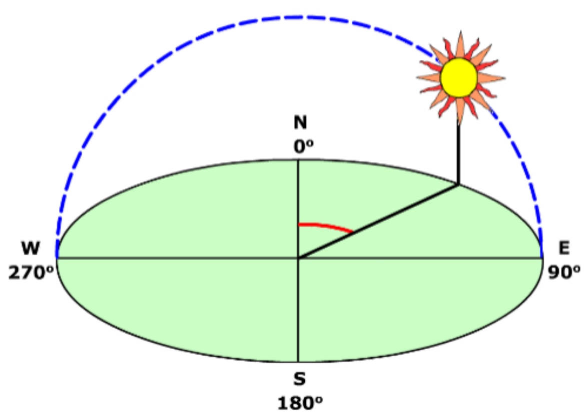

Figure 5: Azimuth angle shown visually. (Honsberg & Bowden, 2019)

3.7 Total solar radiation

Total solar radiation on an inclined surface is a function of three types of radiation. Direct radiation, diffuse radiation and reflected radiation. Total solar radiation (Wh/m^2/(unit of time)) is calculated using equation 5 (Adaramola, 2023a).

$$[5]\ I_C = I_{BC} + I_{DC} + I_{RC},$$

Where I_{BC} is the direct radiation, I_{DC} is the diffuse radiation and I_{RC} is the reflected radiation.

All equations that are specified for inclined surfaces work for horizontally inclined surfaces as well.

3.7.1 Direct radiation

Direct radiation is the radiation from the sun that is not scattered by particles in the atmosphere, and directly reaches the surface of the planet. To calculate the direct radiation on an inclined surface, four components are needed:

- Extraterrestrial flux (W/m^2), A, calculated with equation 6 (Adaramola, 2023a).
  - $[6]\ A = 1160 + 75 * \sin(\frac{360}{365} * (N - 275))$
  - Where N is the day of the year.
- Dimensionless factor, k, calculated with equation 7 (Adaramola, 2023a).
  - $[7]\ k = 0.174 + 0.035 * \sin(\frac{360}{365} * (N - 100)),$
  - Where N is the day of the year.
- Air mass ratio, m, calculated with equation 8 (Adaramola, 2023a).
  - $[8]\ m = \sqrt{(708 * \sin ß)^2 + 1417} - (708 * \sin ß),$
  - Where ß is the altitude angle.
- The incidence angle, Ø, calculated with equation 9 (Adaramola, 2023a).
  - $[9]\ Ø = \cos^{-1}(\cos(ß) * \cos(\varphi) * \sin(\Phi) + \sin(ß) * \cos(\Phi)),$
  - Where ß is the altitude angle, φ is the azimuth angle and Φ is the tilt angle of the solar module.

Using these four components direct radiation can be calculated using Euler's constant, e. Direct radiation on an inclined surface is calculated with equation 10 (Adaramola, 2023a).

$[10]\ I_{BC} = (A * e^{-k*m}) * cos(Ø)$

3.7.2 Diffuse radiation

Diffuse radiation is the solar radiation scattered by particles before reaching the surface of the earth. To calculate the diffuse radiation on an inclined surface accurately, two additional components are needed:

- Sky diffuse factor, C, calculated with equation 11 (Adaramola, 2023a).
  - $[11]\ C = 0.095 + 0.04 * sin(\frac{360}{365} * (N - 100))$,
  - Where N is the day of the year.
- Diffuse radiation factor, R_D, calculated with equation 12 (Adaramola, 2023a).
  - $[12]\ R_D = \frac{1 + cos\,(\Phi)}{2}$,
  - Where Φ is the tilt angle of the solar module.

The diffuse radiation on an inclined surface can then be calculated with equation 13 (Adaramola, 2023a).

$[13]\ I_{DC} = (A * e^{-k*m}) * C * R_D$

Where A is the extraterrestrial flux, e is Eulers constant, k is the dimensionless factor, m is the air mass ratio, C is the sky diffuse factor and R_D is the diffuse radiation factor.

3.7.3 Reflected radiation

The final type of radiation needed to calculate total solar radiation is reflected radiation. The two missing components to calculate reflected radiation are reflected radiation factor and albedo. Albedo is the surface's ability to reflect light (Gjelten, 2023). Different surfaces reflect light in different ratios, as seen in table 3. The area of Ås is primarily forest and cultivated land as well as inhabited areas with buildings etc. Albedo of forest and cultivated land are generally 0.15 and 0.2, respectively. Snow coverage drastically increases the surfaces albedo effect. Fresh snow has up to 0.9 albedo and dirty snow can have around 0.4. Albedo will be chosen on a monthly basis. For the months without snow the albedo will be set to 0.2, for the months with snow albedo will be set between 0.4 and 0.9 (Gjelten, 2023).

Table 3 Albedo of different surfaces (Gjelten, 2023).

Surface	Albedo
Fresh snow	0.9
Old snow	0.4<
Cultivated land	0.2
Forest	0.15
Fresh asphalt	0.05

- Reflected radiation factor, R_R, calculated with equation 14 (Adaramola, 2023a).
    - *[14]* $R_R = \frac{1 - cos\,(\Phi)}{2}$,
    - Where Φ is the tilt angle of the solar module.

Reflected radiation is calculated with equation 15 (Adaramola, 2023a).

$$[15]\ I_{RC} = \rho * (A * e^{-k*m}) * (sin(ß) + C) * R_R,$$

Where ρ is the albedo, A is the extraterrestrial flux, e is Euler's constant, k is the dimensionless factor, m is the air mass ratio, ß is the altitude angle, C is the sky diffuse factor and R_R is the reflected radiation factor.

There is zero reflected radiation on a horizontal surface. Therefore, the reflected radiation will equal to zero for all scenarios because all configurations of solar power systems considered use a tilt angle of 0°.

3.8 Derating factors

To quantify the actual power output of a solar panel, the solar panels rated power must be multiplied with derating factors. Derating factors are factors that cause a loss of output, there are two types. Temperature related derating factors and non-temperature related derating factors. The rated power of a solar panel is calculated using standard testing conditions of 25ºC, the temperature-related derating factor must therefore be applied to account for difference in temperature from the standard testing conditions to the conditions of the system.

Temperature-related derating factors require cell temperature, T_c, to calculate, which in turn requires data from the solar modules as well as irradiance, G_c, on the module. Cell temperature can be calculated using equation 16 (Adaramola, 2023b).

$$[16]\ T_c = T_a + \left(\frac{9.5}{5.7+3.8*Vf} * \frac{NOCT-20°C}{800} * G_c\right)$$

Where T_a is the ambient temperature, V_f is the wind speed, NOCT is the nominal operating cell temperature of the solar module and G_c is the irradiance.

Data for irradiance was impossible to find. Estimations were made by calculating extra-terrestrial irradiance as shown in equation 17 (Adaramola, 2023a).

$$[17]\ I_o = I_{SC} * \left(1 + 0.034 * \cos\left(\frac{360*N}{365}\right)\right)$$

Where I_{SC} = 1367 W/m^2 and N is the day of the year.

This equation does not take into account reduced irradiance from reflection, absorption and scattering in the atmosphere (Adaramola, 2023a). Including the reduction from atmospheric effects, irradiance can reach upwards of 1000 W/m^2. To get a rough estimate of irradiance at Sørhellinga, the equation for extraterrestrial was used with a reduction of 500 W/m^2.

Temperature-related derating factor is given by equation 18 (Adaramola, 2023c).

$$[18]\ F_{temp} = \varepsilon P_{MAX} * (T_c - 25\ °C)$$

Where εP_{MAX} is the temperature coefficient of the solar module and T_c is the cell temperature of the module.

Non-temperature related derating factors are more complicated. All non-temperature related derating factors must be multiplied together. These factors include but are not limited to inverter efficiency, shading and system availability. For this thesis the non-temperature related derating factor has been estimated using table 4. Different values have been chosen for the two systems in the scenarios shown later in the chapter.

Table 4: Non-temperature related derating factors (Quaschning, 2019).

Description	Value
Top-quality system, very good ventilation, no shade, minimal pollution	0.85
Very good system, good ventilation, no shade	0.80
Average system	0.75
Average system with some losses due to shade or poor ventilation	0.70
Poor system with significant losses due to shade, pollution or system failures	0.60
Very poor system with large areas of shade or defects	0.50

Non-temperature related derating factor is given by equation 19 (Adaramola, 2023c).

$$[19]\ F_{non\text{-}temp} = F_1 * F_2 * \ldots * F_n$$

Derating factor is given by equation 20 (Adaramola, 2023c).

$$[20]\ F = F_{temp} * F_{non\text{-}temp}$$

3.9 Choice of modules

There are many solar modules available on the market. The important thing to look out for is primarily the efficiency of the module, which describes the amount of solar radiation that the module can convert to electricity. For this thesis one module with relatively high efficiency and one with relatively average efficiency has been chosen. The high efficiency solar module chosen is Boviet Solar Gamma Series Perc Monofacial, with an efficiency of 20.01% and rated power of 435W (Solar, 2024). The average efficiency solar module chosen is HHEX-300-P30 with an efficiency of 18.44% and a rated power of 300W (Hunterhex, u.å.). The data sheets for the two modules can be found in Appendix A and B.

3.10 Estimated energy output

The estimated energy output of a solar power system is determined by the derating factor, the rated power output of the system and the sun peak hours. Sun peak hours is the amount of hours the solar module is operating at its maximum power point, calculated with equation 21 (Adaramola, 2023c).

$$[21]\ S_h = \frac{I_C}{1},$$

Where I_C is the total solar radiation and 1 is the irradiance at standard testing conditions. Sun peak hours is equal to the total solar radiation.

Estimated energy output is shown in equation 22 (Adaramola, 2023c).

$$[22]\ E = S_h * F * P_r,$$

Where S_h is the sun peak hours, F is the derating factor and P_r is the rated power output of the system.

3.11 Capacity factor

Capacity factor is a calculation to compare the measured output of a system to the theoretical potential of the system (Hofstad, 2022). The capacity factor is a good measurement to compare the same or different power generating technologies. When comparing results from two scenarios of the same technology it is a measurement of operating hours and efficiency of the system. It is effectively only a measurement of operating hours when comparing different technologies. The calculation for annual capacity factor is shown in equation 23 (Hofstad, 2022).

$$[23]\ C_f = \frac{E}{P*8760h},$$

Where E is the energy output of the system, P is the rated capacity of the system, and 8760h represents the number of hours there are in a year.

3.12 Scenarios

The first two scenarios are variations of solar systems to see the energy output from a top-quality system compared to an average system. The scenarios are all fixed tilt, and the same tilt angle will be used for the entire year in all scenarios. Optimally tilted solar panels produce significantly more electricity than horizontal solar panels. A big problem with tilted solar panels is self-shading, the altitude angle of the sun changes throughout the year and shading from one row of solar modules on the one behind can lead to massive losses of output. Thus, installing flat solar panels on a slanted roof is much more lucrative. Sørhellinga’s roof is flat therefore installing rows of tilted modules would lead to shading losses from self-shading.

A self-shading analysis could be done, to analyze the distance between solar panels to prevent self-shading. The shadow would be longest on the winter solstice, 21. December and shortest on 21. June. Using the altitude angle, azimuth angle, measurements of solar modules and sine law, the distance of the shadow cast by the inclined solar module can be calculated. However, as this roof is quite narrow with limited space between rows of inclined solar modules, all scenarios are calculated with solar modules installed horizontally. We do not take into account costs or requirements for additional structural support.

3.12.1 Scenario 1

Scenario 1 calculates the estimated energy output of an installment of an average solar power system. The solar modules are installed horizontally on the flat roof of Sørhellinga. Calculations were made on an hourly basis for each day. Results were consolidated to a monthly basis and compared to potential electricity consumption of the building.

3.12.2 Scenario 2

Scenario 2 is similar to scenario 1, but with higher quality and higher efficiency modules to see the potential energy output of a top-quality system. Solar modules are similarly installed in a horizontal fashion.

3.12.3 Scenario 3

Scenario 3 explores the required area to fully support the electricity demand of the building. Solar power produces more in the summer than in the winter, electricity demand is higher in the winter. This scenario assumes that surplus energy sold in the summer can be bought in the winter for the same price. Therefore, the area where yearly energy output will equal the yearly demand will be calculated. Area will be calculated for two arrays, one for each of the first two scenarios. Solver in excel, as shown in figure 6, is used to calculate the area. Setting the objective of the total produced electricity to equal the electricity consumption. Solver will change the rated power of the array until this criterion is met. Then calculating number of modules and area based on specifications in Appendix A and B.

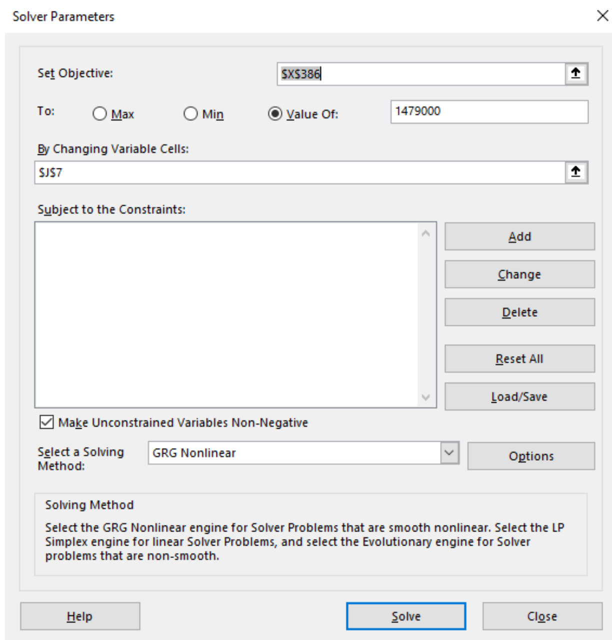

Figure 6: Solver in excel used to calculate power of a solar PV array.

4.0 Results

In this chapter, the solar radiation at Ås, located at 59.66º North, is calculated. The results from these calculations are further used to estimate the potential output of a horizontally inclined solar power system at the roof of Sørhellinga. Scenarios 1 and 2 explore the potential solar output, the first scenario uses an average efficiency solar module, with an average efficiency system. The second scenario uses a high efficiency solar module, with a high efficiency system.

Because this is a purely theoretical approach to calculate potential energy output, an inverter has not been chosen for the system. Although an inverter has not been chosen, inverter efficiency is relevant for the potential energy output and is technically included in the estimated non-temperature related derating factor.

The total solar radiation calculations are done on an hourly basis, but the temperature measurements are given as the mean of each day. This was chosen because it most accurately represented the temperature at production hours and calculations for cell temperature are done on a daily basis, not hourly. Temperature measurements are from the weather station located in Ås, from 2023 (Yr, 2023a). Wind data was not available at the weather station in Ås, therefore data was collected from the closest weather station with available data which was at Blindern, Oslo, also for 2023 (Yr, 2023b).

Scenario 3 estimates the solar power system area required to fully support Sørhellinga with electricity, this scenario assumes that surplus electricity produced in the summer could be bought back for the same price in the winter when the electricity supply from the system is insufficient. Sizing the solar power system for the winter would lead to a massive surplus of electricity in the summer months, and sizing the solar power system for the summer would lead to the system not being able produce enough electricity to equate to the yearly electricity use.

4.1 Total solar radiation

Total solar radiation is calculated using the methods explained in chapter 3.2-3.7 with an excel spreadsheet. Each day of the year has been calculated with an hourly resolution. The solar radiation potential for the 21. day of each month can be seen in appendix C-N. The total solar radiation for the year at 59.66° North with a tilt angle of 0° is 1 370,45 kWh/m^2/year. Daily solar radiation can be seen in figure 7.

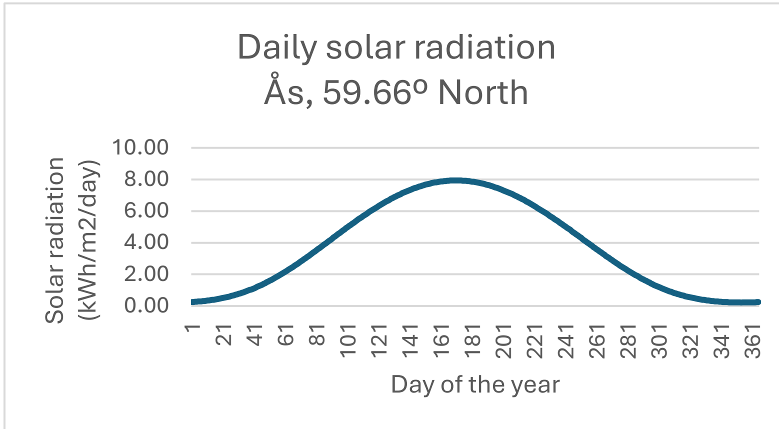

Figure 7: Daily solar radiation in Ås.

4.2 Estimation of electricity use

Energy consumption for various buildings in Norway are shown in figure 8. The figure shows that energy consumption for the average university building corrected for temperature and location is 261 kWh/m^2/year. This includes both electricity and district heating. District heating in Ås uses wood chips, bark, twigs and other waste from foresting industries (Statkraft, u.å.). Therefore, only the electricity consumption from figure 8 will be used to calculate Sørhellinga's energy use. The graph in figure 8 shows approximately 145 kWh/m^2/year energy use in the form of electricity, which is the basis for our calculation.

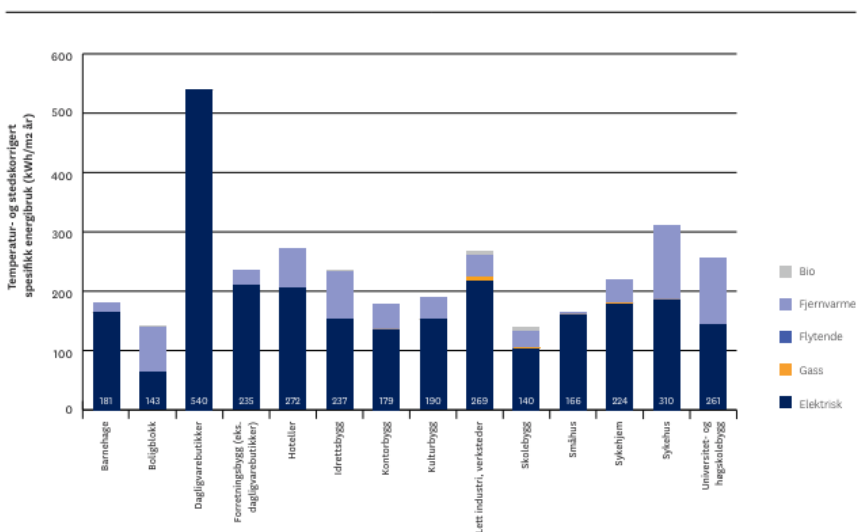

Figure 8: Energy consumption weighted by area for various buildings (Enova, 2017).

Using the area of Sørhellinga , which is 10 200m^2, the electricity consumption will equate to 1 479 000 kWh/year (Byggeindustrien, 2008). To further figure out how this yearly electricity consumption distributes itself monthly, the general consumption of electricity in Norway was used to calculate the percentage of total yearly electricity consumption per month. Table 5 shows the percent electricity use per month for general consumption in Norway. Multiplying these percentages with our estimated electricity use of 1 479 000 kWh/year, gives an estimate for monthly electricity consumption at Sørhellinga, shown in the rightmost column of table 5.

Table 5 General consumption of electricity in Norway and estimated for Sørhellinga (sentralbyrå, 2023a).

Month	Net Consumption (kWh)	Percent/ month	Consumption Sørhellinga (kWh)
January	8,816,223.00	10.93%	161,671.02
February	7,552,886.00	9.36%	138,504.07
March	8,582,449.00	10.64%	157,384.09
April	6,423,280.00	7.96%	117,789.47
May	5,526,349.00	6.85%	101,341.64
June	4,481,177.00	5.56%	82,175.38
July	4,151,586.00	5.15%	76,131.37
August	4,512,611.00	5.60%	82,751.81
September	4,894,750.00	6.07%	89,759.44
October	7,012,584.00	8.69%	128,596.07
November	8,637,207.00	10.71%	158,388.24
December	10,061,534.00	12.48%	184,507.41
Yearly	80,652,636.00	100.00%	1,479,000.00

4.3 Scenario 1

The module used in Scenario 1, HHEX-300-P30, is 1.64m x 0.992m, as can be seen in Appendix A. The roof area of Sørhellinga is 48.5m x 13m. Dividing the length and width of the roof by the height and width of the solar module then rounding down, gives the number of solar modules that fit. Depending on the arrangement of the modules we can either have 29 rows with 13 columns or 48 rows with 7 columns. Installing 29 rows with 13 columns results in better area usage of the roof resulting in 377 modules. With a rated power of 300W for the module the rated power of the array is:

$$P_{array} = 0.3 * 377 = 113.1kW$$

Using the rated power of the array and the calculations for daily solar radiation, each step to estimate daily energy output for an average system are shown in table 6. The chosen non-temperature related derating factor for scenario 1 is 0.75. Table 6 shows the first five days of the year, the calculations have been done for all 365 days of 2023.

Table 6: Calculations for estimated energy output of an average system for the first five days of 2023.

Day	Daily Solar radiation (Wh/m2/day)	Daily Solar radiation (kWh/m2/day)	Temperature (Ta)	Wind	Irradiance	Cell Temperature	Derating Factor (temp)	Derating Factor (non-temp)	Derating Factor average system	Estimated energy output average system (kWh/day)
1	251.74	0.25	-4.2	2.5	913.47	13.64	0.96	0.75	0.72	20.41
2	257.95	0.26	-4.5	1.6	913.45	18.52	0.97	0.75	0.73	21.33
3	264.75	0.26	-9.2	1.3	913.42	16.29	0.97	0.75	0.72	21.69
4	272.13	0.27	-4.1	7.1	913.37	4.20	0.92	0.75	0.69	21.21
5	280.11	0.28	-3.7	5.4	913.31	6.64	0.93	0.75	0.70	22.06

Table 7: Calculations for scenario 1 pertaining to energy output of the system and energy demand, both annually and monthly.

Month	Monthly Solar radiation (Wh/m2/month)	Monthly Solar radiation (kWh/m2/month)	Estimated energy output average system (kWh/month)	Percentage of energy (from consumption)	Energy demand (kWh/month)	Energy output / consumption
January	13,876.75	13.88	1,155.25	10.93%	161,671.02	0.71%
February	38,114.76	38.11	3,182.66	9.36%	138,504.07	2.30%
March	96,469.70	96.47	7,936.59	10.64%	157,384.09	5.04%
April	158,737.19	158.74	13,276.44	7.96%	117,789.47	11.27%
May	219,368.79	219.37	18,748.99	6.85%	101,341.64	18.50%
June	236,221.13	236.22	20,722.41	5.56%	82,175.38	25.22%
July	230,016.66	230.02	20,018.23	5.15%	76,131.37	26.29%
August	181,946.61	181.95	15,919.97	5.60%	82,751.81	19.24%
September	113,232.88	113.23	9,857.36	6.07%	89,759.44	10.98%
October	56,390.58	56.39	4,735.95	8.69%	128,596.07	3.68%
November	18,521.74	18.52	1,511.38	10.71%	158,388.24	0.95%
December	7,554.47	7.55	614.27	12.48%	184,507.41	0.33%
Yearly	1,370,451.27	1,370.45	117,679.49	100.00%	1,479,000.00	7.96%

Table 7 shows the monthly energy output and electricity consumption. The amount of electricity the solar system can output equates at the lowest to 0.33% of the consumption in December to the highest to 26.29% of the consumption in July. The yearly energy output is 7.96% of the electricity consumption.

The capacity factor of the average system was calculated to be 11.9%.

4.4 Scenario 2

Scenario 2 is similar to scenario 1 but explores the energy output benefits of higher efficiency modules and a higher quality system. The modules used, Boviet Solar Gamma Series PERC Monofacial found in Appendix B, have a length and width of 1.917m x 1.134m. Following the same procedure as in scenario 1, the arrangement of modules can either be 25 rows with 11 columns or 42 rows and 6 columns. The arrangement of 25 rows with 11 columns results in the highest number of modules, 275, which gives the highest yield. Resulting rated power of the array is given as:

$$P_{array} = 0.435 * 275 = 119.625kW$$

Calculations for the daily power output of a high-quality system are shown in table 8. The chosen derating factor for scenario 2 is 0.85.

Table 8: Calculations for estimated energy output of a high-quality system for the first five days of 2023.

Day	Daily Solar radiation (Wh/m2/day)	Daily Solar radiation (kWh/m2/day)	Temperature (Ta)	Wind	Irradiance	Cell Temperature	Derating Factor (temp)	Derating Factor (non-temp)	Derating Factor top system	Estimated energy output average system (kWh/day)
1	251.74	0.25	-4.2	2.5	913.47	13.64	0.96	0.85	0.82	24.58
2	257.95	0.26	-4.5	1.6	913.45	18.52	0.98	0.85	0.83	25.63
3	264.75	0.26	-9.2	1.3	913.42	16.29	0.97	0.85	0.82	26.10
4	272.13	0.27	-4.1	7.1	913.37	4.20	0.93	0.85	0.79	25.66
5	280.11	0.28	-3.7	5.4	913.31	6.64	0.94	0.85	0.80	26.65

Table 9: Calculations for scenario 2 pertaining to energy output of the system and energy demand, both annually and monthly.

Month	Monthly Solar radiation (Wh/m2/month)	Monthly Solar radiation (kWh/m2/month)	Estimated energy output average system (kWh/month)	Percentage of energy (from consumption)	Energy demand (kWh/month)	Energy output / consumption
January	13,876.75	13.88	1,387.50	10.93%	161,671.02	0.86%
February	38,114.76	38.11	3,821.31	9.36%	138,504.07	2.76%
March	96,469.70	96.47	9,544.04	10.64%	157,384.09	6.06%
April	158,737.19	158.74	15,937.87	7.96%	117,789.47	13.53%
May	219,368.79	219.37	22,457.41	6.85%	101,341.64	22.16%
June	236,221.13	236.22	24,756.11	5.56%	82,175.38	30.13%
July	230,016.66	230.02	23,933.87	5.15%	76,131.37	31.44%
August	181,946.61	181.95	19,023.76	5.60%	82,751.81	22.99%
September	113,232.88	113.23	11,785.16	6.07%	89,759.44	13.13%
October	56,390.58	56.39	5,682.89	8.69%	128,596.07	4.42%
November	18,521.74	18.52	1,819.07	10.71%	158,388.24	1.15%
December	7,554.47	7.55	739.59	12.48%	184,507.41	0.40%
Yearly	1,370,451.27	1,370.45	140,888.58	100.00%	1,479,000.00	9.53%

The high-quality system provides a energy output that ranges from 0.4%-31.44% of the monthly electricity consumption. As seen in table 9, the yearly energy output of the high-quality system covers 9.53% of the electricity consumption.

The capacity factor of the high-quality system was 13.4%.

4.5 Scenario 3

The electricity use, as calculated in chapter 4.2 is 1 479 000 kWh/year. For scenario 3 the number of modules required to have an energy output of 1 479 000 kWh has been calculated for both the average system in scenario 1 and the high-quality system in scenario 2.

Calculations for scenario 3 are shown in table 10 and table 11. First the rated power of the array needs to be calculated using solver as shown in chapter 3.12.3. The number of modules can be calculated by:

$$(P_{array} / P_{module}) = \text{Number of modules},$$

Where P_{array} is the rated power of the array, and P_{module} is the rated power of the module. The amount of modules needs to be rounded up to produce sufficient power.

The area of each module has been calculated by multiplying the length and width of the module. Total area of the array can then be calculated by multiplying the area of the module with the number of modules.

Sørhellingas roof area is 72m x 28m, which equals 2016m^2. The area assessed as suitable for solar power system in this thesis is 48.5m x 13m which equals 630.5m^2.

Table 10: Area of an average system of solar PV that could meet the electricity use of Sørhellinga.

NOCT	45	ºC
εP_{MAX}	0.39%	%/ºC
PV η avg.	18.44%	%
P module avg.	0.3	kW
Area module avg.	1.63	m2
P array avg.	1421.44	kW
N modules avg.	4739	
Area array avg.	7709.78	m2

The area required to supply the total yearly electricity use of Sørhellinga is 7709.78m^2 for the average system from scenario 1, as shown in table 10. This area is 3.8 times as big as the area of Sørhellingas roof, and 12.2 times as big as the area suitable for a solar power system on the roof.

Table 11 Area of a high-quality system of solar PV that could meet the electricity use of Sørhellinga.

NOCT	45	ºC
εP_{MAX}	0.35%	%/ºC
PV η	20.01%	%
P module top.	0.435	kW
Area module top.	2.17	m2
P array top.	1255.78	kW
N modules top.	2887	
Area array top.	6275.99	m2

As seen in table 11, the required area to supply the total yearly electricity of Sørhellinga is 6275.99m^2, for the high-quality system. This is significantly lower than the average system, being only 81.4% of the area. The area calculated is 3.1 bigger than the area of the roof and 9.9 than the area of the roof that is suitable for a solar power system.

5.0 Discussion

Scenario 1, the average quality system, had an energy output of 117 679.49 kWh/year, which equated to 7.96% of Sørhellingas electricity consumption. Scenario 2, the high-quality system, had an energy output of 140 888.58 kWh/year, which equated to 9.53% of Sørhellingas electricity consumption. A comparison of the two scenarios energy output in relation to electricity consumption is shown in figure 9.

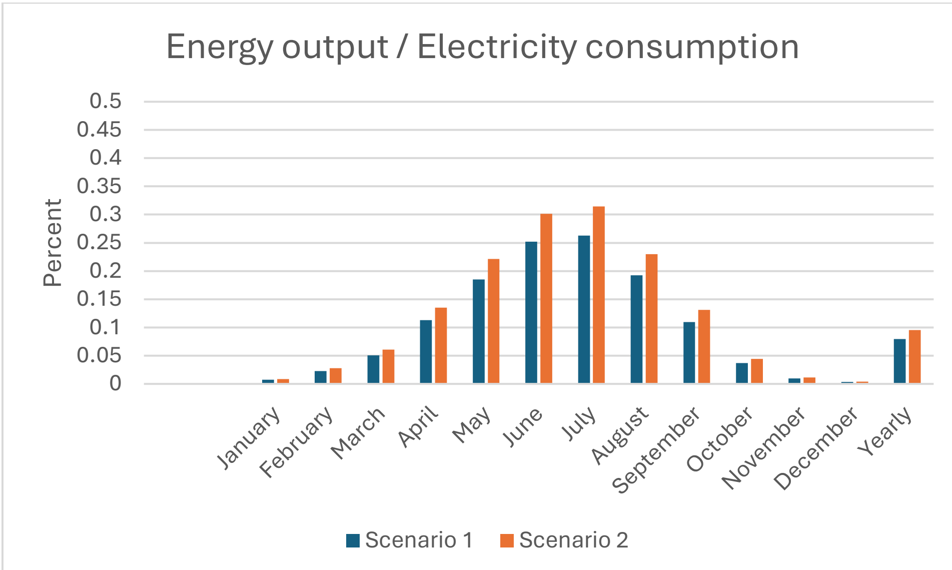

Figure 9: Energy output in relation to electricity consumption for scenario 1 and 2.

The difference in energy output per electricity use between scenario 1 and 2 is 1.57%. This number is the same as the difference in module efficiency of the two modules. This is merely a coincidence. The module efficiency does not directly translate into energy output vs electricity use. Different non-temperature related derating factors were also used for the scenarios which further offsets the efficiency of the system.

The capacity factor for scenario 1 and 2 was calculated to be 11.9% and 13.4% respectively. One could assume that the capacity factor for both scenarios, considering the similarity of the scenarios. The difference is due to the non-temperature related derating factor. The relation between the capacity for factor of the scenarios and the non-temperature related derating factor of the scenarios are approximately equal. Shown below.

$$\frac{11.9}{13.4} = 0.8834 \quad \approx \quad \frac{0.75}{0.85} = 0.8823$$

In the literature review on solar power potential, a solar power system in Turkey was investigated. The study used a real-life scenario of a rooftop solar power system and achieved a capacity factor of 17.35% (Ates & Singh, 2021). The difference in capacity factor is most likely related to solar radiation. The system reviewed received a total solar radiation of 1 818 kWh/m^2/year in comparison to this thesis' system which received 1 370,45 kWh/m^2/year. At the latitude of 38.7º North the sun is higher in the sky than at 59.66° North, resulting in the sunrays being more concentrated per area. The solar power system in Turkey installed the modules at an incline of 12º which would further increase the solar radiation reaching the collector which in turn increases output and capacity factor.

For scenario 3 it was discovered that the average solar power system required 7709.78m^2 and the high-quality solar power system required 6275.99m^2 to sufficiently cover the electricity consumption at Sørhellinga. The results are respectively 12.2 and 9.9 times as large as the suitable are for a solar power system. If the full area of the roof was suitable for solar power the area required is only 3.8 and 3.1 times bigger. For both the average system and the high-quality system, the area required to fully cover the electricity consumption of the building is less than the total area of the building. Meaning buildings with fewer floors would be able to

5.1 Limitations

The practical applications of the thesis are limited. Costs have not been taken into account for this research, which is arguably one of the most important factors to consider for investment. Ignoring cost could also make comparing the two systems quite easy, because the added benefits of the average quality solar power system, most likely being cheaper, are not considered. However, because the thesis is meant to be a theoretical foundation for the energy output from rooftop solar systems in relation to electricity consumption, costs were not considered key to the thesis.

Solar collectors receive much more solar radiation when they are tilted in relation to the height of the sun at that latitude, varying with season. Optimal tilt angles can be calculated throughout the day, or on a yearly basis depending on whether the collector is fixed tilt or tracking. Tilted collectors pose a problem with self-shading, particularly on such a narrow roof as Sørhellingas. Because there needs to be space between the rows of inclined collectors, the available area is not fully utilized. A positive effect of inclined collectors other than increased production, specifically for countries with snow, is that snow doesn't gather up on the collector. Shading losses from snowfall and clouds is included in the non-temperature related derating factors of the scenarios. It is assumed with the non-temperature related derating factor of the high-quality system that the system is better maintained, and snow is manually removed. The output in the winter months is low compared to the output in the summer months, so the shading losses in the winter are arguably insignificant. The research into inclined collectors must be studied further.

Transposing the results to other buildings may not be feasible, depending on the building. As seen in the report from Enova on building statistics, different categories of buildings have different electricity consumption (Enova, 2017). In addition, the ratio between the suitable area for a solar power system on the roof and the total area of Sørhellinga is quite small. This is due to Sørhellinga having many floors. For buildings with fewer floors and comparatively more surface area on the roof than the total area of the building could see much higher results for self-sufficiency from a rooftop solar power system.

The energy use has been estimated per month. Daily variation of load has not been considered in the results of this thesis. Daily variation of load is generally high in the morning, low in the midday, and very high in the afternoon. Effectively opposite of the solar power output. The daily variation of load in relation to solar power output is called the duck curve effect, visualized in figure 10.

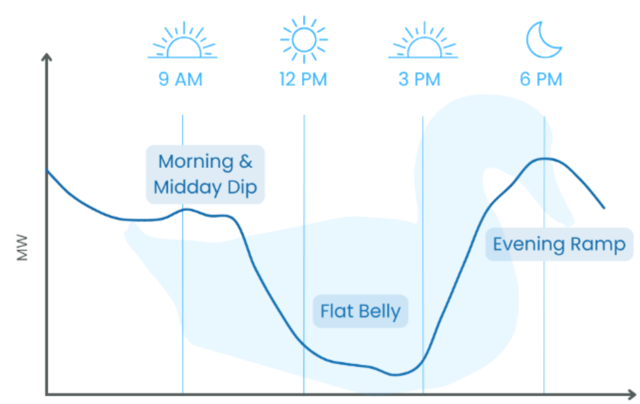

Figure 10: The duck curve effect (Oliveira, 2023).

Even though daily variation of load has not been considered in the results, it is relevant to discuss daily variation of load for the practical applications of rooftop solar systems. For scenarios 1 and

2 respectively the output is between 0.33%-26.29% and 0.4%-31.44%. Considering the fact that demand for electricity is low during the hours of peak production for solar power, the solar power systems from scenarios 1 and 2 will have higher output in relation to consumption than what is shown in the results. Potentially covering the electricity consumption completely.

The results from scenario 3 may seem to support full self-sufficiency for some categories of buildings in combination with single story buildings. Particularly the relation between the area required to support the building sufficiently with electricity and the buildings area. However, as seen with the duck curve, the output is low when the demand is high. Full self-sufficiency is therefore not possible without battery systems. Solar power needs to work in conjunction with other power generating technologies to provide adequate electricity.

6.0 Conclusion

The aim of this research paper was to calculate the potential for horizontally inclined solar power systems in relation to electricity consumption. For the purpose of seeing the potential contribution solar power could have on a buildings electricity consumption in a future with increased power demand, while not having an impact on habitat loss as a result of land seizure.

The method approach was purely theoretical without the help of advanced practical measuring equipment. The calculations were done using solar equations in an excel spreadsheet. The research was conducted for two scenarios which used different modules for the solar power system. One scenario was meant to be an average system and the other a high-quality system. The third and final scenario investigated the area required to fully supply the buildings electricity consumption with solar power.

The research showed that a horizontally inclined solar power system at Sørhellinga could have an energy output of 117 679.49 kWh/year and 140 888.58 kWh/year for an average and high-quality system, respectively. Which equated to 7.96% and 9.53% of the building's electricity consumption. The area required to fully support the building estimated in scenario 3 was 7709.78m^2 and 6275.99m^2 for scenario 1 and 2, respectively. Even though horizontally inclined rooftop solar power systems could theoretically output enough electricity to sufficiently support a building, daily variation in load makes this impossible without working in conjunction with other power generating technologies.

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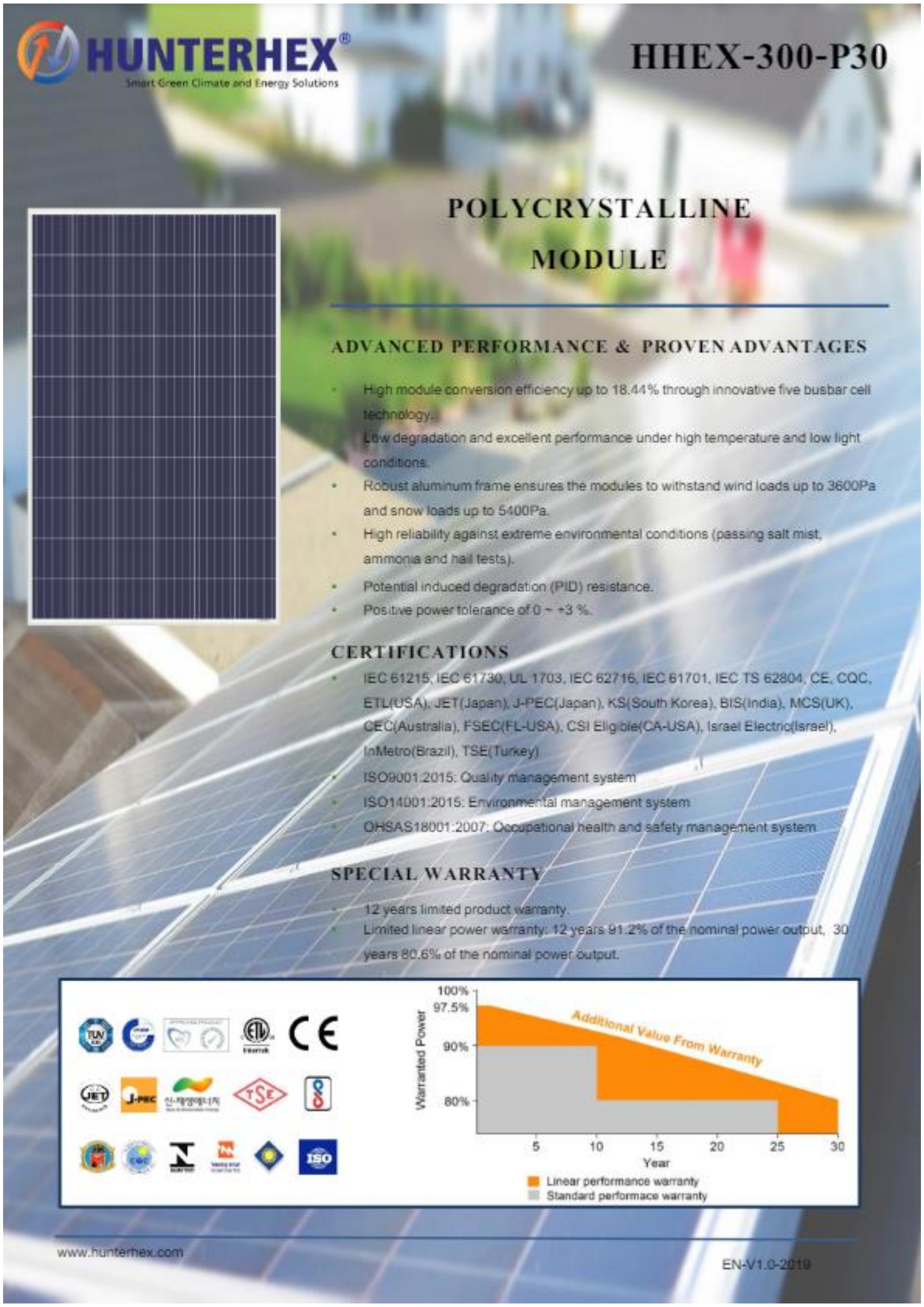
Appendices

Appendix A.



HUNTERHEX®
Smart Green Climate and Energy Solutions

HHEX-300-P30

POLYCRYSTALLINE MODULE

ADVANCED PERFORMANCE & PROVEN ADVANTAGES

- High module conversion efficiency up to 18.44% through innovative five busbar cell technology.
- Low degradation and excellent performance under high temperature and low light conditions.
- Robust aluminum frame ensures the modules to withstand wind loads up to 3600Pa and snow loads up to 5400Pa.
- High reliability against extreme environmental conditions (passing salt mist, ammonia and hail tests).
- Potential induced degradation (PID) resistance.
- Positive power tolerance of 0 ~ +3 %.

CERTIFICATIONS

- IEC 61215, IEC 61730, UL 1703, IEC 62716, IEC 61701, IEC TS 62804, CE, CQC, ETL(USA), JET(Japan), J-PEC(Japan), KS(South Korea), BIS(India), MCS(UK), CEC(Australia), FSEC(FL-USA), CSI Eligible(CA-USA), Israel Electric(Israel), InMetro(Brazil), TSE(Turkey)
- ISO9001:2015: Quality management system
- ISO14001:2015: Environmental management system
- OHSAS18001:2007: Occupational health and safety management system

SPECIAL WARRANTY

- 12 years limited product warranty.
- Limited linear power warranty: 12 years 91.2% of the nominal power output, 30 years 80.6% of the nominal power output.

www.hunterhex.com

EN-V1.0-2019

ELECTRICAL CHARACTERISTICS AT STC

Maximum Power (P_{max})	270W	275W	280W	285W	290W	295W	300W
Open Circuit Voltage (V_{OC})	38.4V	38.6V	38.8V	39.0V	39.2V	39.4V	39.6V
Short Circuit Current (I_{SC})	9.15A	9.26A	9.37A	9.48A	9.59A	9.70A	9.80A
Voltage at Maximum Power (V_{mp})	31.2V	31.4V	31.6V	31.8V	32.0V	32.2V	32.4V
Current at Maximum Power (I_{mp})	8.66A	8.76A	8.87A	8.97A	9.07A	9.17A	9.26A
Module Efficiency (%)	16.60	16.90	17.21	17.52	17.83	18.13	18.44
Operating Temperature	-40°C to +85°C						
Maximum System Voltage	1000V DC/1500V DC						
Fire Resistance Rating	Type 1(in accordance with UL 1703)/Class C(IEC 61730)						
Maximum Series Fuse Rating	15A						

STC: Irradiance 1000W/m², Cell temperature 25°C, AM1.5

ELECTRICAL CHARACTERISTICS AT NOCT

Maximum Power (P_{max})	200W	204W	207W	211W	215W	218W	222W
Open Circuit Voltage (V_{OC})	35.3V	35.5V	35.7V	35.9V	36.1V	36.3V	36.5V
Short Circuit Current (I_{SC})	7.41A	7.50A	7.59A	7.68A	7.77A	7.86A	7.94A
Voltage at Maximum Power (V_{mp})	28.4V	28.6V	28.8V	29.0V	29.2V	29.4V	29.6V
Current at Maximum Power (I_{mp})	7.05A	7.14A	7.19A	7.28A	7.37A	7.42A	7.50A

NOCT: Irradiance 800W/m², Ambient temperature 20°C, Wind Speed 1 m/s

MECHANICAL CHARACTERISTICS

Cell type	Polycrystalline 6inch
Number of cells	60 (6x10)
Module dimensions	1640x992x35mm (64.57x39.06x1.38inches)
Weight	17.5kg (38.6lbs)
Front cover	3.2mm (0.13inches) tempered glass with AR coating
Frame	Anodized aluminum alloy
Junction box	IP67, 3 diodes
Cable	4mm² (0.006inches²), 900mm (35.43inches)
Connector	MC4 or MC4 compatible

TEMPERATURE CHARACTERISTICS

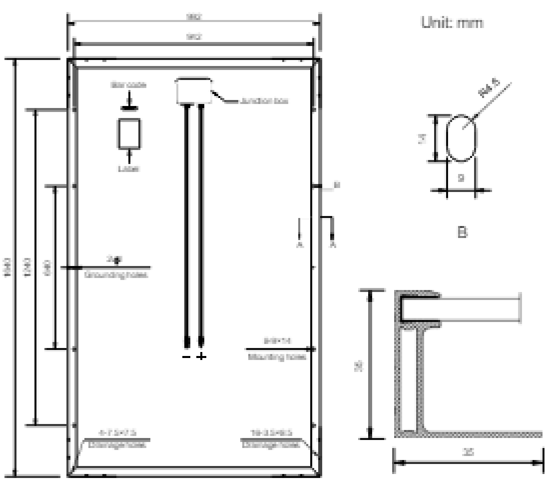
Nominal Operating Cell Temperature (NOCT)	45°C±2°C
Temperature Coefficients of P_{max}	-0.39%/°C
Temperature Coefficients of V_{OC}	-0.30%/°C
Temperature Coefficients of I_{SC}	0.05%/°C

PACKAGING

Standard packaging	30pcs/pallet
Module quantity per 20' container	360pcs
Module quantity per 40' container	840pcs(GP)/924pcs(HQ)

ENGINEERING DRAWINGS

Unit: mm



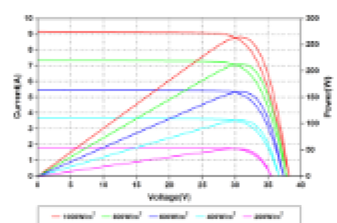
B

Rear View

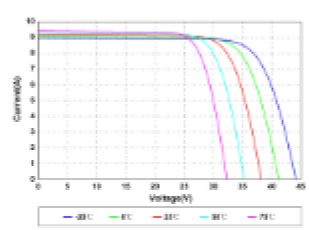
Section A-A

Specifications in this datasheet are subject to change without prior notice.

IV CURVES



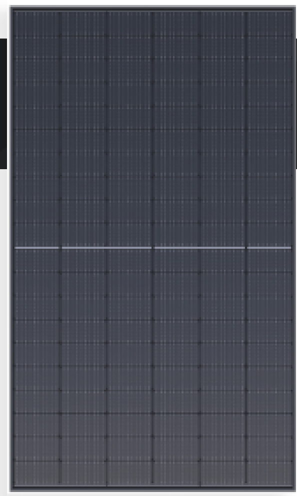
Current-Voltage and Power-Voltage Curves at Different Irradiances



Current-Voltage Curves at Different Temperatures

Appendix B

BOVIET SOLAR



GAMMA SERIES™

MONOFACIAL | PV MODULE

PERC Cell Technology | P-Type

Power Range:	435W | 440W | 445W I 450W I 455W I 460W
Technology:	PERC I Half cut cell I 10 Busbar I 120 Cells
Design:	Single Glass I Black Frame I Black Backsheet
Module Efficiency:	21.16%
Cell Efficiency:	22.5%~23.3%
Power Tolerance:	0~+5W
System Voltage:	1000/1500 V DC
Module Size:	75.47 x 44.65 x 1.38 inch
Module Weight:	52.70 lb.
Module Code:	BVM7610M-XXX-H-HC

DESIGNED TO PERFORM AND BUILT TO LAST

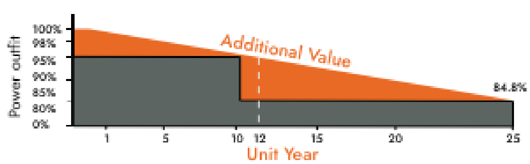
Our PV modules are designed with better technology in mind, made from robust product components, under stringent quality control steps and high-tech manufacturing processes.

PERC, half-cut, multi-busbar, and large cell designs enables our PV modules to pack more power per module, capture more photons, produce more energy, and provide reliable, dependable system performance under different installations requirements, difficult weather, or environmental conditions. Whether you are EPC, installer, contractor, or project developer, we have the right and better PV module for your residential, commercial, industrial, and utility scale solar projects.

- Monocrystalline technology
- P-Type semiconductor
- Passivated emitter and rear cell technology
- Half cut cell
- Multi-Busbar cell
- Large wafer design
- Beautiful aesthetic
- Robust product component

WARRANTY

25- Year linear power warranty
12 -Year product warranty



Output Linear Warranty
Standard Warranty

1 (12) years product warranty

2 Out linear warranty with 2% degradation in the 1st year and less than 0.55% degradation each year from 2nd year to 25th year

CERTIFICATES

UL 61730 I IEC 61215 I IEC 61730 I CEC Listed I CE

ISO 9001 Quality management system

ISO 14001 Environmental management system

ISO 45001 Occupational health and safety Management System

*Please contact with Boviet Solar representative for Full list of certificates according to local requirements and PV module product type.

ELECTRICAL CHARACTERISTICS I STC

Maximum Power (Pmax)	435W	440W	445W	450W	455W	460W
Maximum Power Current (Imp)	12.53A	12.60A	12.67A	12.73A	12.79A	12.85A
Maximum Power Voltage (Vmp)	34.78V	34.99V	35.18V	35.41V	35.64V	35.86V
Short Circuit Current (Isc)	13.32A	13.38A	13.45A	13.54A	13.62A	13.74A
Open Circuit Voltage (Voc)	41.21V	41.46V	41.69V	41.96V	42.23V	42.49V
Module Efficiency	20.01%	20.24%	20.47%	20.7%	20.93%	21.16%
Power Tolerance	0~+5W	0~+5W	0~+5W	0~+5W	0~+5W	0~+5W

STC: AM1.5 Irradiance 1000W/m², 25° C

ELECTRICAL CHARACTERISTICS I NOCT

Maximum Power (Pmax)	435W	440W	445W	450W	455W	460W
Maximum Power (Pmax)	329.52W	333.36W	337.03W	340.84W	344.67W	348.43W
Maximum Power Current (Imp)	10.16A	10.22A	10.28A	10.33A	10.37A	10.42A
Maximum Power Voltage (Vmp)	32.42V	32.62V	32.79V	33.01V	33.22V	33.43V
Short Circuit Current (Isc)	10.70A	10.75A	10.81A	10.88A	10.95A	11.04A
Open Circuit Voltage (Voc)	38.61V	38.85V	39.06V	39.31V	39.57V	39.81V

NOCT: AM 1.5 Irradiance 800W/m², 20° C, Wind speed 1m/s

MECHANICAL CHARACTERISTICS

Solar Cell	Monocrystalline I PERC PV Cells 182mm Cell I Half-cut I 10 Busbar I 120 (6x20) pcs in series
Solar Modules	Monofacial I 75.47 x 44.65 x 1.38 inch I Weight: 52.70 lb. ±3%
Module Glass	3.2 mm (0.13 inch) High transparency, low iron, AR-coated tempered glass
Module Frame	Frame 35 mm Ultra-strong anodized aluminum allow frame
Module Junction Box	IP68 rated, 3 bypass diodes
Module Output Cable	4mm² (EU) 12 AWG (US), 39.38 inch
Module Connector	JM608
Module Encapsulant	EVA (ethyl vinyl acetate)
Module Backsheet	FFC backsheet
Module Fire Type	Type 1 Fire rated

PACKING INFORMATION

Pieces per pallet:	31 pcs
Pallets per container (40HQ):	24 pallets
Pieces per container (40HQ):	744 pcs
Pallet Weight:	1732.83 lb. (786kg)
Pallet Dimension:	76.46 x 44.69 x 49.49 inch (1942 x 1135 x 1257 mm)

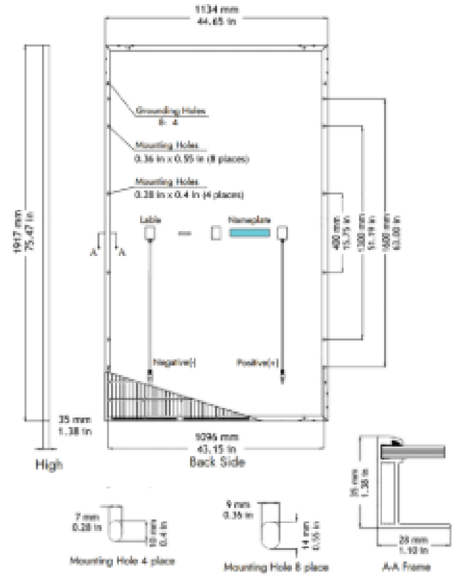
MAXIMUM RATING

Operating Temperature	-40°F~185°F
Maximum Series Fuse Rating	30A
Maximum System Voltage	1000/1500V DC

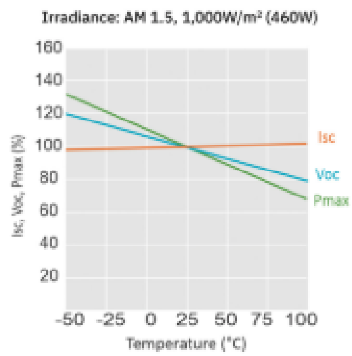
THERMAL CHARACTERISTICS

Pmax Temperature Coefficient	-0.35%/K
Voc Temperature Coefficient	-0.28%/K
Isc Temperature Coefficient	+0.049%/K
NOCT	113±35.6°F

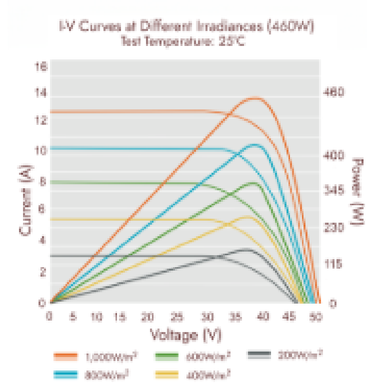
PV Module: Mechanical Drawing



PV Module: IV Curve



PV Module: IV Curve



Appendix C.

January 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radation (Ic)
59.66	21	1	0	-20.14	165	-49.04	158.24	1230.71	0.14	1070.72	1.2E-62	-0.76	-9.4E-63	0.06	6.9E-64	1	6.9E-64	0.6	0.0E+00	-8.68E-63
59.66	21	2	0	-20.14	150	-45.06	138.35	1230.71	0.14	1003.72	1.4E-58	-0.71	-1.0E-58	0.06	8.1E-60	1	8.1E-60	0.6	0.0E+00	-9.44E-59
59.66	21	3	0	-20.14	135	-39.23	121.01	1230.71	0.14	897.17	0.00	-0.63	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	4	0	-20.14	120	-32.29	105.88	1230.71	0.14	758.37	0.00	-0.53	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	5	0	-20.14	105	-24.83	92.26	1230.71	0.14	596.92	0.00	-0.42	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	6	0	-20.14	90	-17.29	79.51	1230.71	0.14	424.08	0.00	-0.30	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	7	0	-20.14	75	-10.04	67.07	1230.71	0.14	252.54	0.00	-0.17	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	8	0	-20.14	60	-3.44	54.54	1230.71	0.14	99.25	0.00	-0.06	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	9	0	-20.14	45	2.19	41.63	1230.71	0.14	19.30	82.88	0.04	3.17	0.06	4.63	1	4.63	0.6	0.00	7.80
59.66	21	10	0	-20.14	30	6.52	28.20	1230.71	0.14	8.37	381.77	0.11	43.36	0.06	21.34	1	21.34	0.6	0.00	64.70
59.66	21	11	0	-20.14	15	9.26	14.25	1230.71	0.14	6.06	527.86	0.16	84.96	0.06	29.50	1	29.50	0.6	0.00	114.46
59.66	21	**12**	0	**-20.14**	**0**	**10.20**	**0.00**	**1230.71**	**0.14**	**5.53**	**568.30**	**0.18**	**100.66**	**0.06**	**31.76**	1	**31.76**	0.6	0.00	**132.42**
59.66	21	13	0	-20.14	-15	9.26	-14.25	1230.71	0.14	6.06	527.86	0.16	84.96	0.06	29.50	1	29.50	0.6	0.00	114.46
59.66	21	14	0	-20.14	-30	6.52	-28.20	1230.71	0.14	8.37	381.77	0.11	43.36	0.06	21.34	1	21.34	0.6	0.00	64.70
59.66	21	15	0	-20.14	-45	2.19	-41.63	1230.71	0.14	19.30	82.88	0.04	3.17	0.06	4.63	1	4.63	0.6	0.00	7.80
59.66	21	16	0	-20.14	-60	-3.44	-54.54	1230.71	0.14	99.25	0.00	-0.06	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	17	0	-20.14	-75	-10.04	-67.07	1230.71	0.14	252.54	0.00	-0.17	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	18	0	-20.14	-90	-17.29	-79.51	1230.71	0.14	424.08	0.00	-0.30	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	19	0	-20.14	-105	-24.83	-92.26	1230.71	0.14	596.92	0.00	-0.42	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	20	0	-20.14	-120	-32.29	-105.88	1230.71	0.14	758.37	0.00	-0.53	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	21	0	-20.14	-135	-39.23	-121.01	1230.71	0.14	897.17	0.00	-0.63	0.00	0.06	0.00	1	0.00	0.6	0.00	0.00
59.66	21	22	0	-20.14	-150	-45.06	-138.35	1230.71	0.14	1003.72	1.4E-58	-0.71	0.00	0.06	0.00	1	8.1E-60	0.6	0.0E+00	-9.44E-59
59.66	21	23	0	-20.14	-165	-49.04	-158.24	1230.71	0.14	1070.72	1.2E-62	-0.76	-9.4E-63	0.06	6.9E-64	1	6.9E-64	0.6	0.0E+00	-8.68E-63
59.66	21	24	0	-20.14	-180	-50.48	-180.00	1230.71	0.14	1093.57	5.1E-64	-0.77	-3.9E-64	0.06	2.8E-65	1	2.8E-65	0.6	0.0E+00	-3.64E-64

Appendix D.

February 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radation (Ic)
59.66	52	1	0	-11.23	165	-40.29	160.56	1208.15	0.15	917.14	1.1E-56	-0.65	-6.9E-57	0.07	7.0E-58	1	7.0E-58	0.4	0.0E+00	-6.21E-57
59.66	52	2	0	-11.23	150	-36.66	142.31	1208.15	0.15	847.18	3.4E-52	-0.60	-2.0E-52	0.07	2.2E-53	1	2.2E-53	0.4	0.0E+00	-1.82E-52
59.66	52	3	0	-11.23	135	-31.22	125.80	1208.15	0.15	735.93	0.00	-0.52	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	4	0	-11.23	120	-24.57	110.93	1208.15	0.15	591.10	0.00	-0.42	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	5	0	-11.23	105	-17.23	97.26	1208.15	0.15	422.85	0.00	-0.30	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	6	0	-11.23	90	-9.67	84.27	1208.15	0.15	243.73	0.00	-0.17	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	7	0	-11.23	75	-2.28	71.48	1208.15	0.15	75.18	0.02	-0.04	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	8	0	-11.23	60	4.57	58.45	1208.15	0.15	11.40	222.81	0.08	17.76	0.07	14.61	1	14.61	0.4	0.00	32.37
59.66	52	9	0	-11.23	45	10.51	44.86	1208.15	0.15	5.38	544.41	0.18	99.26	0.07	35.70	1	35.70	0.4	0.00	134.97
59.66	52	10	0	-11.23	30	15.13	30.53	1208.15	0.15	3.79	688.36	0.26	179.71	0.07	45.14	1	45.14	0.4	0.00	224.85
59.66	52	11	0	-11.23	15	18.09	15.49	1208.15	0.15	3.20	751.87	0.31	233.50	0.07	49.31	1	49.31	0.4	0.00	282.81
59.66	52	**12**	0	**-11.23**	**0**	**19.11**	**0.00**	**1208.15**	**0.15**	**3.04**	**770.23**	**0.33**	**252.21**	**0.07**	**50.51**	1	**50.51**	0.4	0.00	**302.72**
59.66	52	13	0	-11.23	-15	18.09	-15.49	1208.15	0.15	3.20	751.87	0.31	233.50	0.07	49.31	1	49.31	0.4	0.00	282.81
59.66	52	14	0	-11.23	-30	15.13	-30.53	1208.15	0.15	3.79	688.36	0.26	179.71	0.07	45.14	1	45.14	0.4	0.00	224.85
59.66	52	15	0	-11.23	-45	10.51	-44.86	1208.15	0.15	5.38	544.41	0.18	99.26	0.07	35.70	1	35.70	0.4	0.00	134.97
59.66	52	16	0	-11.23	-60	4.57	-58.45	1208.15	0.15	11.40	222.81	0.08	17.76	0.07	14.61	1	14.61	0.4	0.00	32.37
59.66	52	17	0	-11.23	-75	-2.28	-71.48	1208.15	0.15	75.18	0.02	-0.04	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	18	0	-11.23	-90	-9.67	-84.27	1208.15	0.15	243.73	0.00	-0.17	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	19	0	-11.23	-105	-17.23	-97.26	1208.15	0.15	422.85	0.00	-0.30	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	20	0	-11.23	-120	-24.57	-110.93	1208.15	0.15	591.10	0.00	-0.42	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	21	0	-11.23	-135	-31.22	-125.80	1208.15	0.15	735.93	0.00	-0.52	0.00	0.07	0.00	1	0.00	0.4	0.00	0.00
59.66	52	22	0	-11.23	-150	-36.66	-142.31	1208.15	0.15	847.18	3.4E-52	-0.60	0.00	0.07	0.00	1	2.2E-53	0.4	0.0E+00	-1.82E-52
59.66	52	23	0	-11.23	-165	-40.29	-160.56	1208.15	0.15	917.14	1.1E-56	-0.65	-6.9E-57	0.07	7.0E-58	1	7.0E-58	0.4	0.0E+00	-6.21E-57
59.66	52	24	0	-11.23	-180	-41.57	-180.00	1208.15	0.15	941.00	3.1E-58	-0.66	-2.1E-58	0.07	2.0E-59	1	2.0E-59	0.4	0.0E+00	-1.86E-58

Appendix E.

March 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radation (Ic)
59.66	80	1	0	-0.40	165	-29.60	162.68	1176.01	0.16	701.50	4.6E-47	-0.49	-2.3E-47	0.08	3.7E-48	1	3.7E-48	0.4	0.0E+00	-1.88E-47
59.66	80	2	0	-0.40	150	-26.33	146.09	1176.01	0.16	630.28	4.7E-42	-0.44	-2.1E-42	0.08	3.9E-43	1	3.9E-43	0.4	0.0E+00	-1.72E-42
59.66	80	3	0	-0.40	135	-21.30	130.63	1176.01	0.16	517.11	0.00	-0.36	0.00	0.08	0.00	1	0.00	0.4	0.00	0.00
59.66	80	4	0	-0.40	120	-14.99	116.30	1176.01	0.16	370.06	0.00	-0.26	0.00	0.08	0.00	1	0.00	0.4	0.00	0.00
59.66	80	5	0	-0.40	105	-7.86	102.82	1176.01	0.16	200.79	0.00	-0.14	0.00	0.08	0.00	1	0.00	0.4	0.00	0.00
59.66	80	6	0	-0.40	90	-0.35	89.80	1176.01	0.16	42.19	1.25	-0.01	-0.01	0.08	0.10	1	0.10	0.4	0.00	0.09
59.66	80	7	0	-0.40	75	7.16	76.78	1176.01	0.16	7.69	337.73	0.12	42.10	0.08	27.52	1	27.52	0.4	0.00	69.62
59.66	80	8	0	-0.40	60	14.27	63.33	1176.01	0.16	4.01	613.32	0.25	151.17	0.08	49.99	1	49.99	0.4	0.00	201.16
59.66	80	9	0	-0.40	45	20.55	49.04	1176.01	0.16	2.83	742.65	0.35	260.74	0.08	60.53	1	60.53	0.4	0.00	321.27
59.66	80	10	0	-0.40	30	25.55	33.66	1176.01	0.16	2.31	808.40	0.43	348.71	0.08	65.88	1	65.88	0.4	0.00	414.60
59.66	80	11	0	-0.40	15	28.80	17.18	1176.01	0.16	2.07	840.55	0.48	405.00	0.08	68.50	1	68.50	0.4	0.00	473.50
59.66	80	**12**	0	**-0.40**	**0**	**29.94**	**0.00**	**1176.01**	**0.16**	**2.00**	**850.29**	**0.50**	**424.33**	**0.08**	**69.30**	1	**69.30**	0.4	0.00	**493.62**
59.66	80	13	0	-0.40	-15	28.80	-17.18	1176.01	0.16	2.07	840.55	0.48	405.00	0.08	68.50	1	68.50	0.4	0.00	473.50
59.66	80	14	0	-0.40	-30	25.55	-33.66	1176.01	0.16	2.31	808.40	0.43	348.71	0.08	65.88	1	65.88	0.4	0.00	414.60
59.66	80	15	0	-0.40	-45	20.55	-49.04	1176.01	0.16	2.83	742.65	0.35	260.74	0.08	60.53	1	60.53	0.4	0.00	321.27
59.66	80	16	0	-0.40	-60	14.27	-63.33	1176.01	0.16	4.01	613.32	0.25	151.17	0.08	49.99	1	49.99	0.4	0.00	201.16
59.66	80	17	0	-0.40	-75	7.16	-76.78	1176.01	0.16	7.69	337.73	0.12	42.10	0.08	27.52	1	27.52	0.4	0.00	69.62
59.66	80	18	0	-0.40	-90	-0.35	-89.80	1176.01	0.16	42.19	1.25	-0.01	-0.01	0.08	0.10	1	0.10	0.4	0.00	0.09
59.66	80	19	0	-0.40	-105	-7.86	-102.82	1176.01	0.16	200.79	0.00	-0.14	0.00	0.08	0.00	1	0.00	0.4	0.00	0.00
59.66	80	20	0	-0.40	-120	-14.99	-116.30	1176.01	0.16	370.06	0.00	-0.26	0.00	0.08	0.00	1	0.00	0.4	0.00	0.00
59.66	80	21	0	-0.40	-135	-21.30	-130.63	1176.01	0.16	517.11	0.00	-0.36	0.00	0.08	0.00	1	0.00	0.4	0.00	0.00
59.66	80	22	0	-0.40	-150	-26.33	-146.09	1176.01	0.16	630.28	4.7E-42	-0.44	0.00	0.08	0.00	1	3.9E-43	0.4	0.0E+00	-1.72E-42
59.66	80	23	0	-0.40	-165	-29.60	-162.68	1176.01	0.16	701.50	4.6E-47	-0.49	-2.3E-47	0.08	3.7E-48	1	3.7E-48	0.4	0.0E+00	-1.88E-47
59.66	80	24	0	-0.40	-180	-30.74	-180.00	1176.01	0.16	725.81	8.8E-49	-0.51	-4.5E-49	0.08	7.2E-50	1	7.2E-50	0.4	0.0E+00	-3.8E-49

Appendix F.

April 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radiation (Ic)
59.66	111	1	0	11.58	165	-17.74	164.56	1136.52	0.18	434.80	9.0E-32	-0.30	-2.7E-32	0.10	9.2E-33	1	9.2E-33	0.2	0.0E+00	-1.82E-32
59.66	111	2	0	11.58	150	-14.79	149.56	1136.52	0.18	365.42	2.5E-26	-0.26	-6.4E-27	0.10	2.6E-27	1	2.6E-27	0.2	0.0E+00	-3.81E-27
59.66	111	3	0	11.58	135	-10.18	135.27	1136.52	0.18	255.72	0.00	-0.18	0.00	0.10	0.00	1	0.00	0.2	0.00	0.00
59.66	111	4	0	11.58	120	-4.26	121.71	1136.52	0.18	117.16	0.00	-0.07	0.00	0.10	0.00	1	0.00	0.2	0.00	0.00
59.66	111	5	0	11.58	105	2.59	108.70	1136.52	0.18	17.42	48.93	0.05	2.21	0.10	5.02	1	5.02	0.2	0.00	7.23
59.66	111	6	0	11.58	90	9.98	84.09	1136.52	0.18	5.65	409.93	0.17	71.01	0.10	42.03	1	42.03	0.2	0.00	113.04
59.66	111	7	0	11.58	75	17.54	82.93	1136.52	0.18	3.30	626.75	0.30	188.84	0.10	64.26	1	64.26	0.2	0.00	253.10
59.66	111	8	0	11.58	60	24.88	69.25	1136.52	0.18	2.37	740.87	0.42	311.65	0.10	75.96	1	75.96	0.2	0.00	387.61
59.66	111	9	0	11.58	45	31.54	54.37	1136.52	0.18	1.91	805.26	0.52	421.27	0.10	82.56	1	82.56	0.2	0.00	503.83
59.66	111	10	0	11.58	30	37.00	37.83	1136.52	0.18	1.66	842.19	0.60	506.82	0.10	86.35	1	86.35	0.2	0.00	593.16
59.66	111	11	0	11.58	15	40.63	19.52	1136.52	0.18	1.53	861.50	0.65	561.03	0.10	88.33	1	88.33	0.2	0.00	649.36
59.66	**111**	**12**	**0**	**11.58**	**0**	**41.92**	**0.00**	**1136.52**	**0.18**	**1.50**	**867.53**	**0.67**	**579.58**	**0.10**	**88.95**	1	**88.95**	0.2	0.00	**668.53**
59.66	111	13	0	11.58	-15	40.63	-19.52	1136.52	0.18	1.53	861.50	0.65	561.03	0.10	88.33	1	88.33	0.2	0.00	649.36
59.66	111	14	0	11.58	-30	37.00	-37.83	1136.52	0.18	1.66	842.19	0.60	506.82	0.10	86.35	1	86.35	0.2	0.00	593.16
59.66	111	15	0	11.58	-45	31.54	-54.37	1136.52	0.18	1.91	805.26	0.52	421.27	0.10	82.56	1	82.56	0.2	0.00	503.83
59.66	111	16	0	11.58	-60	24.88	-69.25	1136.52	0.18	2.37	740.87	0.42	311.65	0.10	75.96	1	75.96	0.2	0.00	387.61
59.66	111	17	0	11.58	-75	17.54	-82.93	1136.52	0.18	3.30	626.75	0.30	188.84	0.10	64.26	1	64.26	0.2	0.00	253.10
59.66	111	18	0	11.58	-90	9.98	-84.09	1136.52	0.18	5.65	409.93	0.17	71.01	0.10	42.03	1	42.03	0.2	0.00	113.04
59.66	111	19	0	11.58	-105	2.59	-108.70	1136.52	0.18	17.42	48.93	0.05	2.21	0.10	5.02	1	5.02	0.2	0.00	7.23
59.66	111	20	0	11.58	-120	-4.26	-121.71	1136.52	0.18	117.16	0.00	-0.07	0.00	0.10	0.00	1	0.00	0.2	0.00	0.00
59.66	111	21	0	11.58	-135	-10.18	-135.27	1136.52	0.18	255.72	0.00	-0.18	0.00	0.10	0.00	1	0.00	0.2	0.00	0.00
59.66	111	22	0	11.58	-150	-14.79	-149.56	1136.52	0.18	365.42	2.5E-26	-0.26	0.00	0.10	0.00	1	2.6E-27	0.2	0.0E+00	-3.81E-27
59.66	111	23	0	11.58	-165	-17.74	-164.56	1136.52	0.18	434.80	9.0E-32	-0.30	-2.7E-32	0.10	9.2E-33	1	9.2E-33	0.2	0.0E+00	-1.82E-32
59.66	111	24	0	11.58	-180	-18.76	-180.00	1136.52	0.18	458.51	1.2E-33	-0.32	-4.0E-34	0.10	1.3E-34	1	1.3E-34	0.2	0.0E+00	-2.73E-34

Appendix G.

May 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radiation (Ic)
59.66	141	1	0	20.14	165	-9.26	165.75	1104.41	0.20	233.97	1.1E-17	-0.16	-1.8E-18	0.12	1.4E-18	1	1.4E-18	0.2	0.0E+00	-4.55E-19
59.66	141	2	0	20.14	150	-6.52	151.80	1104.41	0.20	169.21	3.9E-12	-0.11	-4.4E-13	0.12	4.7E-13	1	4.7E-13	0.2	0.0E+00	2.855E-14
59.66	141	3	0	20.14	135	-2.19	138.37	1104.41	0.20	73.41	0.00	-0.04	0.00	0.12	0.00	1	0.00	0.2	0.00	0.00
59.66	141	4	0	20.14	120	3.44	125.46	1104.41	0.20	14.28	66.59	0.06	4.00	0.12	8.05	1	8.05	0.2	0.00	12.05
59.66	141	5	0	20.14	105	10.04	112.93	1104.41	0.20	5.61	366.27	0.17	63.87	0.12	44.30	1	44.30	0.2	0.00	108.17
59.66	141	6	0	20.14	90	17.29	79.51	1104.41	0.20	3.34	572.39	0.30	170.07	0.12	69.23	1	69.23	0.2	0.00	239.30
59.66	141	7	0	20.14	75	24.83	87.74	1104.41	0.20	2.37	692.37	0.42	290.71	0.12	83.74	1	83.74	0.2	0.00	374.45
59.66	141	8	0	20.14	60	32.29	74.12	1104.41	0.20	1.87	764.74	0.53	408.57	0.12	92.49	1	92.49	0.2	0.00	501.06
59.66	141	9	0	20.14	45	39.23	58.99	1104.41	0.20	1.58	809.48	0.63	511.98	0.12	97.90	1	97.90	0.2	0.00	609.88
59.66	141	10	0	20.14	30	45.06	41.65	1104.41	0.20	1.41	836.62	0.71	592.20	0.12	101.19	1	101.19	0.2	0.00	693.38
59.66	141	11	0	20.14	15	49.04	21.76	1104.41	0.20	1.32	851.28	0.76	642.91	0.12	102.96	1	102.96	0.2	0.00	745.87
59.66	**141**	**12**	**0**	**20.14**	**0**	**50.48**	**0.00**	**1104.41**	**0.20**	**1.30**	**855.93**	**0.77**	**660.25**	**0.12**	**103.52**	1	**103.52**	0.2	0.00	**763.77**
59.66	141	13	0	20.14	-15	49.04	-21.76	1104.41	0.20	1.32	851.28	0.76	642.91	0.12	102.96	1	102.96	0.2	0.00	745.87
59.66	141	14	0	20.14	-30	45.06	-41.65	1104.41	0.20	1.41	836.62	0.71	592.20	0.12	101.19	1	101.19	0.2	0.00	693.38
59.66	141	15	0	20.14	-45	39.23	-58.99	1104.41	0.20	1.58	809.48	0.63	511.98	0.12	97.90	1	97.90	0.2	0.00	609.88
59.66	141	16	0	20.14	-60	32.29	-74.12	1104.41	0.20	1.87	764.74	0.53	408.57	0.12	92.49	1	92.49	0.2	0.00	501.06
59.66	141	17	0	20.14	-75	24.83	-87.74	1104.41	0.20	2.37	692.37	0.42	290.71	0.12	83.74	1	83.74	0.2	0.00	374.45
59.66	141	18	0	20.14	-90	17.29	-79.51	1104.41	0.20	3.34	572.39	0.30	170.07	0.12	69.23	1	69.23	0.2	0.00	239.30
59.66	141	19	0	20.14	-105	10.04	-112.93	1104.41	0.20	5.61	366.27	0.17	63.87	0.12	44.30	1	44.30	0.2	0.00	108.17
59.66	141	20	0	20.14	-120	3.44	-125.46	1104.41	0.20	14.28	66.59	0.06	4.00	0.12	8.05	1	8.05	0.2	0.00	12.05
59.66	141	21	0	20.14	-135	-2.19	-138.37	1104.41	0.20	73.41	0.00	-0.04	0.00	0.12	0.00	1	0.00	0.2	0.00	0.00
59.66	141	22	0	20.14	-150	-6.52	-151.80	1104.41	0.20	169.21	3.9E-12	-0.11	0.00	0.12	0.00	1	4.7E-13	0.2	0.0E+00	2.855E-14
59.66	141	23	0	20.14	-165	-9.26	-165.75	1104.41	0.20	233.97	1.1E-17	-0.16	-1.8E-18	0.12	1.4E-18	1	1.4E-18	0.2	0.0E+00	-4.55E-19
59.66	141	24	0	20.14	-180	-10.20	-180.00	1104.41	0.20	256.33	1.4E-19	-0.18	-2.5E-20	0.12	1.7E-20	1	1.7E-20	0.2	0.0E+00	-7.86E-21

Appendix H.

June 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radiation (Ic)
59.66	172	1	0	23.45	165	-5.98	166.19	1086.53	0.21	156.57	9.0E-12	-0.10	-9.4E-13	0.13	1.2E-12	1	1.2E-12	0.2	0.0E+00	2.58E-13
59.66	172	2	0	23.45	150	-3.32	152.65	1086.53	0.21	96.63	2.2E-06	-0.06	-1.3E-07	0.13	2.9E-07	1	2.9E-07	0.2	0.0E+00	1.66E-07
59.66	172	3	0	23.45	135	0.90	139.55	1086.53	0.21	28.10	3.22	0.02	0.05	0.13	0.43	1	0.43	0.2	0.00	0.48
59.66	172	4	0	23.45	120	6.42	126.92	1086.53	0.21	8.50	186.90	0.11	20.88	0.13	24.83	1	24.83	0.2	0.00	45.71
59.66	172	5	0	23.45	105	12.91	114.61	1086.53	0.21	4.42	435.40	0.22	97.31	0.13	57.83	1	57.83	0.2	0.00	155.14
59.66	172	6	0	23.45	90	20.09	77.64	1086.53	0.21	2.90	596.39	0.34	204.83	0.13	79.21	1	79.21	0.2	0.00	284.04
59.66	172	7	0	23.45	75	27.61	89.75	1086.53	0.21	2.15	695.74	0.46	322.39	0.13	92.41	1	92.41	0.2	0.00	414.80
59.66	172	8	0	23.45	60	35.11	76.22	1086.53	0.21	1.74	758.38	0.58	436.18	0.13	100.73	1	100.73	0.2	0.00	536.91
59.66	172	9	0	23.45	45	42.15	61.05	1086.53	0.21	1.49	798.26	0.67	535.73	0.13	106.03	1	106.03	0.2	0.00	641.76
59.66	172	10	0	23.45	30	48.14	43.42	1086.53	0.21	1.34	822.90	0.74	612.87	0.13	109.30	1	109.30	0.2	0.00	722.17
59.66	172	11	0	23.45	15	52.29	22.84	1086.53	0.21	1.26	836.36	0.79	661.62	0.13	111.09	1	111.09	0.2	0.00	772.70
59.66	**172**	**12**	**0**	**23.45**	**0**	**53.79**	**0.00**	**1086.53**	**0.21**	**1.24**	**840.65**	**0.81**	**678.28**	**0.13**	**111.66**	1	**111.66**	0.2	0.00	**789.94**
59.66	172	13	0	23.45	-15	52.29	-22.84	1086.53	0.21	1.26	836.36	0.79	661.62	0.13	111.09	1	111.09	0.2	0.00	772.70
59.66	172	14	0	23.45	-30	48.14	-43.42	1086.53	0.21	1.34	822.90	0.74	612.87	0.13	109.30	1	109.30	0.2	0.00	722.17
59.66	172	15	0	23.45	-45	42.15	-61.05	1086.53	0.21	1.49	798.26	0.67	535.73	0.13	106.03	1	106.03	0.2	0.00	641.76
59.66	172	16	0	23.45	-60	35.11	-76.22	1086.53	0.21	1.74	758.38	0.58	436.18	0.13	100.73	1	100.73	0.2	0.00	536.91
59.66	172	17	0	23.45	-75	27.61	-89.75	1086.53	0.21	2.15	695.74	0.46	322.39	0.13	92.41	1	92.41	0.2	0.00	414.80
59.66	172	18	0	23.45	-90	20.09	-77.64	1086.53	0.21	2.90	596.39	0.34	204.83	0.13	79.21	1	79.21	0.2	0.00	284.04
59.66	172	19	0	23.45	-105	12.91	-114.61	1086.53	0.21	4.42	435.40	0.22	97.31	0.13	57.83	1	57.83	0.2	0.00	155.14
59.66	172	20	0	23.45	-120	6.42	-126.92	1086.53	0.21	8.50	186.90	0.11	20.88	0.13	24.83	1	24.83	0.2	0.00	45.71
59.66	172	21	0	23.45	-135	0.90	-139.55	1086.53	0.21	28.10	3.22	0.02	0.05	0.13	0.43	1	0.43	0.2	0.00	0.48
59.66	172	22	0	23.45	-150	-3.32	-152.65	1086.53	0.21	96.63	2.2E-06	-0.06	0.00	0.13	0.00	1	2.9E-07	0.2	0.0E+00	1.66E-07
59.66	172	23	0	23.45	-165	-5.98	-166.19	1086.53	0.21	156.57	9.0E-12	-0.10	-9.4E-13	0.13	1.2E-12	1	1.2E-12	0.2	0.0E+00	2.58E-13
59.66	172	24	0	23.45	-180	-6.89	-180.00	1086.53	0.21	177.84	1.1E-13	-0.12	-1.3E-14	0.13	1.5E-14	1	1.5E-14	0.2	0.0E+00	1.413E-15

Appendix I.

July 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radation (Ic)
59.66	202	1	0	20.44	165	-8.96	165.79	1088.67	0.21	226.82	3.2E-18	-0.16	-5.0E-19	0.13	4.3E-19	1	4.3E-19	0.2	0.0E+00	-6.9E-20
59.66	202	2	0	20.44	150	-6.23	151.88	1088.67	0.21	162.35	2.2E-12	-0.11	-2.4E-13	0.13	3.0E-13	1	3.0E-13	0.2	0.0E+00	5.689E-14
59.66	202	3	0	20.44	135	-1.91	138.48	1088.67	0.21	67.96	0.00	-0.03	0.00	0.13	0.00	1	0.00	0.2	0.00	0.00
59.66	202	4	0	20.44	120	3.71	125.59	1088.67	0.21	13.47	65.68	0.06	4.25	0.13	8.82	1	8.82	0.2	0.00	13.08
59.66	202	5	0	20.44	105	10.31	113.08	1088.67	0.21	5.47	347.84	0.18	62.23	0.13	46.72	1	46.72	0.2	0.00	108.95
59.66	202	6	0	20.44	90	17.54	79.34	1088.67	0.21	3.29	547.91	0.30	165.15	0.13	73.59	1	73.59	0.2	0.00	238.75
59.66	202	7	0	20.44	75	25.08	87.92	1088.67	0.21	2.35	666.93	0.42	282.73	0.13	89.58	1	89.58	0.2	0.00	372.31
59.66	202	8	0	20.44	60	32.55	74.31	1088.67	0.21	1.86	739.57	0.54	397.95	0.13	99.34	1	99.34	0.2	0.00	497.29
59.66	202	9	0	20.44	45	39.50	59.17	1088.67	0.21	1.57	784.80	0.64	499.22	0.13	105.41	1	105.41	0.2	0.00	604.63
59.66	202	10	0	20.44	30	45.34	41.80	1088.67	0.21	1.40	812.35	0.71	577.85	0.13	109.11	1	109.11	0.2	0.00	686.96
59.66	202	11	0	20.44	15	49.34	21.85	1088.67	0.21	1.32	827.28	0.76	627.58	0.13	111.12	1	111.12	0.2	0.00	738.70
59.66	202	**12**	0	**20.44**	**0**	**50.78**	**0.00**	**1088.67**	**0.21**	**1.29**	**832.01**	**0.77**	**644.59**	**0.13**	**111.75**	1	**111.75**	0.2	0.00	**756.34**
59.66	202	13	0	20.44	-15	49.34	-21.85	1088.67	0.21	1.32	827.28	0.76	627.58	0.13	111.12	1	111.12	0.2	0.00	738.70
59.66	202	14	0	20.44	-30	45.34	-41.80	1088.67	0.21	1.40	812.35	0.71	577.85	0.13	109.11	1	109.11	0.2	0.00	686.96
59.66	202	15	0	20.44	-45	39.50	-59.17	1088.67	0.21	1.57	784.80	0.64	499.22	0.13	105.41	1	105.41	0.2	0.00	604.63
59.66	202	16	0	20.44	-60	32.55	-74.31	1088.67	0.21	1.86	739.57	0.54	397.95	0.13	99.34	1	99.34	0.2	0.00	497.29
59.66	202	17	0	20.44	-75	25.08	-87.92	1088.67	0.21	2.35	666.93	0.42	282.73	0.13	89.58	1	89.58	0.2	0.00	372.31
59.66	202	18	0	20.44	-90	17.54	-79.34	1088.67	0.21	3.29	547.91	0.30	165.15	0.13	73.59	1	73.59	0.2	0.00	238.75
59.66	202	19	0	20.44	-105	10.31	-113.08	1088.67	0.21	5.47	347.84	0.18	62.23	0.13	46.72	1	46.72	0.2	0.00	108.95
59.66	202	20	0	20.44	-120	3.71	-125.59	1088.67	0.21	13.47	65.68	0.06	4.25	0.13	8.82	1	8.82	0.2	0.00	13.08
59.66	202	21	0	20.44	-135	-1.91	-138.48	1088.67	0.21	67.96	0.00	-0.03	0.00	0.13	0.00	1	0.00	0.2	0.00	0.00
59.66	202	22	0	20.44	-150	-6.23	-151.88	1088.67	0.21	162.35	2.2E-12	-0.11	0.00	0.13	0.00	1	3.0E-13	0.2	0.0E+00	5.689E-14
59.66	202	23	0	20.44	-165	-8.96	-165.79	1088.67	0.21	226.82	3.2E-18	-0.16	-5.0E-19	0.13	4.3E-19	1	4.3E-19	0.2	0.0E+00	-6.9E-20
59.66	202	24	0	20.44	-180	-9.90	-180.00	1088.67	0.21	249.10	3.1E-20	-0.17	-5.3E-21	0.13	4.2E-21	1	4.2E-21	0.2	0.0E+00	-1.16E-21

Appendix J.

August 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radation (Ic)
59.66	233	1	0	11.75	165	-17.57	164.59	1110.38	0.20	430.74	3.7E-35	-0.30	-1.1E-35	0.13	4.6E-36	1	4.6E-36	0.2	0.0E+00	-6.53E-36
59.66	233	2	0	11.75	150	-14.62	149.61	1110.38	0.20	361.42	4.0E-29	-0.25	-1.0E-29	0.13	5.0E-30	1	5.0E-30	0.2	0.0E+00	-5.06E-30
59.66	233	3	0	11.75	135	-10.01	135.33	1110.38	0.20	251.84	0.00	-0.17	0.00	0.13	0.00	1	0.00	0.2	0.00	0.00
59.66	233	4	0	11.75	120	-4.10	121.78	1110.38	0.20	113.65	0.00	-0.07	0.00	0.13	0.00	1	0.00	0.2	0.00	0.00
59.66	233	5	0	11.75	105	2.74	108.78	1110.38	0.20	16.77	38.56	0.05	1.84	0.13	4.82	1	4.82	0.2	0.00	6.67
59.66	233	6	0	11.75	90	10.13	84.00	1110.38	0.20	5.57	363.97	0.18	63.99	0.13	45.53	1	45.53	0.2	0.00	109.52
59.66	233	7	0	11.75	75	17.69	83.02	1110.38	0.20	3.27	576.82	0.30	175.24	0.13	72.16	1	72.16	0.2	0.00	247.41
59.66	233	8	0	11.75	60	25.03	69.35	1110.38	0.20	2.36	692.59	0.42	293.02	0.13	86.65	1	86.65	0.2	0.00	379.67
59.66	233	9	0	11.75	45	31.70	54.46	1110.38	0.20	1.90	758.94	0.53	398.82	0.13	94.95	1	94.95	0.2	0.00	493.77
59.66	233	10	0	11.75	30	37.16	37.90	1110.38	0.20	1.65	797.29	0.60	481.64	0.13	99.75	1	99.75	0.2	0.00	581.39
59.66	233	11	0	11.75	15	40.81	19.56	1110.38	0.20	1.53	817.44	0.65	534.20	0.13	102.27	1	102.27	0.2	0.00	636.46
59.66	233	**12**	0	**11.75**	**0**	**42.09**	**0.00**	**1110.38**	**0.20**	**1.49**	**823.74**	**0.67**	**552.19**	**0.13**	**103.05**	1	**103.05**	0.2	0.00	**655.25**
59.66	233	13	0	11.75	-15	40.81	-19.56	1110.38	0.20	1.53	817.44	0.65	534.20	0.13	102.27	1	102.27	0.2	0.00	636.46
59.66	233	14	0	11.75	-30	37.16	-37.90	1110.38	0.20	1.65	797.29	0.60	481.64	0.13	99.75	1	99.75	0.2	0.00	581.39
59.66	233	15	0	11.75	-45	31.70	-54.46	1110.38	0.20	1.90	758.94	0.53	398.82	0.13	94.95	1	94.95	0.2	0.00	493.77
59.66	233	16	0	11.75	-60	25.03	-69.35	1110.38	0.20	2.36	692.59	0.42	293.02	0.13	86.65	1	86.65	0.2	0.00	379.67
59.66	233	17	0	11.75	-75	17.69	-83.02	1110.38	0.20	3.27	576.82	0.30	175.24	0.13	72.16	1	72.16	0.2	0.00	247.41
59.66	233	18	0	11.75	-90	10.13	-84.00	1110.38	0.20	5.57	363.97	0.18	63.99	0.13	45.53	1	45.53	0.2	0.00	109.52
59.66	233	19	0	11.75	-105	2.74	-108.78	1110.38	0.20	16.77	38.56	0.05	1.84	0.13	4.82	1	4.82	0.2	0.00	6.67
59.66	233	20	0	11.75	-120	-4.10	-121.78	1110.38	0.20	113.65	0.00	-0.07	0.00	0.13	0.00	1	0.00	0.2	0.00	0.00
59.66	233	21	0	11.75	-135	-10.01	-135.33	1110.38	0.20	251.84	0.00	-0.17	0.00	0.13	0.00	1	0.00	0.2	0.00	0.00
59.66	233	22	0	11.75	-150	-14.62	-149.61	1110.38	0.20	361.42	4.0E-29	-0.25	0.00	0.13	0.00	1	5.0E-30	0.2	0.0E+00	-5.06E-30
59.66	233	23	0	11.75	-165	-17.57	-164.59	1110.38	0.20	430.74	3.7E-35	-0.30	-1.1E-35	0.13	4.6E-36	1	4.6E-36	0.2	0.0E+00	-6.53E-36
59.66	233	24	0	11.75	-180	-18.59	-180.00	1110.38	0.20	454.43	3.2E-37	-0.32	-1.0E-37	0.13	4.0E-38	1	4.0E-38	0.2	0.0E+00	-6.21E-38

Appendix K.

September 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radation (Ic)
59.66	264	1	0	-0.20	165	-29.40	162.72	1145.88	0.18	697.23	1.1E-53	-0.49	-5.6E-54	0.11	1.2E-54	1	1.2E-54	0.2	0.0E+00	-4.34E-54
59.66	264	2	0	-0.20	150	-26.14	146.16	1145.88	0.18	626.00	6.0E-48	-0.44	-2.6E-48	0.11	6.4E-49	1	6.4E-49	0.2	0.0E+00	-1.98E-48
59.66	264	3	0	-0.20	135	-21.11	130.71	1145.88	0.18	512.83	0.00	-0.36	0.00	0.11	0.00	1	0.00	0.2	0.00	0.00
59.66	264	4	0	-0.20	120	-14.81	116.39	1145.88	0.18	365.81	0.00	-0.26	0.00	0.11	0.00	1	0.00	0.2	0.00	0.00
59.66	264	5	0	-0.20	105	-7.69	102.92	1145.88	0.18	196.63	0.00	-0.13	0.00	0.11	0.00	1	0.00	0.2	0.00	0.00
59.66	264	6	0	-0.20	90	-0.17	89.90	1145.88	0.18	39.86	0.72	0.00	0.00	0.11	0.08	1	0.08	0.2	0.00	0.08
59.66	264	7	0	-0.20	75	7.34	76.88	1145.88	0.18	7.52	284.97	0.13	36.39	0.11	30.64	1	30.64	0.2	0.00	67.03
59.66	264	8	0	-0.20	60	14.45	63.42	1145.88	0.18	3.97	550.26	0.25	137.30	0.11	59.17	1	59.17	0.2	0.00	196.47
59.66	264	9	0	-0.20	45	20.74	49.12	1145.88	0.18	2.81	681.43	0.35	241.32	0.11	73.27	1	73.27	0.2	0.00	314.59
59.66	264	10	0	-0.20	30	25.75	33.72	1145.88	0.18	2.30	749.53	0.43	325.61	0.11	80.59	1	80.59	0.2	0.00	406.20
59.66	264	11	0	-0.20	15	29.00	17.21	1145.88	0.18	2.06	783.17	0.48	379.74	0.11	84.21	1	84.21	0.2	0.00	463.95
59.66	264	**12**	0	**-0.20**	**0**	**30.14**	**0.00**	**1145.88**	**0.18**	**1.99**	**793.39**	**0.50**	**398.35**	**0.11**	**85.31**	1	**85.31**	0.2	0.00	**483.66**
59.66	264	13	0	-0.20	-15	29.00	-17.21	1145.88	0.18	2.06	783.17	0.48	379.74	0.11	84.21	1	84.21	0.2	0.00	463.95
59.66	264	14	0	-0.20	-30	25.75	-33.72	1145.88	0.18	2.30	749.53	0.43	325.61	0.11	80.59	1	80.59	0.2	0.00	406.20
59.66	264	15	0	-0.20	-45	20.74	-49.12	1145.88	0.18	2.81	681.43	0.35	241.32	0.11	73.27	1	73.27	0.2	0.00	314.59
59.66	264	16	0	-0.20	-60	14.45	-63.42	1145.88	0.18	3.97	550.26	0.25	137.30	0.11	59.17	1	59.17	0.2	0.00	196.47
59.66	264	17	0	-0.20	-75	7.34	-76.88	1145.88	0.18	7.52	284.97	0.13	36.39	0.11	30.64	1	30.64	0.2	0.00	67.03
59.66	264	18	0	-0.20	-90	-0.17	-89.90	1145.88	0.18	39.86	0.72	0.00	0.00	0.11	0.08	1	0.08	0.2	0.00	0.08
59.66	264	19	0	-0.20	-105	-7.69	-102.92	1145.88	0.18	196.63	0.00	-0.13	0.00	0.11	0.00	1	0.00	0.2	0.00	0.00
59.66	264	20	0	-0.20	-120	-14.81	-116.39	1145.88	0.18	365.81	0.00	-0.26	0.00	0.11	0.00	1	0.00	0.2	0.00	0.00
59.66	264	21	0	-0.20	-135	-21.11	-130.71	1145.88	0.18	512.83	0.00	-0.36	0.00	0.11	0.00	1	0.00	0.2	0.00	0.00
59.66	264	22	0	-0.20	-150	-26.14	-146.16	1145.88	0.18	626.00	6.0E-48	-0.44	0.00	0.11	0.00	1	6.4E-49	0.2	0.0E+00	-1.98E-48
59.66	264	23	0	-0.20	-165	-29.40	-162.72	1145.88	0.18	697.23	1.1E-53	-0.49	-5.6E-54	0.11	1.2E-54	1	1.2E-54	0.2	0.0E+00	-4.34E-54
59.66	264	24	0	-0.20	-180	-30.54	-180.00	1145.88	0.18	721.53	1.3E-55	-0.51	-6.4E-56	0.11	1.4E-56	1	1.4E-56	0.2	0.0E+00	-5.06E-56

Appendix L.

October 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radation (Ic)
59.66	294	1	0	-11.75	165	-40.81	160.44	1184.10	0.17	926.88	6.3E-65	-0.65	-4.1E-65	0.09	5.5E-66	1	5.5E-66	0.2	0.0E+00	-3.59E-65
59.66	294	2	0	-11.75	150	-37.16	142.10	1184.10	0.17	857.05	7.4E-60	-0.60	-4.5E-60	0.09	6.5E-61	1	6.5E-61	0.2	0.0E+00	-3.84E-60
59.66	294	3	0	-11.75	135	-31.70	125.54	1184.10	0.17	746.01	0.00	-0.53	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	4	0	-11.75	120	-25.03	110.65	1184.10	0.17	601.44	0.00	-0.42	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	5	0	-11.75	105	-17.69	96.98	1184.10	0.17	433.46	0.00	-0.30	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	6	0	-11.75	90	-10.13	84.00	1184.10	0.17	254.52	0.00	-0.18	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	7	0	-11.75	75	-2.74	71.22	1184.10	0.17	84.48	0.00	-0.05	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	8	0	-11.75	60	4.10	58.22	1184.10	0.17	12.47	147.40	0.07	10.53	0.09	12.84	1	12.84	0.2	0.00	23.38
59.66	294	9	0	-11.75	45	10.01	44.67	1184.10	0.17	5.63	462.40	0.17	80.40	0.09	40.29	1	40.29	0.2	0.00	120.69
59.66	294	10	0	-11.75	30	14.62	30.39	1184.10	0.17	3.92	614.94	0.25	155.25	0.09	53.58	1	53.58	0.2	0.00	208.84
59.66	294	11	0	-11.75	15	17.57	15.41	1184.10	0.17	3.29	683.33	0.30	206.28	0.09	59.54	1	59.54	0.2	0.00	265.82
59.66	294	**12**	0	**-11.75**	**0**	**18.59**	**0.00**	**1184.10**	**0.17**	**3.12**	**703.20**	**0.32**	**224.13**	**0.09**	**61.27**	1	**61.27**	0.2	0.00	**285.40**
59.66	294	13	0	-11.75	-15	17.57	-15.41	1184.10	0.17	3.29	683.33	0.30	206.28	0.09	59.54	1	59.54	0.2	0.00	265.82
59.66	294	14	0	-11.75	-30	14.62	-30.39	1184.10	0.17	3.92	614.94	0.25	155.25	0.09	53.58	1	53.58	0.2	0.00	208.84
59.66	294	15	0	-11.75	-45	10.01	-44.67	1184.10	0.17	5.63	462.40	0.17	80.40	0.09	40.29	1	40.29	0.2	0.00	120.69
59.66	294	16	0	-11.75	-60	4.10	-58.22	1184.10	0.17	12.47	147.40	0.07	10.53	0.09	12.84	1	12.84	0.2	0.00	23.38
59.66	294	17	0	-11.75	-75	-2.74	-71.22	1184.10	0.17	84.48	0.00	-0.05	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	18	0	-11.75	-90	-10.13	-84.00	1184.10	0.17	254.52	0.00	-0.18	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	19	0	-11.75	-105	-17.69	-96.98	1184.10	0.17	433.46	0.00	-0.30	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	20	0	-11.75	-120	-25.03	-110.65	1184.10	0.17	601.44	0.00	-0.42	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	21	0	-11.75	-135	-31.70	-125.54	1184.10	0.17	746.01	0.00	-0.53	0.00	0.09	0.00	1	0.00	0.2	0.00	0.00
59.66	294	22	0	-11.75	-150	-37.16	-142.10	1184.10	0.17	857.05	7.4E-60	-0.60	0.00	0.09	0.00	1	6.5E-61	0.2	0.0E+00	-3.84E-60
59.66	294	23	0	-11.75	-165	-40.81	-160.44	1184.10	0.17	926.88	6.3E-65	-0.65	-4.1E-65	0.09	5.5E-66	1	5.5E-66	0.2	0.0E+00	-3.59E-65
59.66	294	24	0	-11.75	-180	-42.09	-180.00	1184.10	0.17	950.71	1.2E-66	-0.67	-7.9E-67	0.09	1.0E-67	1	1.0E-67	0.2	0.0E+00	-6.9E-67

Appendix M.

November 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radation (Ic)
59.66	325	1	0	-20.44	165	-49.34	158.15	1216.87	0.15	1075.51	5.4E-68	-0.76	-4.1E-68	0.07	3.7E-69	1	3.7E-69	0.2	0.0E+00	-3.74E-68
59.66	325	2	0	-20.44	150	-45.34	138.20	1216.87	0.15	1008.64	1.3E-63	-0.71	-9.1E-64	0.07	8.7E-65	1	8.7E-65	0.2	0.0E+00	-8.23E-64
59.66	325	3	0	-20.44	135	-39.50	120.83	1216.87	0.15	902.30	0.00	-0.64	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	4	0	-20.44	120	-32.55	105.69	1216.87	0.15	763.78	0.00	-0.54	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	5	0	-20.44	105	-25.08	92.08	1216.87	0.15	602.63	0.00	-0.42	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	6	0	-20.44	90	-17.54	79.34	1216.87	0.15	430.10	0.00	-0.30	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	7	0	-20.44	75	-10.31	66.92	1216.87	0.15	258.82	0.00	-0.18	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	8	0	-20.44	60	-3.71	54.41	1216.87	0.15	105.17	0.00	-0.06	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	9	0	-20.44	45	1.91	41.52	1216.87	0.15	20.85	52.65	0.03	1.75	0.07	3.59	1	3.59	0.2	0.00	5.35
59.66	325	10	0	-20.44	30	6.23	28.12	1216.87	0.15	8.73	326.83	0.11	35.46	0.07	22.32	1	22.32	0.2	0.00	57.77
59.66	325	11	0	-20.44	15	8.96	14.21	1216.87	0.15	6.25	474.90	0.16	73.98	0.07	32.43	1	32.43	0.2	0.00	106.40
59.66	325	**12**	0	**-20.44**	**0**	**9.90**	**0.00**	**1216.87**	**0.15**	**5.69**	**516.60**	**0.17**	**88.80**	**0.07**	**35.27**	1	**35.27**	0.2	0.00	**124.08**
59.66	325	13	0	-20.44	-15	8.96	-14.21	1216.87	0.15	6.25	474.90	0.16	73.98	0.07	32.43	1	32.43	0.2	0.00	106.40
59.66	325	14	0	-20.44	-30	6.23	-28.12	1216.87	0.15	8.73	326.83	0.11	35.46	0.07	22.32	1	22.32	0.2	0.00	57.77
59.66	325	15	0	-20.44	-45	1.91	-41.52	1216.87	0.15	20.85	52.65	0.03	1.75	0.07	3.59	1	3.59	0.2	0.00	5.35
59.66	325	16	0	-20.44	-60	-3.71	-54.41	1216.87	0.15	105.17	0.00	-0.06	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	17	0	-20.44	-75	-10.31	-66.92	1216.87	0.15	258.82	0.00	-0.18	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	18	0	-20.44	-90	-17.54	-79.34	1216.87	0.15	430.10	0.00	-0.30	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	19	0	-20.44	-105	-25.08	-92.08	1216.87	0.15	602.63	0.00	-0.42	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	20	0	-20.44	-120	-32.55	-105.69	1216.87	0.15	763.78	0.00	-0.54	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	21	0	-20.44	-135	-39.50	-120.83	1216.87	0.15	902.30	0.00	-0.64	0.00	0.07	0.00	1	0.00	0.2	0.00	0.00
59.66	325	22	0	-20.44	-150	-45.34	-138.20	1216.87	0.15	1008.64	1.3E-63	-0.71	0.00	0.07	0.00	1	8.7E-65	0.2	0.0E+00	-8.23E-64
59.66	325	23	0	-20.44	-165	-49.34	-158.15	1216.87	0.15	1075.51	5.4E-68	-0.76	-4.1E-68	0.07	3.7E-69	1	3.7E-69	0.2	0.0E+00	-3.74E-68
59.66	325	24	0	-20.44	-180	-50.78	-180.00	1216.87	0.15	1098.32	1.7E-69	-0.77	-1.4E-69	0.07	1.2E-70	1	1.2E-70	0.2	0.0E+00	-1.23E-69

Appendix N.

December 21. 2023

Latitude	Day	Hour	Tilt Angle	Declination Angle	Hour Angle	Altitude Angle	Azimuth Angle	Extraterrestrial flux (A)	Dimensionless factor (k)	Air mass ratio (m)	Direct Radiation (Ib)	Incidence Angle	Direct Radtion collector (Ibc)	Sky diffuse factor (C)	Diffuse radiation horizontal (Idh)	Diffuse radiation factor (Rd)	Diffuse radiation collector (Idc)	Albedo	Reflected radiation collector (Irc)	Total Solar radation (Ic)
59.66	355	1	0	-23.45	165	-52.29	157.16	1233.60	0.14	1121.41	3.3E-66	-0.79	-2.6E-66	0.06	1.9E-67	1	1.9E-67	0.8	0.0E+00	-2.4E-66
59.66	355	2	0	-23.45	150	-48.14	136.58	1233.60	0.14	1055.94	3.3E-62	-0.74	-2.5E-62	0.06	1.9E-63	1	1.9E-63	0.8	0.0E+00	-2.27E-62
59.66	355	3	0	-23.45	135	-42.15	118.95	1233.60	0.14	951.80	0.00	-0.67	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	4	0	-23.45	120	-35.11	103.78	1233.60	0.14	816.15	0.00	-0.58	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	5	0	-23.45	105	-27.61	90.25	1233.60	0.14	658.30	0.00	-0.46	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	6	0	-23.45	90	-20.09	77.64	1233.60	0.14	489.21	0.00	-0.34	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	7	0	-23.45	75	-12.91	65.39	1233.60	0.14	320.90	0.00	-0.22	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	8	0	-23.45	60	-6.42	53.08	1233.60	0.14	166.72	0.00	-0.11	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	9	0	-23.45	45	-0.90	40.45	1233.60	0.14	50.42	1.02	-0.02	-0.02	0.06	0.06	1	0.06	0.8	0.00	0.04
59.66	355	10	0	-23.45	30	3.32	27.35	1233.60	0.14	14.66	156.46	0.06	9.06	0.06	8.93	1	8.93	0.8	0.00	17.98
59.66	355	11	0	-23.45	15	5.98	13.81	1233.60	0.14	9.05	344.92	0.10	35.93	0.06	19.68	1	19.68	0.8	0.00	55.62
59.66	355	**12**	0	**-23.45**	**0**	**6.89**	**0.00**	**1233.60**	**0.14**	**7.97**	**401.73**	**0.12**	**48.19**	**0.06**	**22.92**	1	**22.92**	0.8	0.00	**71.12**
59.66	355	13	0	-23.45	-15	5.98	-13.81	1233.60	0.14	9.05	344.92	0.10	35.93	0.06	19.68	1	19.68	0.8	0.00	55.62
59.66	355	14	0	-23.45	-30	3.32	-27.35	1233.60	0.14	14.66	156.46	0.06	9.06	0.06	8.93	1	8.93	0.8	0.00	17.98
59.66	355	15	0	-23.45	-45	-0.90	-40.45	1233.60	0.14	50.42	1.02	-0.02	-0.02	0.06	0.06	1	0.06	0.8	0.00	0.04
59.66	355	16	0	-23.45	-60	-6.42	-53.08	1233.60	0.14	166.72	0.00	-0.11	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	17	0	-23.45	-75	-12.91	-65.39	1233.60	0.14	320.90	0.00	-0.22	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	18	0	-23.45	-90	-20.09	-77.64	1233.60	0.14	489.21	0.00	-0.34	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	19	0	-23.45	-105	-27.61	-90.25	1233.60	0.14	658.30	0.00	-0.46	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	20	0	-23.45	-120	-35.11	-103.78	1233.60	0.14	816.15	0.00	-0.58	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	21	0	-23.45	-135	-42.15	-118.95	1233.60	0.14	951.80	0.00	-0.67	0.00	0.06	0.00	1	0.00	0.8	0.00	0.00
59.66	355	22	0	-23.45	-150	-48.14	-136.58	1233.60	0.14	1055.94	3.3E-62	-0.74	0.00	0.06	0.00	1	1.9E-63	0.8	0.0E+00	-2.27E-62
59.66	355	23	0	-23.45	-165	-52.29	-157.16	1233.60	0.14	1121.41	3.3E-66	-0.79	-2.6E-66	0.06	1.9E-67	1	1.9E-67	0.8	0.0E+00	-2.4E-66
59.66	355	24	0	-23.45	-180	-53.79	-180.00	1233.60	0.14	1143.75	1.4E-67	-0.81	-1.1E-67	0.06	8.0E-69	1	8.0E-69	0.8	0.0E+00	-1.06E-67

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