TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE

ENGINEERING #15 **SPOKANE, WASHINGTON**
October 2009

DESIGN OF SOLAR POWERED WATER PUMP SYSTEMS

SUMMARY
Where conventional power supplies are unavailable or an alternative energy source is desired, solar energy can power water pumps. This technical note provides guidance for the design of solar powered water pump systems.

BACKGROUND
Solar powered water pumps are comprised of three basic components: solar panels, controller, and pump.

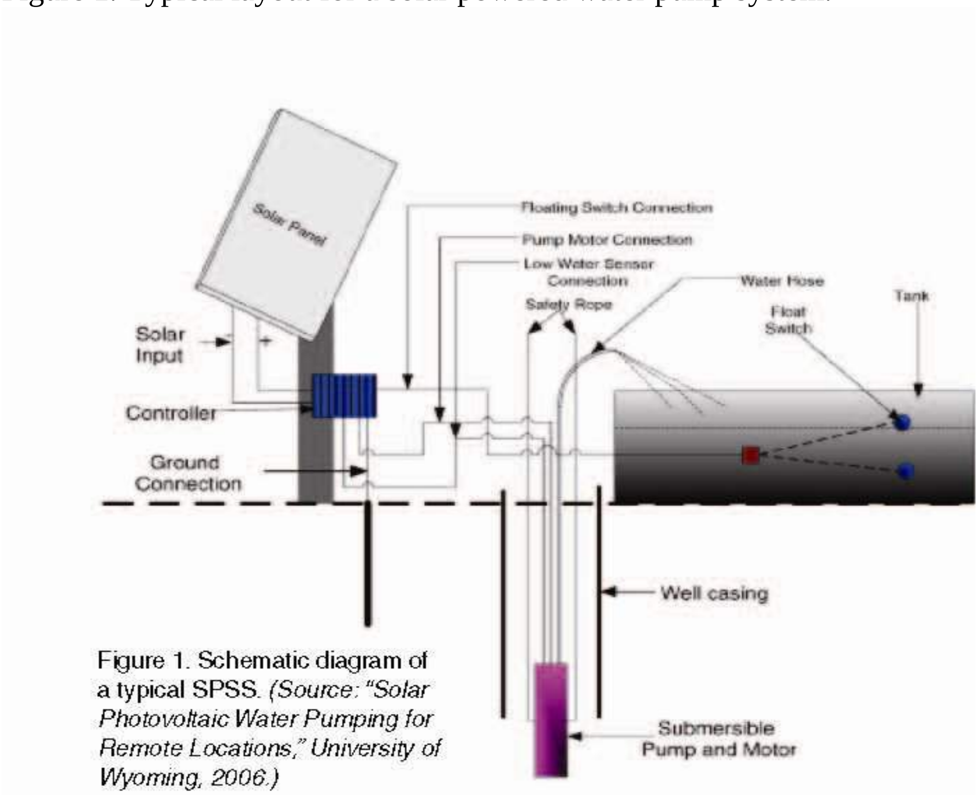
Solar panels
The type and number of solar panels required are a function of: the geographic location of the site, the rating of the solar panels, the volume of water needed, and the height differential between the water in the well and the receiving body on the surface.

Controller
The controller monitors the energy generated from the solar panels and the operation of the pump. It combines this information to more efficiently supply power for the operation of the pump.

Pump
A direct current submersible pump designed to operate under a range of voltages likely to occur during changing light conditions.

Figure 1 provides an example of a typical solar powered water pump system. This system consists of solar panels, a controller, a pump and a tank for water storage. This system will pump water only when there is sufficient solar radiation to power the pump. Some systems incorporate batteries to store excess solar power that can then be used to power the pump when there is no sunshine.

Figure 1. Typical layout for a solar powered water pump system.



DESIGN PARAMETERS

1. Quantity of water required (e.g. 100 animals @ 10 gallons/day = 1000 gallons/day).
2. Maximum feet of lift required from water well to trough or tank (e.g. trough elev. 100 ft – water surface elev. 40 ft = 60 ft of lift).
3. Installation location (e.g. Yakima, Yakima County, WA, 46.57 degrees North latitude).
4. Solar panel energy rating (i.e. wattage, voltage and amperage).

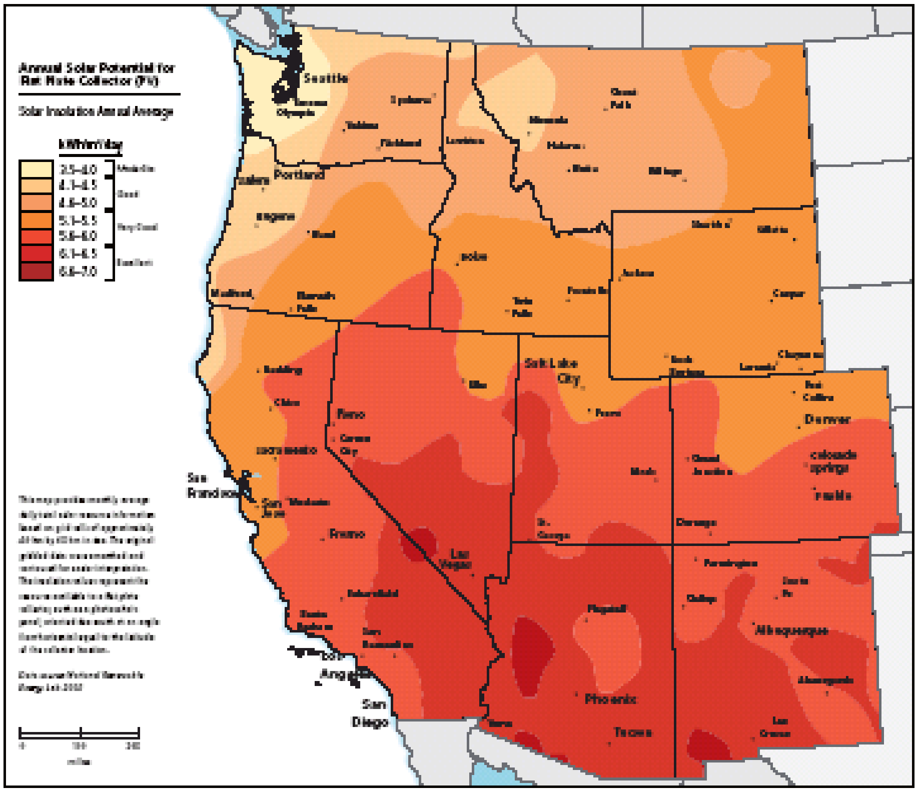
DESIGN OF SYSTEM COMPONENTS

<u>Solar Panels</u>

1. Solar Insolation

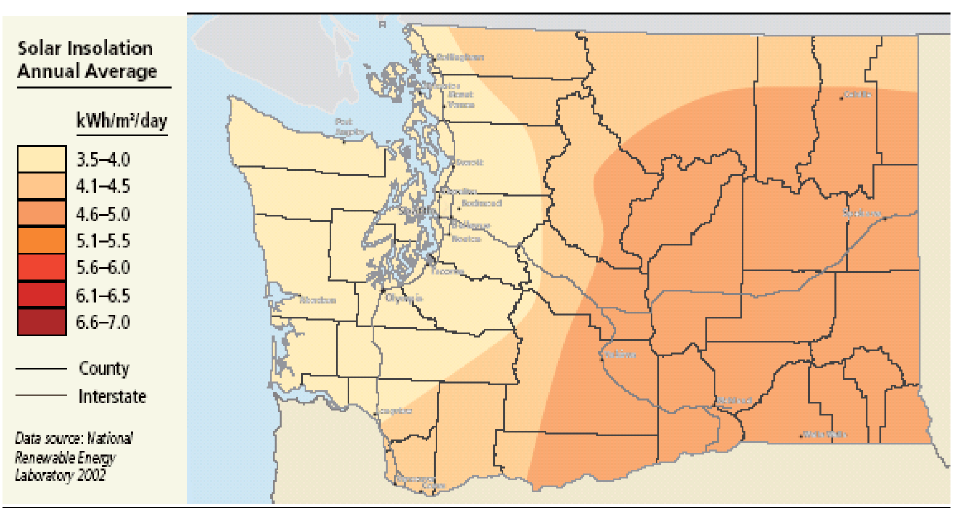
Solar panels receive solar radiation. Solar insolation is the measure of the amount of solar radiation received and is recorded in units of kilowatt-hours per square meter per day ($kWh/m^2/day$). Solar insolation varies by geographic location and time of year. Most reference maps (Figures 2 and 3) report annual average solar insolation, so for the northern hemisphere users can expect higher values in the summer months and lower values in the winter months.

Figure 2. Western US Average Annual Solar Insolation (kWh/m^2/day)



Source: *U.S. Department of Energy, National Renewable Energy Lab (NREL)*

Figure 3. Washington State Average Annual Solar Insolation (kWh/m^2/day)



The tables in Appendix A should be used for design of solar powered watering systems in Washington State. The designer can use the values from the five stations in Appendix A for interpolation of values for specific project sites.

Appendix A includes tables of average monthly insolation (solar radiation) values for five stations in Washington State. For example, the average monthly solar radiation ($kWh/m^2/day$) available in Yakima for a fixed plate collector facing south with a tilt angle of latitude minus 15 degrees would be:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
2.2	3.3	4.7	5.7	6.4	6.8	7.3	6.8	6.0	4.4	2.5	1.9	4.8

2. Solar power

Solar panels are commonly called photovoltaic (PV) panels and are rated in Watts (W_p) and direct current (DC) volts. The rating is measured at a maximum available power of 1000 W/m^2 of solar irradiance. For the panels, W_p can be found by multiplying volts times amps (W_p = volts x amps). By wiring multiple panels in parallel or in series, the designer can increase the available voltage or amperage.

When panels are wired in parallel, the amps are added and the voltage remains equal to the value of a single panel. When panels are wired in series, the voltage of each panel is added together, while the amps remain equal to the value from a single panel. For example, if the pump motor needs 36 volts and each panel produces 12 volts, three panels wired in series would be needed.

3. Orientation

The amount of solar radiation received is also a function of the orientation of the solar panel. Solar panels can either be set in a fixed position or can be allowed to rotate along one or two axes to track the path of the sun. If panels are mounted in a fixed position, the most efficient position for collecting summer sun is with the solar panels facing south with a tilt angle from horizontal equal to the latitude of the site less 15 degrees. For a site at 47 degrees north latitude, the most efficient tilt angle would be 47 – 15 = 32 degrees from horizontal.

One axis tracking (fixed tilt angle, tracks sun from east to west during the day) can increase solar collection by 25 to 40% in Washington State. Two axes tracking (changing tilt angle throughout the year, tracks sun from east to west during the day) provides a slight 2% increase in solar collection over one axis summer tracking.

4. Sunshine hours

The hours of available sunshine are used with the solar radiation data in Appendix A to size the solar panels for the given project. The actual hours of sunshine per day will be only a fraction of the clear day values shown in Table 1 as some days will be cloudy, foggy, overcast or otherwise obstructed due to changing weather conditions. Designers in western Washington shall apply a factor of 0.5 to the above clear day values (Table 2) and designers in eastern Washington shall apply a factor of 0.67 (Table 3) to adjust for local weather conditions.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours	8.7	10.0	11.6	13.3	14.9	15.7	15.3	14.1	12.3	10.6	9.1	8.3

Table 1. The mean hours of clear day sunshine per day at 47 degrees north latitude (center of Washington State) for the 15^{th} day of the month (Source: FAO Paper 56).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours	4.4	5.0	5.8	6.7	7.5	7.9	7.7	7.1	6.2	5.3	4.6	4.2

Table 2. Mean hours of sunshine for design of solar powered water pumps in **Western Washington.**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours	5.8	6.7	7.8	8.9	10.0	10.5	10.3	9.4	8.2	7.1	6.1	5.6

Table 3. Mean hours of sunshine for design of solar powered water pumps in **Eastern Washington.**

Controller

Controllers regulate the pump and monitor the voltage from the solar panels. Controllers can also accommodate connections from other power sources such as batteries, wind machines, and generators. The controller ensures the most efficient use of power to pump the most water. The controller will also vary the voltage and amperage to start the pump during low sun times and protect the motor from overheating. It is recommended to use controllers and pumps that are made by the same manufacturer to ensure compatibility.

Controllers may be configured in a number of different ways depending on the system needs and conditions where they will be installed. Caution should be used in researching the power source for the planned system to identify the correct controller.

Solar Pumps

Solar pumps are designed to use direct current (DC) from either solar panels or batteries. They can generally operate under a range of voltages from 24 to 300 volts DC, so are ideal for use under changing light conditions. During times of low sunlight, the solar panels will still produce electricity, but the pump will run at a lower speed reducing both the flow and lift produced.

Solar pumps are rated by flow, Q (measured in gallons per minute, gpm), lift (measured in feet, ft), and power required, W_p (measured in watts, W). The efficiency of the pump determines the power required to achieve the planned flow and lift. Establish solar pump specifications to match project site conditions.

The flow, Q, which the pump must produce, is a function of the amount of water needed (gallons/day) and the number of hours of sunshine per day to power the pump (hours/day).

For example:

Q = 3000 (gal/day) / 10 (hrs/day) of sunshine / 60 (min/hr) = 5 (gal/min)

Submersible solar pumps are used to lift a volume of water to a desired elevation. The change in height from the water surface elevation in the well to the discharge point (e.g. tank or trough) is a measure of the lift or feet of head pressure, H. The pump must develop enough force to overcome this head plus any friction loss.

H = 100 (ft) discharge elev. – 40 (ft) water surface elev. + friction loss = 60 (ft) + friction loss.

Siting

Access for upkeep and maintenance to the solar pump and panels is important to ensure a long life for the system. Locate the components of the system in sites where there is full sun to the panels but out of the way. Locate the solar panels to reduce the possibility of damage from vandalism and target practice. Clear sun view is important but placing the panels off of the top of a ridge should not drastically reduce the amount of water pumped.

EXAMPLE DESIGN

Livestock watering system

Determine the solar panel, controller and pump requirements for a typical livestock watering system, given the following design parameters:

- 1500 gallons of water per day pumped to a trough for storage
- 6-inch diameter well, with a static water level of 126 ft and total depth of 180 ft
- 5 gallon per minute maximum flow rate
- Trough located 100 ft from well, at the same elevation plus trough height of 3 ft
- 100 watt solar panels at a fixed angle of latitude minus 15 degrees
- Located in Okanogan County
- Water needed from May 1 to October 31

Solar insolation

Referring to the tables of solar radiation in Appendix A and interpolating from the available data for Spokane and Yakima, there are a minimum of 4.2 kWh/m^2/day of solar radiation available during the period from May 1 to Oct 31.

Sunshine hours

In order to provide 1500 gallons of water per day, a 5 gallon/minute pump must work for at least 5 hours per day ([1500 gallons/day]/[5 gallons/minute * 60 minutes/hour] = 5 hours/day). Using Table 3, the mean number of hours of sunshine available in October are 7.1 hours per day, so there are sufficient hours of available sunshine.

Lift or feet of Head Pressure

The well has a static water level of 126 ft which will be drawn down during pumping and will vary seasonally, but will not be less than 180 ft unless the well runs dry. The trough where the water will be stored is located 100 ft from the well and the inlet is 3 ft above ground surface. The maximum head equals 183 ft + 10% to accommodate friction loss. Apply a head of 200 ft as the pressure the pump will need to produce.

Pump selection

A solar pump must be selected from a manufacturer that can generate 200 feet of vertical lift at a rate of 5 gpm. A number of manufacturers can provide solar pumps that meet these criteria, but the one recommended can do this using only 450 watts of power.

Solar panels

For this design the solar panels must supply a minimum of 450 watts of power. The individual panels recommended are capable of generating 100 watts each, so a minimum of 5 panels are required, in order to get up to the 450 watts. The panels are wired in parallel to provide the additive amperage power needs of the pump.

However, if higher voltage is required the panels could be wired in series for additive voltage. Work with your dealer/supplier/electrician to ensure adequate voltage and wattage and capability of the pump and solar panels.

Controller

A controller from any manufacturer that meets the system needs could be used, but it is often best to select a controller made by the same manufacturer as the pump to ensure compatibility and proper functioning. The controller will adjust the power generated by the solar panels to the voltage and amperage requirements of the pump for the most efficient use of power.

REFERENCES

Bushermohle, M.J. and R.T. Burns, Solar-powered Livestock Watering Systems, PB1640-1M-1/00, Agricultural Extension Service, University of Tennessee, 16p.

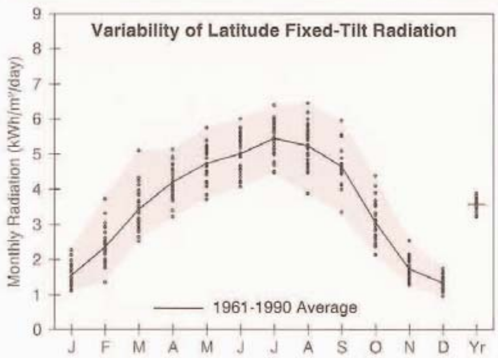
U.S. Department of Energy, National Renewable Energy Laboratory
http://www.nrel.gov

Renewable Energy Atlas of the West
Http://www.energyatlas.org

FAO Irrigation and Drainage Paper 56 - Crop evapotranspiration; Guidelines for computing crop water requirements; Table 2.7; Mean daylight hours (N) for different latitudes for the 15th of the month

Lorentz Solar Pumps and Panels
http://www.lorentz.de/

Appendix A



Olympia, WA

WBAN NO. 24227

LATITUDE: 46.97° N
LONGITUDE: 122.90° W
ELEVATION: 61 meters
MEAN PRESSURE: 1010 millibars

STATION TYPE: Secondary

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.0	1.7	2.8	4.0	5.0	5.6	5.9	5.1	3.8	2.2	1.2	0.9	3.3
	Min/Max	0.8/1.3	1.3/2.2	2.3/3.6	3.2/4.6	4.1/5.9	4.6/6.6	4.9/6.9	4.0/6.0	3.0/4.6	1.9/2.8	1.0/1.5	0.8/1.0	3.0/3.5
Latitude -15	Average	1.4	2.3	3.4	4.4	5.1	5.5	5.9	5.5	4.6	3.0	1.6	1.2	3.7
	Min/Max	1.1/2.1	1.4/3.4	2.5/4.9	3.4/5.3	4.0/6.1	4.4/6.5	4.8/6.9	4.1/6.7	3.4/5.9	2.1/4.1	1.2/2.3	0.9/1.6	3.3/4.0
Latitude	Average	1.5	2.4	3.4	4.2	4.7	5.0	5.5	5.2	4.6	3.1	1.7	1.3	3.6
	Min/Max	1.1/2.3	1.4/3.7	2.5/5.1	3.2/5.1	3.7/5.8	4.1/6.0	4.5/6.4	3.9/6.4	3.3/6.0	2.1/4.4	1.3/2.5	1.0/1.8	3.2/3.9
Latitude +15	Average	1.6	2.4	3.3	3.9	4.2	4.3	4.8	4.7	4.4	3.0	1.8	1.4	3.3
	Min/Max	1.1/2.4	1.3/3.8	2.4/5.0	2.9/4.8	3.3/5.1	3.5/5.2	3.9/5.6	3.5/5.8	3.1/5.7	2.0/4.4	1.3/2.6	0.9/1.8	3.0/3.6
90	Average	1.4	2.0	2.6	2.8	2.8	2.7	3.0	3.2	3.4	2.6	1.6	1.3	2.4
	Min/Max	1.0/2.2	1.1/3.4	1.9/4.1	2.1/3.4	2.2/3.3	2.3/3.1	2.6/3.4	2.5/4.0	2.4/4.4	1.7/3.8	1.1/2.4	0.8/1.7	2.2/2.7

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.2	2.1	3.5	5.0	6.3	7.1	7.7	6.7	5.2	2.9	1.4	1.0	4.2
	Min/Max	0.9/1.8	1.3/3.2	2.6/5.1	3.6/6.1	4.7/7.9	5.3/8.8	5.8/9.5	4.5/8.4	3.6/7.0	2.1/4.1	1.1/2.0	0.8/1.3	3.7/4.6
Latitude -15	Average	1.6	2.5	4.0	5.3	6.5	7.1	7.9	7.1	5.8	3.5	1.8	1.3	4.5
	Min/Max	1.1/2.3	1.4/4.1	2.8/6.1	3.8/6.6	4.7/8.2	5.2/8.9	5.8/9.7	4.7/9.1	3.9/8.0	2.3/5.1	1.3/2.7	0.9/1.7	4.0/5.0
Latitude	Average	1.7	2.6	4.1	5.2	6.2	6.8	7.6	7.0	5.9	3.6	1.9	1.4	4.5
	Min/Max	1.1/2.5	1.4/4.3	2.8/6.3	3.7/6.6	4.5/7.9	5.0/8.6	5.6/9.4	4.5/8.9	3.8/8.1	2.3/5.3	1.4/2.8	1.0/1.9	4.0/5.0
Latitude +15	Average	1.7	2.6	4.0	5.0	5.9	6.3	7.1	6.6	5.7	3.5	1.9	1.4	4.3
	Min/Max	1.1/2.6	1.4/4.4	2.8/6.2	3.5/6.3	4.2/7.5	4.6/8.0	5.2/8.8	4.3/8.5	3.7/7.9	2.2/5.3	1.4/2.9	1.0/2.0	3.8/4.8

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	1.7	2.7	4.1	5.3	6.6	7.3	8.0	7.2	5.9	3.6	1.9	1.5	4.7
	Min/Max	1.1/2.7	1.4/4.4	2.9/6.3	3.8/6.7	4.8/8.3	5.4/9.1	5.9/9.9	4.7/9.1	3.9/8.1	2.3/5.4	1.4/2.9	1.0/2.0	4.1/5.1

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	0.7	1.1	1.7	2.0	2.5	3.0	3.7	3.3	2.8	1.7	0.8	0.6	2.0
	Min/Max	0.2/1.4	0.3/2.6	0.8/3.3	1.0/2.9	1.3/3.8	1.5/4.5	2.1/5.2	1.4/4.7	1.2/4.5	0.6/3.0	0.5/1.5	0.3/1.0	1.6/2.4
1-Axis, N-S Horiz Axis	Average	0.4	0.9	1.8	2.5	3.3	3.9	4.8	4.2	3.2	1.5	0.6	0.4	2.3
	Min/Max	0.1/0.9	0.3/2.0	0.9/3.3	1.2/3.6	1.7/4.9	2.0/5.8	2.6/6.8	1.7/6.0	1.4/5.3	0.6/2.7	0.3/1.0	0.2/0.6	1.8/2.8
1-Axis, N-S Tilt=Latitude	Average	0.8	1.3	2.2	2.7	3.3	3.8	4.7	4.4	3.8	2.1	0.9	0.7	2.6
	Min/Max	0.2/1.5	0.4/3.0	1.1/4.3	1.3/3.9	1.7/4.9	1.9/5.6	2.6/6.7	1.9/6.3	1.6/6.3	0.8/3.7	0.5/1.6	0.3/1.0	2.1/3.1
2-Axis	Average	0.8	1.4	2.2	2.8	3.5	4.1	5.0	4.6	3.8	2.1	1.0	0.7	2.7
	Min/Max	0.2/1.6	0.4/3.1	1.1/4.3	1.4/4.0	1.8/5.2	2.1/6.1	2.8/7.2	1.9/6.5	1.6/6.3	0.8/3.8	0.5/1.7	0.3/1.1	2.1/3.2

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	3.3	5.1	6.6	8.6	11.8	14.8	17.2	17.4	14.4	9.8	5.8	3.4	9.8
Daily Minimum Temp	-0.2	0.4	0.9	2.3	5.0	8.0	9.6	9.7	7.1	3.8	1.7	0.1	4.0
Daily Maximum Temp	6.9	9.7	12.2	14.9	18.5	21.6	24.7	25.1	21.7	15.8	10.0	6.8	15.7
Record Minimum Temp	-22.2	-18.3	-12.8	-5.0	-3.9	-1.1	1.7	0.6	-3.9	-6.7	-18.3	-21.7	-22.2
Record Maximum Temp	17.2	22.8	24.4	30.6	35.6	38.3	39.4	40.0	36.7	32.2	23.3	17.8	40.0
HDD, Base 18.3°C	465	372	365	292	203	112	53	57	123	263	375	462	3142
CDD, Base 18.3°C	0	0	0	0	0	7	17	27	5	0	0	0	56
Relative Humidity (%)	88	85	80	75	73	72	71	72	78	85	88	89	80
Wind Speed (m/s)	3.3	3.2	3.3	3.4	3.3	3.1	2.9	2.8	2.7	2.7	3.3	3.1	3.1

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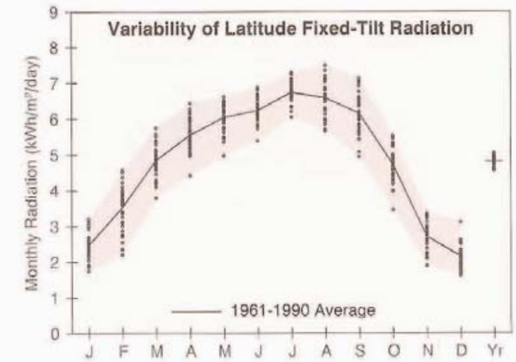


Yakima, WA

WBAN NO. 24243

LATITUDE: 46.57° N
LONGITUDE: 120.53° W
ELEVATION: 325 meters
MEAN PRESSURE: 978 millibars

STATION TYPE: Secondary

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.4	2.2	3.6	5.0	6.2	6.9	7.2	6.2	4.7	3.0	1.6	1.1	4.1
	Min/Max	1.2/1.6	1.7/2.5	3.0/4.1	4.1/5.6	5.3/6.8	6.0/7.7	6.5/7.8	5.4/6.9	4.0/5.3	2.5/3.3	1.3/1.8	1.0/1.3	4.0/4.3
Latitude -15	Average	2.2	3.3	4.7	5.7	6.4	6.8	7.3	6.8	6.0	4.4	2.5	1.9	4.8
	Min/Max	1.6/2.8	2.1/4.2	3.7/5.5	4.5/6.5	5.3/7.1	5.9/7.5	6.5/7.9	5.9/7.8	4.9/7.0	3.3/5.1	1.8/3.0	1.5/2.7	4.6/5.1
Latitude	Average	2.5	3.5	4.8	5.5	6.0	6.2	6.7	6.6	6.1	4.7	2.7	2.2	4.8
	Min/Max	1.7/3.2	2.2/4.6	3.8/5.8	4.4/6.4	5.0/6.6	5.4/6.9	6.0/7.3	5.7/7.5	4.9/7.1	3.5/5.5	1.9/3.3	1.6/3.1	4.6/5.0
Latitude +15	Average	2.6	3.6	4.7	5.1	5.3	5.3	5.8	5.9	5.9	4.8	2.8	2.3	4.5
	Min/Max	1.8/3.4	2.2/4.7	3.7/5.7	4.1/6.0	4.4/5.8	4.7/5.9	5.3/6.3	5.1/6.8	4.7/6.9	3.4/5.6	1.9/3.5	1.7/3.3	4.3/4.7
90	Average	2.5	3.2	3.8	3.7	3.4	3.2	3.5	4.0	4.5	4.1	2.6	2.2	3.4
	Min/Max	1.6/3.3	1.9/4.2	3.0/4.6	2.9/4.3	2.8/3.6	2.8/3.4	3.2/3.7	3.4/4.5	3.6/5.3	2.9/4.8	1.7/3.3	1.5/3.2	3.1/3.6

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.9	3.1	5.1	6.9	8.6	9.5	10.3	9.0	7.1	4.5	2.2	1.6	5.8
	Min/Max	1.4/2.4	1.9/4.0	4.0/6.0	5.3/8.0	6.9/9.7	7.9/11.0	8.9/11.5	7.6/10.6	5.5/8.4	3.2/5.4	1.6/2.7	1.3/2.2	5.4/6.2
Latitude -15	Average	2.5	3.9	5.9	7.5	8.9	9.6	10.5	9.6	8.2	5.6	2.9	2.2	6.5
	Min/Max	1.8/3.4	2.3/5.2	4.6/7.2	5.7/8.8	7.1/10.0	7.9/11.2	9.1/11.8	8.1/11.4	6.2/9.7	3.9/6.7	2.0/3.6	1.6/3.2	6.0/6.8
Latitude	Average	2.8	4.1	6.1	7.4	8.6	9.2	10.2	9.5	8.2	5.8	3.1	2.4	6.5
	Min/Max	1.9/3.7	2.4/5.5	4.6/7.3	5.6/8.8	6.8/9.7	7.6/10.8	8.8/11.4	7.9/11.2	6.3/9.8	4.0/7.0	2.1/3.9	1.7/3.5	6.0/6.8
Latitude +15	Average	2.9	4.2	6.0	7.1	8.2	8.6	9.6	9.0	8.1	5.8	3.2	2.5	6.3
	Min/Max	1.9/3.9	2.4/5.6	4.5/7.3	5.3/8.5	6.4/9.2	7.1/10.1	8.3/10.8	7.5/10.8	6.1/9.6	4.0/7.1	2.1/4.0	1.8/3.8	5.8/6.6

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	2.9	4.2	6.1	7.6	9.0	9.8	10.7	9.7	8.3	5.9	3.2	2.5	6.7
	Min/Max	1.9/3.9	2.4/5.6	4.6/7.3	5.7/8.9	7.2/10.1	8.1/11.5	9.3/12.1	8.1/11.5	6.3/9.8	4.1/7.1	2.1/4.0	1.8/3.8	6.2/7.1

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	1.4	2.2	3.0	3.5	4.4	5.0	5.8	5.2	4.5	3.4	1.7	1.3	3.5
	Min/Max	0.6/2.5	0.4/3.4	1.9/4.0	2.3/4.6	2.9/5.4	3.6/6.5	4.6/6.9	3.9/6.6	2.9/5.8	1.9/4.3	0.9/2.5	0.6/2.5	3.1/3.8
1-Axis, N-S Horiz Axis	Average	0.9	1.8	3.2	4.5	5.9	6.6	7.8	6.8	5.3	3.1	1.2	0.8	4.0
	Min/Max	0.3/1.6	0.4/2.8	2.1/4.2	2.8/5.7	4.0/7.3	4.7/8.7	6.1/9.3	5.2/8.8	3.3/6.9	1.7/4.1	0.6/1.8	0.4/1.5	3.5/4.4
1-Axis, N-S Tilt=Latitude	Average	1.5	2.6	4.0	4.9	5.8	6.4	7.6	7.1	6.3	4.2	1.9	1.4	4.5
	Min/Max	0.6/2.7	0.5/4.0	2.6/5.3	3.1/6.3	4.0/7.2	4.5/8.4	5.9/9.1	5.4/9.2	4.0/8.1	2.3/5.5	1.0/2.8	0.7/2.6	3.9/4.9
2-Axis	Average	1.7	2.7	4.0	5.0	6.2	6.9	8.1	7.4	6.3	4.3	2.0	1.5	4.7
	Min/Max	0.6/2.9	0.5/4.1	2.6/5.3	3.2/6.4	4.2/7.6	4.9/9.1	6.3/9.7	5.6/9.5	4.0/8.1	2.4/5.6	1.1/2.9	0.7/2.8	4.1/5.1

Average Climatic Conditions

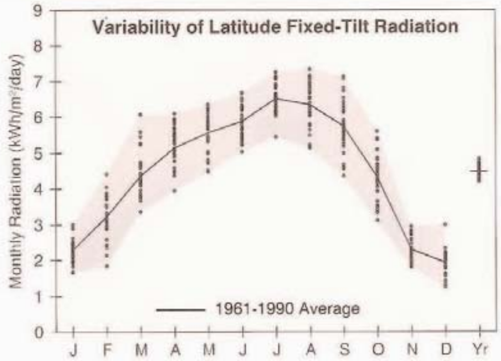
Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-1.3	2.4	6.1	9.7	13.9	18.1	21.1	20.6	15.9	9.9	3.7	-1.2	9.9
Daily Minimum Temp	-5.7	-3.1	-0.7	1.9	5.7	9.6	11.7	11.3	7.0	1.8	-1.7	-5.5	2.7
Daily Maximum Temp	3.1	8.0	12.9	17.3	22.0	26.6	30.4	29.8	24.9	18.0	9.1	3.1	17.1
Record Minimum Temp	-29.4	-31.7	-18.3	-6.7	-3.9	-1.1	1.1	1.7	-4.4	-11.7	-25.0	-27.2	-31.7
Record Maximum Temp	20.0	20.6	26.7	33.3	38.9	39.4	42.2	43.3	37.8	30.6	22.8	19.4	43.3
HDD, Base 18.3°C	608	445	379	260	142	50	11	21	94	260	440	606	3315
CDD, Base 18.3°C	0	0	0	0	4	43	95	90	22	0	0	0	254
Relative Humidity (%)	78	73	61	52	48	47	44	48	56	63	75	80	60
Wind Speed (m/s)	2.6	3.0	3.5	3.8	3.8	3.8	3.6	3.4	3.4	3.0	2.8	2.4	3.3

Spokane, WA

WBAN NO. 24157

LATITUDE: 47.63° N
LONGITUDE: 117.53° W
ELEVATION: 721 meters
MEAN PRESSURE: 932 millibars

STATION TYPE: Secondary



Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt ($kWh/m^2/day$), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.3	2.0	3.2	4.6	5.8	6.5	7.0	5.9	4.4	2.7	1.4	1.1	3.8
	Min/Max	1.0/1.6	1.5/2.5	2.7/4.2	3.8/5.3	4.8/6.5	5.7/7.4	5.9/7.7	5.0/6.8	3.7/5.2	2.2/3.2	1.2/1.6	0.8/1.4	3.7/4.1
Latitude -15	Average	2.1	3.0	4.2	5.3	6.0	6.4	7.0	6.6	5.7	4.0	2.1	1.7	4.5
	Min/Max	1.5/2.7	1.8/4.0	3.3/5.8	4.1/6.2	4.8/6.8	5.5/7.3	5.9/7.8	5.4/7.6	4.4/7.0	3.0/5.2	1.7/2.7	1.2/2.6	4.3/4.9
Latitude	Average	2.3	3.2	4.4	5.2	5.6	5.9	6.5	6.3	5.7	4.3	2.3	1.9	4.5
	Min/Max	1.7/3.0	1.8/4.4	3.4/6.1	3.9/6.1	4.5/6.3	5.0/6.7	5.4/7.3	5.2/7.3	4.4/7.1	3.1/5.6	1.8/3.0	1.3/3.0	4.2/4.8
Latitude +15	Average	2.4	3.3	4.3	4.8	4.9	5.1	5.6	5.7	5.5	4.4	2.4	2.0	4.2
	Min/Max	1.7/3.2	1.8/4.6	3.2/6.1	3.6/5.6	3.9/5.6	4.3/5.7	4.7/6.3	4.6/6.6	4.1/6.9	3.1/5.7	1.9/3.1	1.3/3.2	3.9/4.5
90	Average	2.3	3.0	3.5	3.4	3.2	3.1	3.5	3.9	4.3	3.8	2.2	2.0	3.2
	Min/Max	1.6/3.1	1.5/4.2	2.6/5.3	2.6/4.1	2.6/3.6	2.7/3.4	3.0/3.8	3.2/4.5	3.1/5.4	2.6/5.0	1.7/2.9	1.2/3.2	2.9/3.5

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis ($kWh/m^2/day$), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.8	2.8	4.6	6.4	7.9	8.9	10.0	8.7	6.6	4.1	1.9	1.4	5.4
	Min/Max	1.3/2.3	1.7/3.8	3.5/6.5	4.8/7.7	6.3/9.2	7.5/10.8	7.9/11.3	6.8/10.4	5.2/8.5	2.9/5.3	1.5/2.4	1.0/2.1	5.1/5.9
Latitude -15	Average	2.4	3.6	5.4	7.0	8.2	9.1	10.2	9.3	7.6	5.1	2.4	1.9	6.0
	Min/Max	1.6/3.1	1.9/5.0	4.0/7.7	5.1/8.4	6.4/9.5	7.6/10.9	8.0/11.6	7.2/11.2	5.7/9.9	3.5/6.8	1.9/3.2	1.2/3.0	5.6/6.5
Latitude	Average	2.5	3.7	5.5	6.9	8.0	8.7	9.9	9.2	7.7	5.3	2.6	2.1	6.0
	Min/Max	1.8/3.4	2.0/5.3	4.0/7.9	5.1/8.4	6.2/9.3	7.3/10.5	7.8/11.2	7.1/11.1	5.7/10.0	3.6/7.1	2.0/3.4	1.3/3.4	5.6/6.5
Latitude +15	Average	2.6	3.8	5.4	6.6	7.5	8.2	9.3	8.7	7.5	5.3	2.6	2.2	5.8
	Min/Max	1.8/3.5	2.0/5.4	3.9/7.9	4.8/8.1	5.8/8.8	6.8/9.9	7.3/10.6	6.7/10.6	5.5/9.8	3.6/7.2	2.0/3.5	1.4/3.6	5.4/6.3

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors ($kWh/m^2/day$), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	2.7	3.8	5.5	7.0	8.3	9.3	10.4	9.4	7.7	5.4	2.7	2.2	6.2
	Min/Max	1.8/3.6	2.0/5.4	4.1/7.9	5.2/8.5	6.5/9.7	7.8/11.2	8.2/11.9	7.3/11.3	5.7/10.0	3.7/7.2	2.0/3.5	1.4/3.6	5.7/6.7

Direct Beam Solar Radiation for Concentrating Collectors ($kWh/m^2/day$), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	1.2	1.8	2.6	3.1	3.8	4.5	5.5	4.9	4.1	3.0	1.3	1.0	3.1
	Min/Max	0.4/2.1	0.6/3.4	1.7/3.9	1.8/4.3	2.4/4.9	3.3/6.2	3.8/6.7	3.3/6.4	2.5/5.9	1.7/4.5	0.8/2.0	0.4/2.0	2.7/3.5
1-Axis, N-S Horiz Axis	Average	0.7	1.5	2.8	4.0	5.1	6.0	7.4	6.5	4.9	2.8	0.9	0.6	3.6
	Min/Max	0.2/1.3	0.5/2.7	1.7/4.2	2.4/5.4	3.3/6.7	4.5/8.3	5.0/8.9	4.4/8.6	3.1/7.1	1.5/4.2	0.5/1.4	0.3/1.1	3.1/4.0
1-Axis, N-S Tilt=Latitude	Average	1.3	2.2	3.5	4.4	5.2	5.8	7.3	6.8	5.7	3.8	1.5	1.1	4.0
	Min/Max	0.4/2.3	0.7/4.0	2.2/5.3	2.6/5.9	3.3/6.7	4.3/8.0	4.9/8.7	4.6/9.0	3.6/8.4	2.1/5.7	0.8/2.2	0.5/2.0	3.5/4.6
2-Axis	Average	1.4	2.2	3.5	4.5	5.5	6.3	7.8	7.0	5.8	3.9	1.6	1.1	4.2
	Min/Max	0.4/2.5	0.7/4.1	2.2/5.3	2.7/6.1	3.5/7.1	4.7/8.7	5.3/9.3	4.7/9.3	3.6/8.4	2.1/5.8	0.9/2.3	0.5/2.2	3.7/4.7

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-2.7	0.7	3.7	7.7	12.2	16.7	20.4	20.2	14.9	8.5	1.7	-2.3	8.5
Daily Minimum Temp	-6.2	-3.4	-1.3	1.5	5.5	9.6	12.4	12.4	7.7	2.2	-1.8	-5.7	2.7
Daily Maximum Temp	0.7	4.8	8.7	13.9	18.8	23.7	28.4	28.1	22.2	14.8	5.2	1.0	14.2
Record Minimum Temp	-30.0	-27.2	-21.7	-8.3	-4.4	0.6	2.8	1.7	-4.4	-12.2	-29.4	-31.7	-31.7
Record Maximum Temp	15.0	16.1	21.7	32.2	35.6	37.8	39.4	42.2	36.7	30.0	19.4	13.3	42.2
HDD, Base 18.3°C	653	493	453	318	191	77	17	31	124	305	498	641	3801
CDD, Base 18.3°C	0	0	0	0	0	27	82	89	22	0	0	0	221
Relative Humidity (%)	83	79	70	61	58	54	44	45	54	67	83	85	65
Wind Speed (m/s)	4.2	4.3	4.5	4.7	4.4	4.3	4.1	3.8	3.9	3.8	4.2	3.7	4.2

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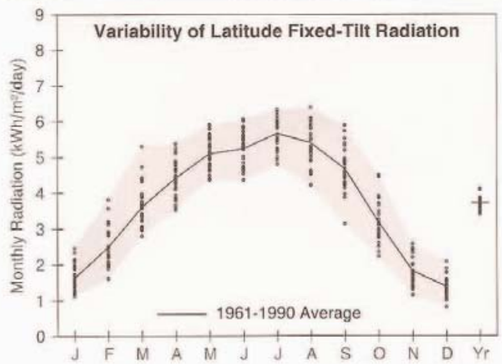


Seattle, WA

WBAN NO. 24233

LATITUDE: 47.45° N
LONGITUDE: 122.30° W
ELEVATION: 122 meters
MEAN PRESSURE: 1001 millibars

STATION TYPE: Primary

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.0	1.7	2.8	4.1	5.3	5.8	6.1	5.2	3.8	2.2	1.2	0.8	3.3
	Min/Max	0.8/1.2	1.2/2.1	2.4/3.6	3.5/4.8	4.6/6.1	4.8/6.7	5.2/6.7	4.2/5.9	2.9/4.5	1.8/2.8	0.9/1.4	0.6/1.0	3.2/3.6
Latitude -15	Average	1.5	2.3	3.5	4.6	5.4	5.7	6.1	5.6	4.7	3.0	1.7	1.3	3.8
	Min/Max	1.1/2.2	1.5/3.5	2.8/5.1	3.7/5.5	4.7/6.3	4.7/6.6	5.2/6.8	4.4/6.6	3.2/5.8	2.2/4.2	1.1/2.3	0.8/1.8	3.5/4.2
Latitude	Average	1.6	2.5	3.6	4.4	5.1	5.2	5.7	5.4	4.7	3.2	1.8	1.4	3.7
	Min/Max	1.1/2.5	1.6/3.8	2.8/5.3	3.5/5.4	4.4/5.9	4.4/6.1	4.8/6.3	4.2/6.4	3.1/5.9	2.2/4.5	1.1/2.6	0.8/2.1	3.4/4.1
Latitude +15	Average	1.7	2.5	3.5	4.1	4.5	4.5	4.9	4.9	4.5	3.2	1.8	1.4	3.5
	Min/Max	1.1/2.6	1.6/3.9	2.7/5.2	3.2/5.0	3.9/5.2	3.8/5.2	4.2/5.5	3.8/5.8	3.0/5.7	2.2/4.5	1.1/2.7	0.8/2.2	3.2/3.8
90	Average	1.5	2.2	2.8	3.0	3.0	2.8	3.1	3.4	3.4	2.7	1.7	1.3	2.6
	Min/Max	1.0/2.5	1.4/3.5	2.2/4.3	2.3/3.6	2.6/3.3	2.4/3.2	2.8/3.4	2.7/4.0	2.3/4.4	1.8/3.9	1.0/2.5	0.7/2.1	2.3/2.9

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.2	2.2	3.7	5.2	6.7	7.3	8.0	6.9	5.1	3.0	1.5	1.0	4.3
	Min/Max	0.9/1.8	1.5/3.3	2.9/5.4	4.1/6.3	5.3/8.2	5.8/9.1	6.1/9.0	5.0/8.4	3.4/6.6	2.1/4.2	0.9/2.0	0.7/1.4	3.8/4.8
Latitude -15	Average	1.6	2.7	4.2	5.6	6.9	7.3	8.2	7.3	5.8	3.6	1.9	1.4	4.7
	Min/Max	1.1/2.5	1.7/4.3	3.2/6.5	4.3/7.0	5.3/8.6	5.8/9.3	6.2/9.2	5.3/9.0	3.7/7.6	2.5/5.2	1.1/2.7	0.8/2.1	4.1/5.3
Latitude	Average	1.8	2.8	4.3	5.5	6.7	7.0	7.9	7.2	5.9	3.7	2.0	1.5	4.7
	Min/Max	1.2/2.8	1.8/4.6	3.3/6.7	4.2/6.9	5.1/8.3	5.5/8.9	5.9/8.9	5.2/8.8	3.7/7.7	2.5/5.5	1.1/2.9	0.8/2.3	4.1/5.3
Latitude +15	Average	1.8	2.8	4.2	5.3	6.3	6.6	7.4	6.8	5.7	3.7	2.0	1.5	4.5
	Min/Max	1.2/2.9	1.7/4.6	3.2/6.6	4.0/6.6	4.7/7.8	5.1/8.3	5.5/8.4	4.9/8.4	3.6/7.5	2.4/5.5	1.1/3.0	0.8/2.4	3.9/5.1

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	1.8	2.9	4.3	5.6	7.0	7.5	8.3	7.4	5.9	3.7	2.0	1.5	4.9
	Min/Max	1.2/2.9	1.8/4.7	3.3/6.7	4.3/7.0	5.4/8.7	5.9/9.5	6.3/9.4	5.3/9.0	3.8/7.7	2.5/5.5	1.1/3.0	0.8/2.4	4.2/5.5

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W	Average	0.9	1.4	1.9	2.3	3.0	3.3	4.0	3.5	2.9	1.8	1.0	0.8	2.2
Horiz Axis	Min/Max	0.4/1.8	0.6/2.9	1.2/3.8	1.3/3.3	1.5/4.3	1.7/4.9	2.3/5.1	2.0/4.7	1.4/4.2	1.0/3.2	0.3/1.7	0.3/1.5	1.6/2.6
1-Axis, N-S	Average	0.5	1.1	1.9	2.8	3.8	4.2	5.2	4.4	3.2	1.6	0.6	0.4	2.5
Horiz Axis	Min/Max	0.2/1.1	0.5/2.3	1.1/3.8	1.6/4.0	1.7/5.7	2.1/6.4	2.8/6.5	2.4/5.9	1.6/4.8	0.7/2.8	0.2/1.2	0.2/0.8	1.8/3.0
1-Axis, N-S	Average	0.9	1.6	2.5	3.1	3.9	4.1	5.1	4.7	3.9	2.2	1.1	0.8	2.8
Tilt=Latitude	Min/Max	0.4/2.0	0.7/3.4	1.4/4.9	1.8/4.4	1.7/5.7	2.0/6.2	2.8/6.4	2.6/6.3	1.9/5.7	1.1/3.9	0.3/1.9	0.3/1.5	2.0/3.3
2-Axis	Average	1.0	1.7	2.5	3.1	4.1	4.4	5.5	4.8	3.9	2.3	1.1	0.9	2.9
	Min/Max	0.4/2.1	0.7/3.5	1.5/4.9	1.8/4.5	1.8/6.0	2.2/6.7	3.0/6.9	2.7/6.5	1.9/5.7	1.1/4.0	0.3/2.0	0.3/1.6	2.1/3.5

Average Climatic Conditions

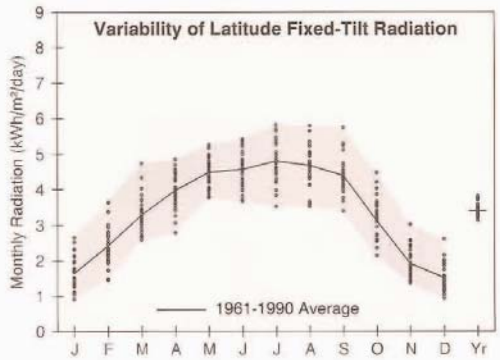
Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	4.5	6.4	7.6	9.6	12.8	16.1	18.4	18.6	15.9	11.6	7.4	4.7	11.1
Daily Minimum Temp	1.8	3.0	3.6	5.1	7.9	11.1	12.9	13.2	11.1	7.7	4.5	2.1	7.0
Daily Maximum Temp	7.2	9.7	11.5	14.0	17.7	21.1	24.0	24.0	20.7	15.4	10.3	7.3	15.2
Record Minimum Temp	-17.8	-17.2	-11.7	-1.7	-2.2	3.3	6.1	6.7	1.7	-2.2	-14.4	-14.4	-17.8
Record Maximum Temp	17.8	21.1	23.9	29.4	33.9	35.6	37.2	37.2	36.7	31.7	23.3	17.2	37.2
HDD, Base 18.3°C	429	334	334	263	171	80	32	36	87	210	328	422	2727
CDD, Base 18.3°C	0	0	0	0	0	12	36	45	13	0	0	0	106
Relative Humidity (%)	78	75	74	71	69	67	66	68	73	79	80	80	73
Wind Speed (m/s)	4.1	4.0	4.0	4.0	3.7	3.7	3.5	3.4	3.4	3.5	4.0	4.0	3.8

Quillayute, WA

WBAN NO. 94240

LATITUDE: 47.95° N
LONGITUDE: 124.55° W
ELEVATION: 55 meters
MEAN PRESSURE: 1010 millibars

STATION TYPE: Secondary



Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.0	1.6	2.6	3.7	4.7	5.1	5.2	4.5	3.5	2.1	1.2	0.8	3.0
	Min/Max	0.7/1.3	1.2/2.0	2.2/3.3	2.8/4.3	4.1/5.4	4.2/5.9	4.0/6.2	3.6/5.4	3.0/4.4	1.7/2.7	1.0/1.5	0.7/1.1	2.8/3.2
Latitude -15	Average	1.5	2.3	3.2	4.1	4.8	5.0	5.2	4.9	4.4	3.0	1.8	1.4	3.5
	Min/Max	0.9/2.3	1.4/3.3	2.6/4.6	2.9/5.0	4.1/5.6	4.0/5.9	3.8/6.3	3.7/6.0	3.5/5.7	2.1/4.2	1.3/2.7	0.9/2.3	3.2/3.8
Latitude	Average	1.6	2.4	3.3	4.0	4.5	4.6	4.8	4.7	4.4	3.1	1.9	1.5	3.4
	Min/Max	0.9/2.7	1.5/3.6	2.6/4.7	2.8/4.8	3.8/5.3	3.7/5.4	3.5/5.8	3.5/5.8	3.4/5.8	2.1/4.5	1.4/3.0	0.9/2.6	3.1/3.8
Latitude +15	Average	1.7	2.4	3.2	3.7	4.0	4.0	4.2	4.2	4.2	3.1	2.0	1.6	3.2
	Min/Max	0.9/2.8	1.4/3.7	2.5/4.7	2.5/4.5	3.3/4.6	3.2/4.7	3.1/5.1	3.2/5.3	3.2/5.5	2.1/4.5	1.4/3.2	0.9/2.8	2.9/3.6
90	Average	1.6	2.1	2.6	2.7	2.7	2.5	2.7	3.0	3.2	2.6	1.8	1.5	2.4
	Min/Max	0.8/2.7	1.2/3.4	2.0/3.9	1.9/3.3	2.3/3.0	2.1/2.9	2.1/3.2	2.3/3.6	2.5/4.3	1.7/3.9	1.2/3.0	0.8/2.7	2.2/2.8

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	1.3	2.1	3.4	4.7	5.9	6.3	6.5	5.8	4.9	2.9	1.5	1.1	3.9
	Min/Max	0.8/1.9	1.3/3.1	2.6/4.8	3.1/5.9	4.9/7.2	4.9/7.6	4.6/8.3	4.2/7.4	3.7/6.7	2.0/4.2	1.2/2.3	0.8/1.7	3.5/4.3
Latitude -15	Average	1.7	2.7	3.9	5.1	6.0	6.3	6.6	6.2	5.5	3.6	2.0	1.5	4.3
	Min/Max	0.9/2.7	1.5/4.1	3.0/5.7	3.2/6.4	4.9/7.5	4.8/7.8	4.6/8.5	4.3/8.0	4.1/7.7	2.3/5.3	1.4/3.2	0.9/2.6	3.9/4.8
Latitude	Average	1.8	2.8	4.0	5.0	5.8	6.0	6.4	6.1	5.6	3.7	2.1	1.6	4.2
	Min/Max	0.9/3.0	1.5/4.3	3.0/5.9	3.2/6.3	4.7/7.3	4.6/7.4	4.4/8.2	4.2/7.9	4.0/7.8	2.4/5.5	1.5/3.5	1.0/2.9	3.8/4.9
Latitude +15	Average	1.8	2.8	3.9	4.7	5.5	5.6	6.0	5.7	5.4	3.7	2.2	1.7	4.1
	Min/Max	0.9/3.1	1.5/4.4	2.9/5.8	3.0/6.1	4.4/6.8	4.2/6.9	4.1/7.7	4.0/7.5	3.9/7.6	2.3/5.5	1.5/3.6	1.0/3.1	3.7/4.7

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	1.9	2.8	4.0	5.1	6.1	6.5	6.8	6.2	5.6	3.7	2.2	1.7	4.4
	Min/Max	0.9/3.2	1.5/4.4	3.0/5.9	3.3/6.4	5.0/7.6	4.9/7.9	4.7/8.7	4.4/8.1	4.1/7.8	2.4/5.6	1.5/3.6	1.0/3.2	4.0/5.0

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	0.9	1.4	1.7	2.0	2.5	2.7	3.0	2.8	2.7	1.9	1.1	0.9	2.0
	Min/Max	0.3/2.0	0.5/2.8	0.9/3.2	0.9/3.1	1.5/3.7	1.2/3.9	1.5/4.5	1.3/4.2	1.5/4.4	0.8/3.3	0.5/2.3	0.3/2.2	1.7/2.5
1-Axis, N-S Horiz Axis	Average	0.6	1.1	1.8	2.5	3.2	3.4	3.8	3.5	3.1	1.7	0.7	0.5	2.2
	Min/Max	0.2/1.2	0.4/2.2	1.0/3.2	1.1/3.9	2.0/4.8	1.7/5.0	2.0/5.9	1.6/5.3	1.7/5.1	0.7/3.0	0.3/1.5	0.2/1.2	1.9/2.7
1-Axis, N-S Tilt=Latitude	Average	1.0	1.6	2.3	2.8	3.2	3.3	3.8	3.7	3.7	2.4	1.2	1.0	2.5
	Min/Max	0.3/2.2	0.6/3.3	1.3/4.2	1.2/4.3	1.9/4.8	1.6/4.8	1.9/5.8	1.8/5.6	2.0/6.1	1.0/4.2	0.6/2.5	0.3/2.2	2.2/3.2
2-Axis	Average	1.1	1.7	2.3	2.8	3.4	3.6	4.0	3.8	3.7	2.4	1.3	1.0	2.6
	Min/Max	0.3/2.3	0.6/3.4	1.3/4.2	1.2/4.3	2.1/5.0	1.8/5.2	2.1/6.2	1.8/5.8	2.0/6.1	1.0/4.2	0.6/2.7	0.3/2.4	2.3/3.3

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	4.4	5.6	6.3	7.9	10.5	13.0	14.9	15.2	13.7	10.2	6.7	4.6	9.4
Daily Minimum Temp	0.9	1.6	1.8	2.9	5.4	8.1	9.7	9.8	7.9	5.2	2.9	1.3	4.8
Daily Maximum Temp	7.8	9.5	10.8	12.8	15.5	17.9	20.1	20.6	19.4	15.2	10.5	7.9	14.0
Record Minimum Temp	-13.9	-11.7	-7.2	-4.4	-1.7	0.6	3.3	2.2	-2.2	-4.4	-15.0	-13.9	-15.0
Record Maximum Temp	18.3	22.2	21.7	28.3	33.3	35.6	36.1	37.2	36.1	28.3	20.6	17.8	37.2
HDD, Base 18.3°C	432	358	374	313	243	160	107	100	142	252	348	426	3254
CDD, Base 18.3°C	0	0	0	0	0	0	0	3	0	0	0	0	3
Relative Humidity (%)	87	85	83	81	81	82	82	84	83	87	88	89	84
Wind Speed (m/s)	4.6	4.3	4.1	3.7	3.4	3.2	3.1	2.8	3.0	3.6	4.2	4.2	3.7