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Solar-Weather Station Design Proposed for a Solar Radiation and Weather Conditions Measurements with Objective to Obtain Input Data for an Intended Photovoltaic Power Plant at the Stillwater Site in Nevada, USA

A Master Thesis submitted for the degree of
“Master of Science”

Supervised by
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Bratislava, SLOVAKIA
2009

Affidavit

I, Karol Galek, hereby declare

1. that I am the sole author of the present Master Thesis, "Solar-Weather Station Design Proposed for a Solar Radiation and Weather Conditions Measurements with Objective to Obtain Input Data for an Intended Photovoltaic Power Plant at the Stillwater Site in Nevada, USA", 55 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, ________________ ____________________________

Date Signature

ABSTRACT

In respect to Enel NA's latest activities in a field of solar energy are several localities under evaluation. Stillwater in Nevada is one of the most developed sites where a solar-weather station will be installed. The design of the station and evaluation of solar radiation values from two sources are the main topics of my thesis.

As already mentioned, the first task regarding to the site conditions was the evaluation and comparison of existing solar data from various sources based on available information from ground based meteorological stations and satellite measurements as well.

The core question of the thesis was focused on a selection of measurement instruments, their parameters, prices and limits. In connectivity to the measurement instruments and solar weather station its self, several questions about compatibility, powering, and data transmission arose.

An important issue was also the placing of the station within a parcel with a size of 240 acres with respect o several factors, which can influence the exactness of measurement, e.g. vapor from the geothermal power plant near by, dusty roads, flora et al.

All of the questions and tasks were evaluated and elaborated very deep in detail with the most important results as follow:

- All sensors and instruments are 100% compatible with data logger;
- Some of the sensors and instruments can be applied on Stillwater site with limitations only;
- The installed rechargeable battery sources sufficient current for the solar-weather station;
- The used PV panel can easily provide sufficient current for the system;
- The data transmission is design as fully automated system;
- None of the installed sensors or instruments required any periodic adjustment;
- The design and localization of the solar-weather station within the parcel was proposed with only least influence of environment on the measurement.

However the primary purpose for the design of this solar-weather station was to obtain input data for an intended photovoltaic power plant at the Stillwater site, the outputs can be used also as a regular weather data for any others activities in the area.

CONTENT

Introduction

After termination of my previous employment in Slovakia, where I worked for three years in a company involved in a development of renewable energy projects, I got a job opportunity in the USA in the same field for a company Enel North America, Inc. (Enel NA), a subsidiary of Enel S.p.A.

Enel NA is one of leading owners and operators of renewable energy projects in North America, with a presence in 20 U.S. states as well as three Canadian provinces. Enel NA has a uniquely diversified renewable energy portfolio, generating electric power from hydropower, wind, biomass, and geothermal.

The Enel NA's latest activity in the field of renewable energy sources is focused on solar power projects on several possible locations. One of these projects is located in Nevada, approx. one hour drive on east from Reno, near by the Stillwater geothermal power plant.

The solar project is based on availability of 240 acres of unexploited land at the Stillwater site (Fig.1) owned by Enel NA, good solar radiation conditions, idle transmission capacity and existing infrastructure.

The first task in relation to this project was to obtain the values of solar radiation from various sources using data from satellites and ground based meteorological stations around.

After approval of location suitability from external data the next task was to build there an own complex solar-weather station for a long term observation of selected parameters to get the most exact and latest values for energy production calculations:

- Total solar radiation
    - Horizontal
    - Tilt by 20°
- Direct radiation
- Temperature
- Wind speed
- Wind direction
- Precipitation
- Humidity

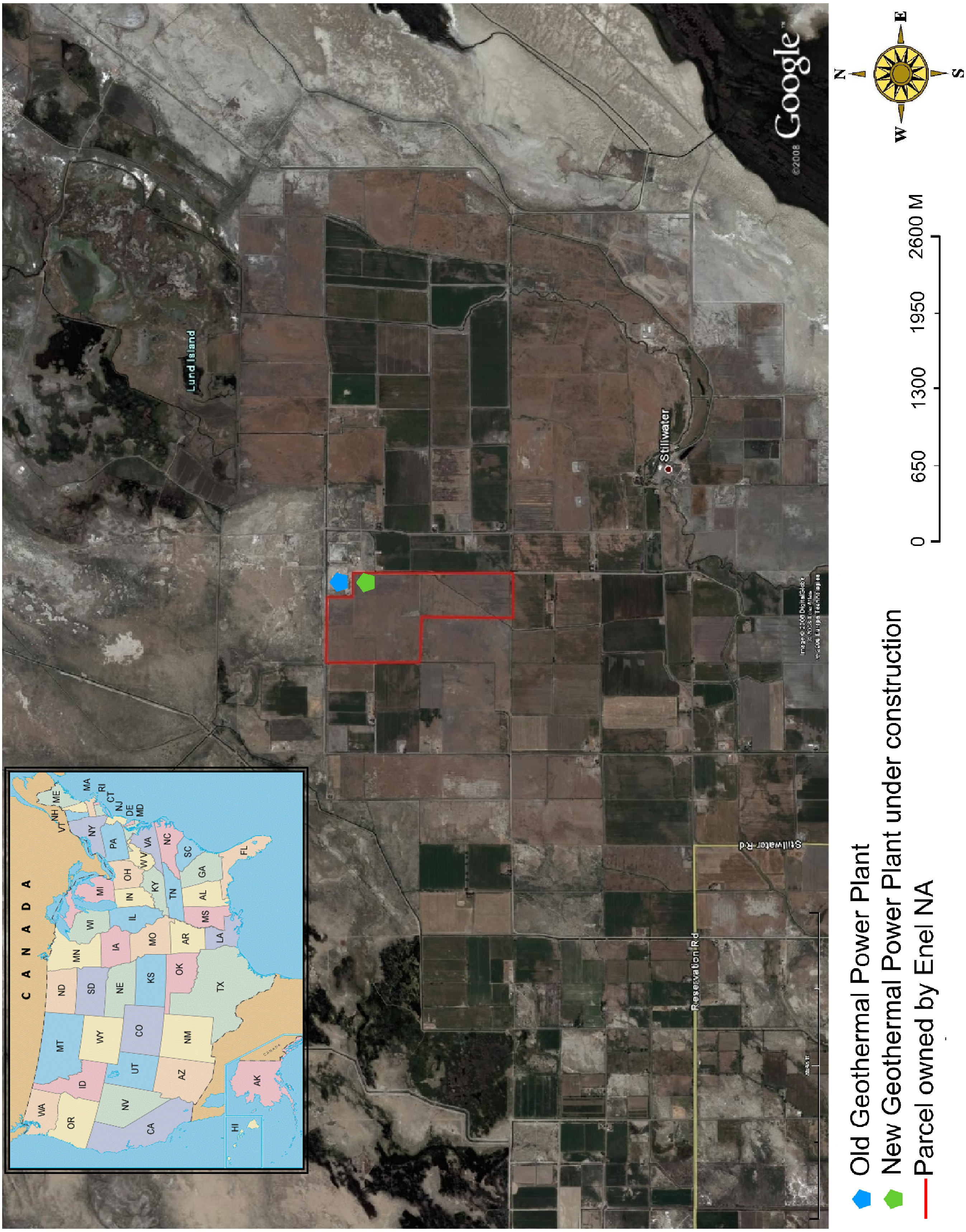


Fig. 1 Stillwater site in Nevada, USA and the parcel owned by Enel North

Seeing that the solar-weather station will be placed within a parcel out of any residential areas, the existing infrastructure is very poor. Powering and data transmission should be for this reason automated and independent as much as possible. However some access roads are available, the maintenance of the instruments and equipments was also designed only on infrequent basis.

1.1 Motivation

Based on my experience with development of projects with focus on geothermal and wind energy, I was really delighted for the opportunity to be a part of a team, which is responsible for the development phase of a solar project with utilization of photovoltaics.

An enthusiastic team and a lot of willingness to bring this project to a successful end were good assumptions for the start. The first task in line was to evaluate and compare the solar radiation data from various sources and afterwards to build an own solar-weather station for a measurement of selected parameters directly on site.

After definition the selection criteria, main parameters and desired accuracy of measurement the assignment was delegated to me. Whereas nobody in the team was really experienced in the field of the solar and weather instruments, the imposed task was at the same time also a big challenge and opportunity to learn something new.

The process of resolution was very complex and included a visit at the locality, station design, dimensioning as well as order of the instruments. However this seems to be a quite easy assignment, the next proceeding opened up several tricky questions, those solving required sometimes sophisticated solutions.

The best part of the assignment is the opportunity to verify the results directly on the locality during the construction as well as in the operation of the solar-weather station. Unfortunately this part was processed already without my presence in December 2008.

1.2 Core objective, the core question, major derived questions

The main objective of my thesis, as I mentioned already, was focused on the design of the solar-weather station. This objective brought immediately from the start several core questions. The questions arose from four main attributes (Fig. 2):

- Instruments – which are the proper instruments for my solar-weather station and how much it will be?
- Power – how much power will I need for the instruments and where the energy will come from?
- Data – how can I record the measurement data and how it will be transmitted to me?
- Site – what is the best situation of the solar-weather station within the parcel and what are the obstacles which should be avoided?

During the preparation phase of the project several criteria for instruments selection were defined:

1. Range limits and accuracy for weather and solar sensors;
2. Instruments compatibility with the data logger must by 100%;
3. Negligible or low energy consumption of the instruments during processing and also in stand-by mode;
4. Each instrument incl. data logger and modem must be suitable for the desert conditions at the Stillwater site;
5. The instruments should be maintenance free as much as possible without any requirements for adjustment.

Seeing that these criteria are applicable for the instruments and all of the instruments together will create one solar-weather station, several questions arose and some criteria for sizing, locating, security and accessibility of the station were also defined:

1. The station must be as complex as possible with ability to measure all of the parameters as defined, preferably one parameter – one instrument

2. The next criteria arose in connectivity with powering of the solar-weather station. Because of localization of the station in the middle of the field, out of any buildings and therefore also out of a connection to the electricity, several powering options were assumed:

   a) Electric power supply with a new constructed electric line,
   b) Electric power supply using alkaline batteries,
   c) Electric power supply using rechargeable batteries and a solar panel for the battery charging.

3. Seeing that the solar-weather station was planned to be automated as much as possible, without any manpower needs, with maximal four visits per year, an another question was about data recording and data transmission. For the data recording was reviewed a number of data-loggers from various manufacturers with different attributes, while for the data transmission were considered only two scenarios:

a) Manual download;
b) Data transmission via cellular network.

4. However the question regarding the selection of instruments was solved by the definition of parameters which should be measured and the accuracy and range limits, in the next process, several equipments were chosen or changed just in order to comply with the financial limit, which was regulated by a limit of $15.000,-.

5. The last core question around the solar-weather station was about the proper positioning and protection against animals and vandals. The parcel owned by Enel North America has 240acres and only 10acres are used for the new geothermal power plant. The residual area is ideally available for the photovoltaic power plant. The planned solar-weather station should cover only 43,56m² (0,010764acres) and can be basically placed wherever in the space, with respect to barriers and obstacles created from the environment or buildings.

The final output of this work is a set-up scheme of instruments and a solar-weather station design with localization in terrain. One component part is also protection of the solar weather station.

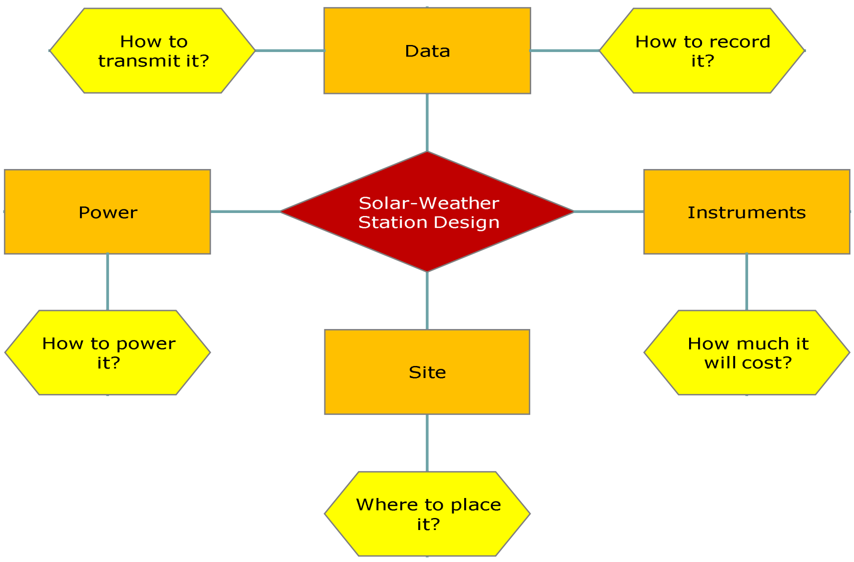


Fig. 2 Main attributes of the solar-weather station and the major derived questions

1.3 Structure of work

The working process applied for elaboration of this thesis (Fig. 3) was in coincidence with the structure of work used for the processing during the preparation phase for the development and design of the solar-weather station during my work session at Enel North America.

The first request came from my superior fellow servant Alberto Iliceto, who defined the main parameters which should be measured at the Stillwater site in Nevada and in the next process coordinated all of the performed procedures.

The first step in the process was the site analysis which defined the horizontal solar conditions at the locality using a preliminary evaluation based on the solar irradiance data from the National Solar Radiation Database (NSRDB) and produced by the NREL. These data were compared with the NASA-SSE data sets.

The on-site analysis was performed on 6^{th} of August 2008 during my business trip to our Reno-office in Nevada. The analysis was based on the in situ description of obstacles, shielding barriers, environment, infrastructure and panoramic photography documentation.

The next step after my arrival to our headquarter in Andover, Massachusetts was the proper selection of solar and weather instruments. In the next process several instruments were changed or the setup was modified in accordance to the other requirements described in other parts of this thesis.

The most important instruments into the solar-weather station scheme were the instruments for the data recording and transmission. For the data recording was selected a data-logger from a list of manufacturers following the required parameters. The data transmission was a little bit more complicated task, however on the location are present three cellular providers. The problem was, that none of them was able to confirm at 100% if the coverage is available for the data service also. For this reason, two options, manual download and automatic data transmission were considered.

After selection of the measurement and data recording and transmission instruments, the power demand was calculated and proper power supply selected. Considered were two options, grid connected, and autonomous solution.

After the process of instruments selection, the next step was to design the whole instruments together, find an adequate positioning at the location and suggest a protection of the instruments against animals and vandals.

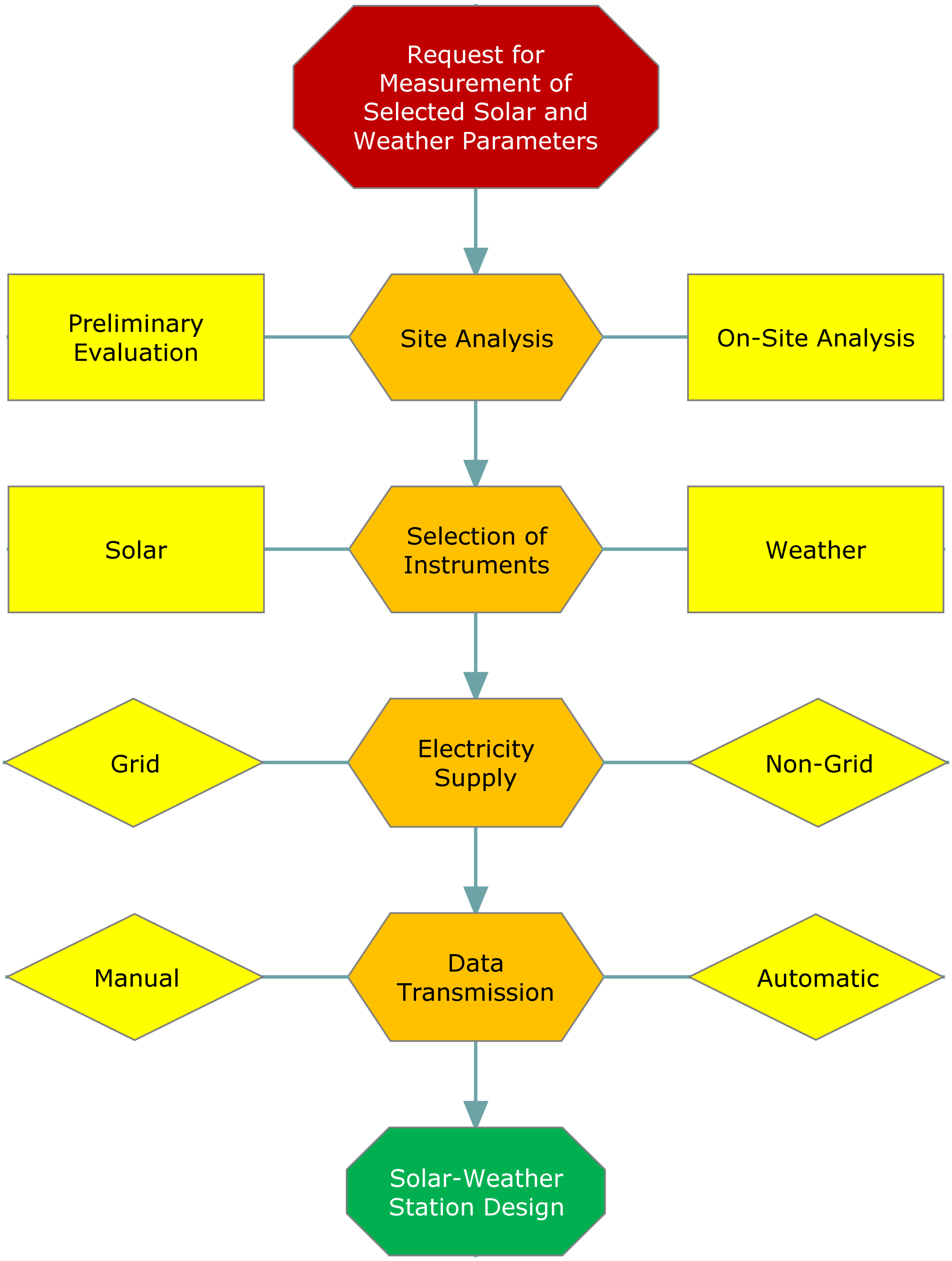


Fig. 3 Structure of the applied working processes

2 Background stories

However this thesis is mostly oriented on practical utilization of the technical background behind the topic, along with questions about connection, design or placing of the solar weather station sometimes some other technical and “non-technical” complications arose.

The very first “non-technical” request, with direct impact on the technical solution started up in the moment, when we were trying to find somebody, who will take care about the proposed shadow ring for one of our pyranometers. The shadow ring needs to be adjusted every 10 days, but nobody at the Stillwater site was able to do it. In the same moment we realize, that the same problem will probably arise in a case of manual downloading of data, which was also under consideration. For this reasons, the weather station was in the next process always considered as autonomous as possible.

Another complication arose in connection with the data transmission. Although at the location of interest are three cellular providers present, after direct query about a data transmission, just one of them was able to confirm this ability. Due to this information was ordered a digital modem assigned for their network and the technical specifications were sent for approval. Surprising in a negative meaning was the subsequent answer from the provider with explanation, that they are really able to transfer the data on the site, but only via partner operator and the specified modem is not compatible with the partner network. The only feasible solution was a modem from them. Unfortunately this modem was not compatible with the selected data-logger. The resolution of this problem brought our colleague who visited the site and tried successfully the data transmission via other cellular provider, which before denoted this area as area without signal.

Those complications seems to be maybe only marginal, but in the final effect their resolution consumed sometimes more time than other procedures directly connected with the process of the solar-weather station design. One another example originated in a process of our bank credit approval, which was asked by one of the suppliers. The supplier sent the inquiry to our bank via fax, but dialing a regular phone number. This mistake caused two weeks delay in the delivery of instruments.

3 Description of method of approach applied

The practical purpose of this thesis with a technical background allows us to utilize only a direct method of approach based on a phased collection of information about instruments and the environment assigned for installation of the solar-weather station.

Before determination which parameters should be measured was important to know, which parameters are for the area already known, and what are the average figures for each parameter. With this knowledge was quite easy to figure out which parameters should be measured more precise and what will be the expected range of measured values.

After determination of parameters came the instruments selection on line. Several manufacturers and suppliers were asked for the technical specifications and quotes. The most important point was the compatibility of the selected instruments with the data-logger. This inquiry was verified in cooperation directly with the manufacturer of the data-logger in a process of the instrument by instrument comparison. Other criteria already described in part 1 of this thesis were evaluated for each instrument separately and in final decision phase only suppliers within the defined range and accuracy were considered.

For a decision regarding the data transmission it was necessary to contact the local cellular network providers and to designate one with the best signal coverage or to find a local person who will download the measured data manually.

The functionality of the data-logger as well as modem is on the other hand dependent from the accurate power supply. To determine the solar-weather station power consumption was important to calculate the consumption of the individual instruments in regard to a logging frequency and specific requirements for the instruments functioning, for example heating of the pyranometer SPN1. In the second step a source for this demand must be found and dimensioned.

For the solar-weather station design was the surrounding environment and the possible influence on the single instruments advised. Also the individual equipments were placed with a minimum or none bilateral interaction. The same method was applied for the fencing, poles and wires dimensioning. For those results was applied a shadow analysis using the solar curves. Shading from obstacles in surroundings was determined in a process of the on-site analyses.

3.1 Stillwater Site

The Stillwater site is located in the USA, state Nevada, Churchill County, 12 miles northeast of the city Fallon, Nevada, in Townships 19 and 20 North and Ranges 30 and 31 East, Nine miles of paved road leading from U.S. Highway 50 provides access to the project site.

The Stillwater area is on smooth, level flood plains and low terraces. Slopes are 0 to 2 percent. Elevation ranges from 1,160 to 1,220 meters, Average annual precipitation is 10 to 15 centimeters. Growing season is about 130 days. This area was periodically inundated during the Pleistocene. Valley fill consists of extremely thick lake-laid materials interwoven with alluvial fill and Aeolian materials.

The majority of the land in the project vicinity consists of irrigated crops and irrigated pasture. Natural vegetation consists primarily of the salt desert scrub vegetation type. Evatz/Teplow (1987)

The Enel NA is owner of 240 acres in one parcel on the Stillwater site and has all of the surface rights except of surface water rights. On the parcel is located only one object, the new geothermal power plant, with occupancy of approximately 10 acres. The proposed 2 MW photovoltaic power plant should be placed on the south of the new power plant and should occupy additional 15 acres.

3.1.1 Preliminary Evaluation of horizontal solar radiation

The preliminary evaluation is based on the horizontal and tilted solar irradiance data produced by the National Renewable Energy Laboratory's (NREL) and compared with the NASA-SSE data (Surface Meteorology and Solar Energy program (Fig. 4). For the comparable data outputs was the PV SYST 4.36 employed.

NREL

Data files of Typical Meteorological Year (TMY) are available for 1020 stations in the USA. These data sets are derived from the National Solar Radiation Database (NSRDB) and produced by the NREL.

TMYs are data sets of hourly values of solar radiation and meteorological elements. They are juxtapositions of months or periods of real data, chosen in the multi-year data set in such a way that they represent a typical 1-year period. Marion/Urban (1995)

Formerly available as TMY2 (239 stations, 1961-1990 data), since 2008 this database has been extended to TMY3 (1020 stations, 1991-2005 data). These new TMY3 are base on more recent and accurate data. For the evaluation of the Stillwater site were data from Fallon NAAS (2000 -2005), the TMY3 set used. Wilcox/George/Myers (2008)

NASA

NASA SSE are monthly data, average of 1983-1993 satellite measurements, provided for any cell in a grid of 1°x1° over the world (111km x 111km·cos(Lat)).

In contrast to ground measurements, the SSE data set is a continuous and consistent 10-year global climatology of insolation and meteorology data. It is derived from several databases, including "Goddard Earth Observing Systems (GEOS-1), the International Satellite Cloud Climatology Project (ISCCP D-1), from data of the Geostationary and Polar Satellites for Environmental Observation (GOES and POES), the European Geostationary satellite Meteosat, and others.

Although the SSE data within a particular grid cell are not necessarily representative of a particular microclimate, or point, within the cell, the data are considered to be the average over the entire area of the cell. For this reason, the SSE data set is not intended to replace quality ground measurement data. Its purpose is to fill the gap where ground measurements are missing, and to augment areas where ground measurements do exist.

The accuracy of Satellite measurements has been evaluated using numerous ground-based measurements. Although the reliability of these ground measurements themselves is not always well assessed, the NASA estimates that the RMS Error on monthly values is around 13-16%, and the Mean Bias Error (MBE) lies from -2% to 0.7%. Whitlock et al. (2004)

The difference between the global irradiation values from NREL (Fig.4) and NASA (Fig.5) were 101.2 kWh/m2 per year by the horizontal measurement (Fig. 6) in behalf of NREL, the difference between tilted global irradiations (Fig. 7) was even more – 138,1 kWh/m2 in a year.

After derivation of diffuse irradiation, the difference between NREL and NASA measured values was noticeable immediately. The values for horizontal diffuse irradiation (Fig. 8) in June, July, August and September are in case of NREL data lower by factor 0.66, 0.66, 0.76, 0.68 and for tilted diffuse irradiation (Fig. 9) by factor 0.67, 0.68, 0.78, 0.71. This difference in factors remitted on generality of NASA data and their simplified method of derivation of diffuse irradiation. For a detailed calculation with diffuse irradiation, the data from ground based meteorological station should be preferred.

Monthly meteo at Fallon Naas	(Lat. 39.4°N	long. 118.7°W		
Plane: tilt 30°	azimuth 0°	bo (IAM)=0.05		
NREL	Horiz. Glob kWh/m².mth	Tilted Glob kWh/m².mth	Horiz. Diff kWh/m².mth	Tilted Diff kWh/m².mth
January	75.2	127.6	25.1	33.2
February	97.4	142.1	32.8	40.2
March	150.5	190	47.9	54.5
April	187.6	204	57.6	60.4
May	225.4	219.9	63.3	62.8
June	251.7	232.5	46.3	45.7
July	248.9	234.8	47.3	47.1
August	214.8	222.7	49.8	51.8
September	173.4	208.7	35.8	41.1
October	128.6	180.8	34	41.9
November	87.7	143.6	27.8	37
December	65	112.9	24.8	32.8
Year	**1906.1**	**2219.8**	**492.5**	**548.5**

Fig. 4 Averaged monthly solar radiation values from the NSRDB for Fallon Naas, NV, meteorological station, measurements 2000 – 2005.

Monthly meteo at Stillwater	(Lat. 39.6°N	long. 118.5°W		
Plane: tilt 30°	azimuth 0°	bo (IAM)=0.05		
	Horiz. Glob kWh/m².mth	Tilted Glob kWh/m².mth	Horiz. Diff kWh/m².mth	Tilted Diff kWh/m².mth
January	71.9	116.9	30.2	38.1
February	93.7	134.2	36.2	43.3
March	146.6	183.8	51.2	57.6
April	177.5	192	62.1	64.3
May	215.4	210	71.7	70.6
June	228.9	212	70.5	67.8
July	232.1	219.2	71	68.9
August	205.8	212.2	65.5	66.6
September	163.8	193.3	52.9	58
October	123.4	169	43.4	51.3
November	79.1	124.2	31.7	39.6
December	66.6	114.8	27	35.6
Year	**1804.9**	**2081.7**	**613.3**	**661.6**

Fig. 5 Averaged monthly solar radiation values from the NASA-SSE, satellite data for Stillwater, NV, measurements 1983 – 1993.

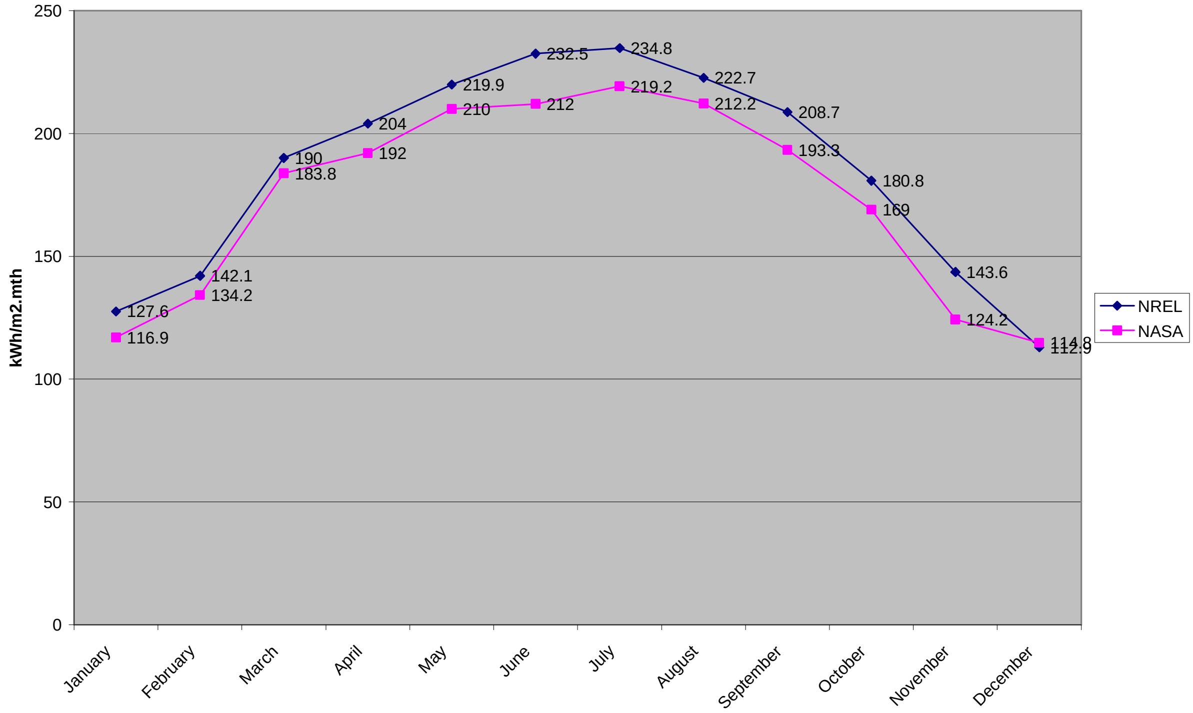


Fig. 6 Comparison of horizontal global irradiation evaluated from NREL (2000 – 2005) and NASA (1983 – 1993) data sets

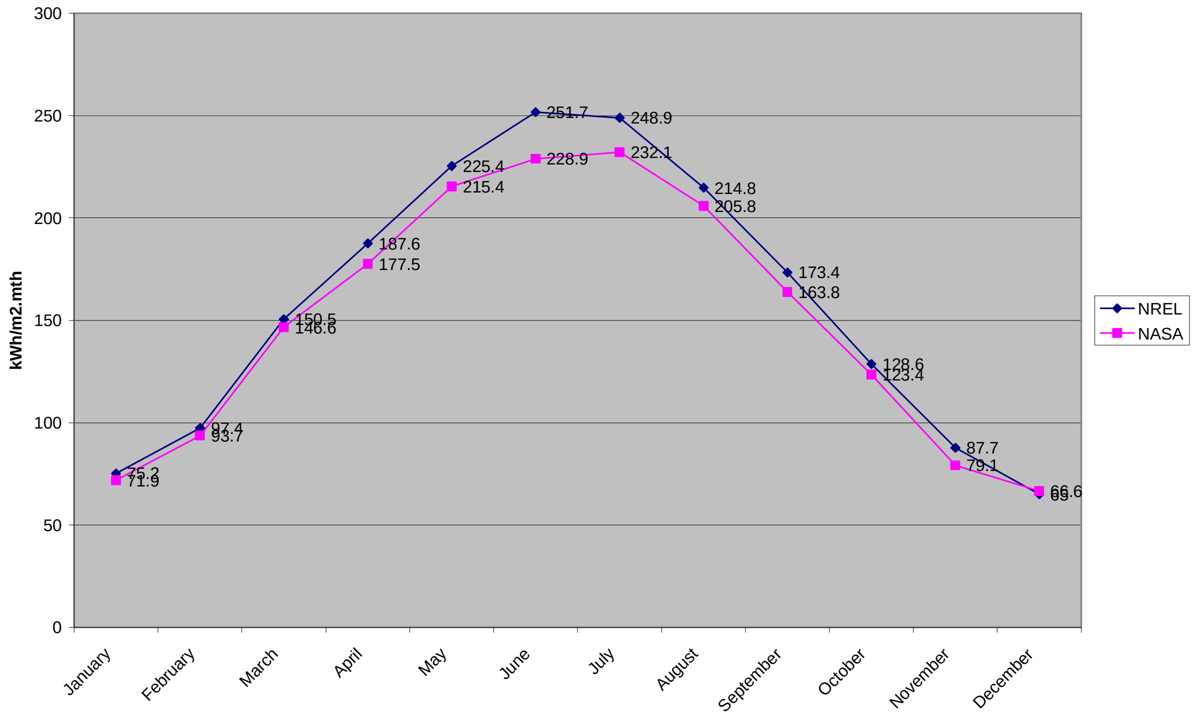


Fig. 7 Comparison of tilted (30°) global irradiation evaluated from NREL (2000 – 2005) and NASA (1983 – 1993) data sets

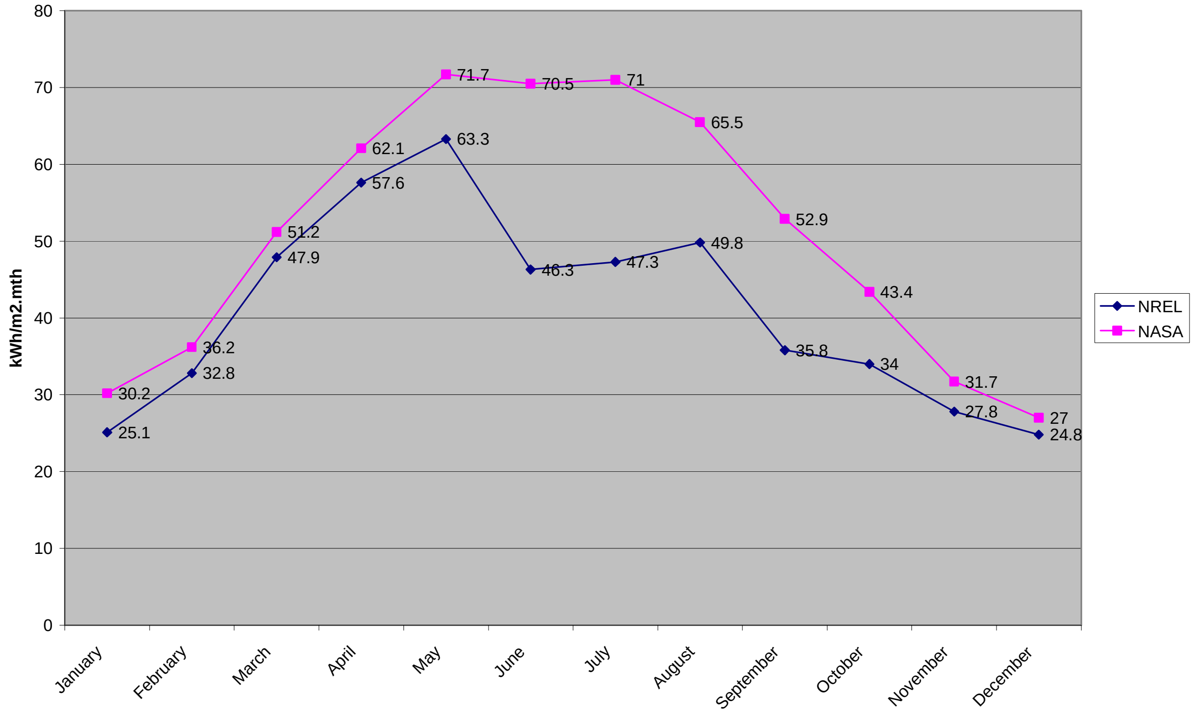


Fig. 8 Comparison of horizontal diffused irradiation evaluated from NREL (2000 – 2005) and NASA (1983 – 1993) data sets

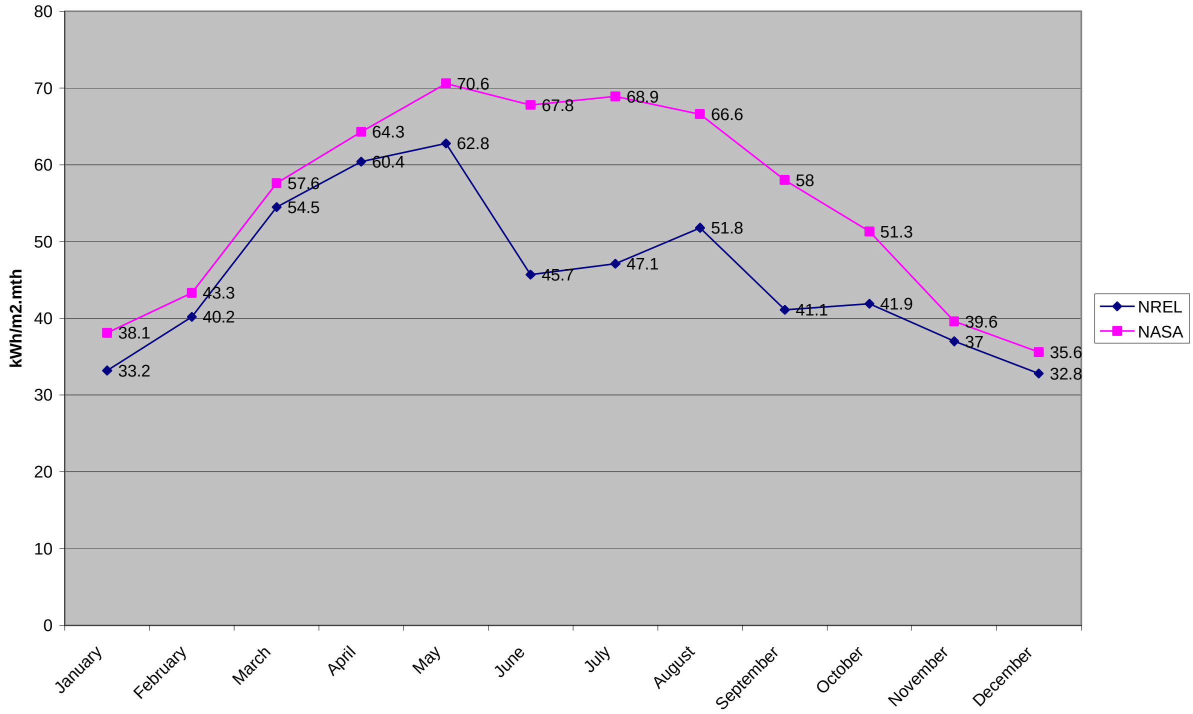


Fig. 9 Comparison of tilted (30°) diffused irradiation evaluated from NREL (2000 – 2005) and NASA (1983 – 1993) data sets

3.1.2 On-Site Analysis

During my business trip to our Reno-office, I got a chance to visit the Stillwater location and accomplish the On-Site Analysis consisting of following parameters evaluation:

a) shielding from terrain formations

b) shielding from vegetation

c) potential shielding from nearby geothermal power plant and other buildings

d) dust nuisance on the location

3.1.2.1 Shielding from Terrain Formations

As shown on the panoramic pictures Nr. 1 to 4, the terrain on the Stillwater site is broadly flat and the nearest hills formation with a camber around 650m on the east is approximately 16km far away, with only minimum influence on the energy yield. There is no other significant influence from the southern and western terrain formations.

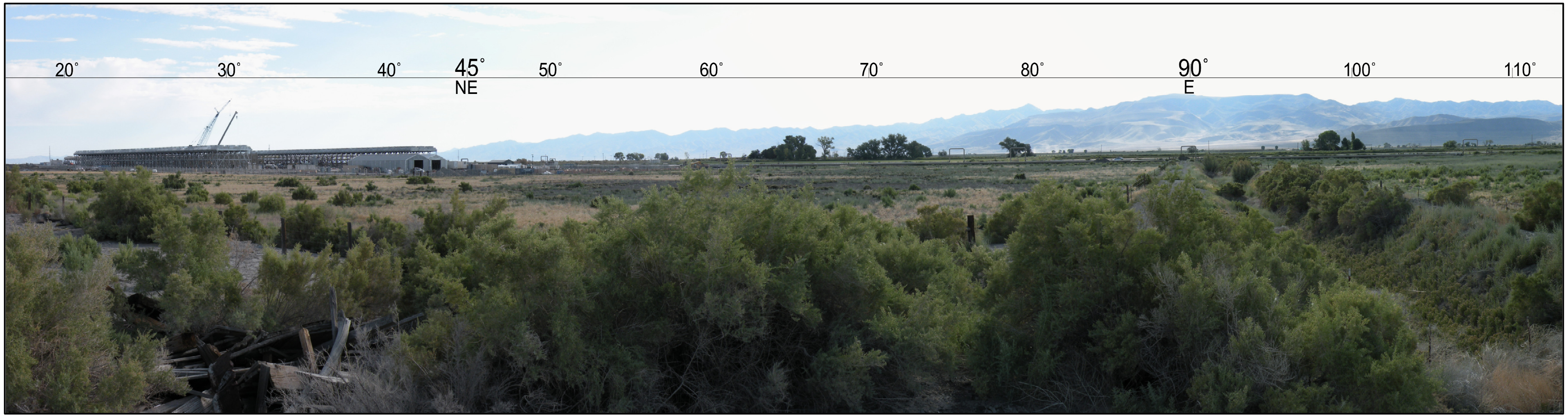
3.1.2.2 Shielding from Vegetation

As shown on the panoramic pictures Nr. 1 to 4, there is no significant vegetation around except of an old bushed overgrow, which can be easily removed if necessary.

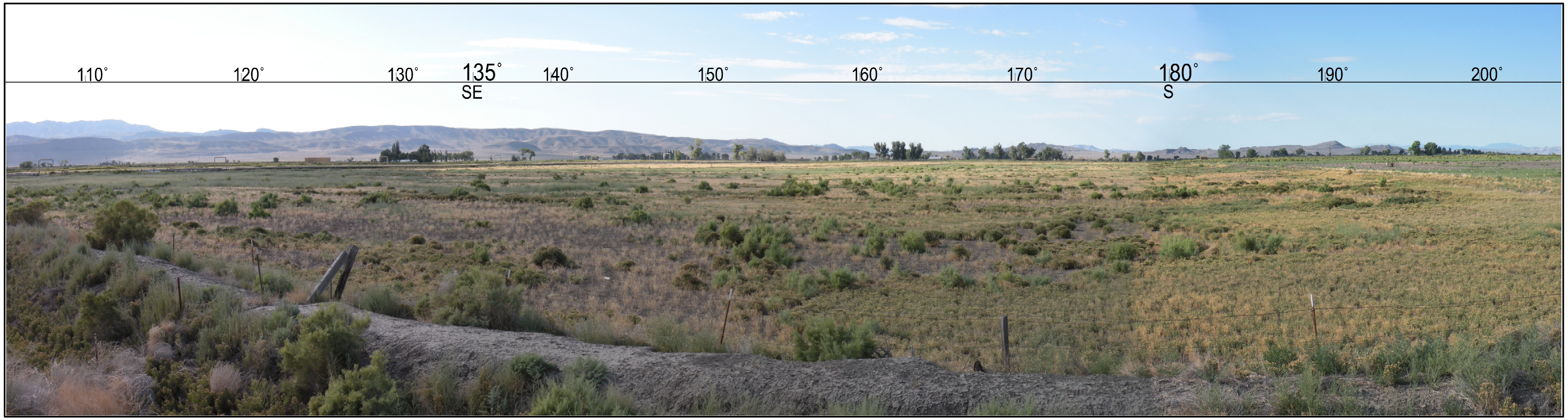
3.1.2.3 Shielding from nearby geothermal power plant and other buildings

As showed on the panoramic pictures Nr. 4, the geothermal power plant is located on the north of the planned photovoltaic power plant and on the north-east from the designed solar-weather station. Those conditions negate any possible shielding of the construction.

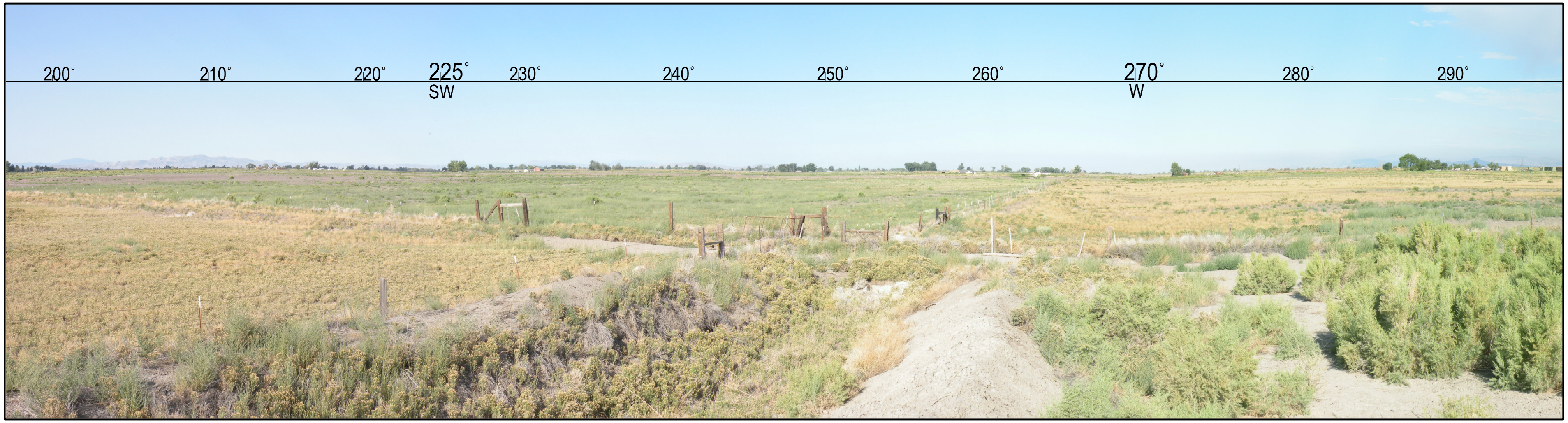
The only concern about possible influence is by reason of the water vapor produced by the geothermal power plant. This can be solved by a distance observance of at least 50m. There are no other buildings creating shielding around.



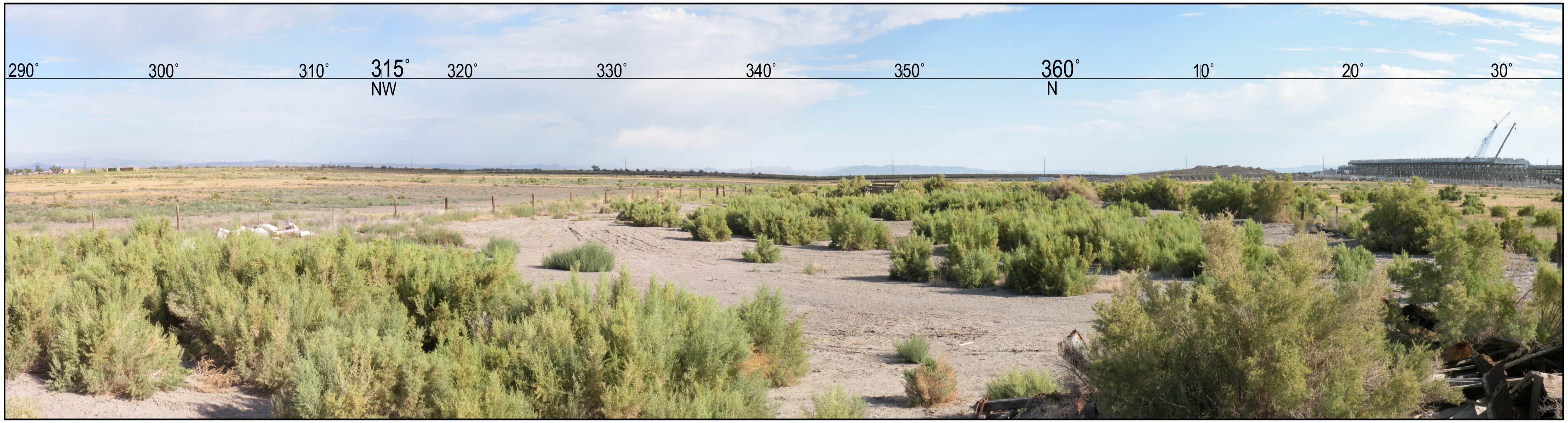
Pic. 1 Panoramic photography from the proposed location for the designed solar-weather station (NE to E)



Pic. 2 Panoramic photography from the proposed location for the designed solar-weather station (SE to S)



Pic. 3 Panoramic photography from the proposed location for the designed solar-weather station (SW to W)



Pic. 4 Panoramic photography from the proposed location for the designed solar-weather station (NW to N)

3.1.2.4 Dust Nuisance

The dust nuisance is the biggest concern caused by the desert environment on the location. The soil around is a compound of sand and clay with very fine fraction on the top. Any activity around the solar-weather station or stronger wind will beget dusting and negatively influence the recording of data.

For those above mentioned reasons is necessary to exclude any agricultural activity on the parcel owned by Enel NA and restrict the traffic in a radius of at least 50m around.

3.2 Parameters and instruments selection

The decision to measure the weather and solar parameters on the Stillwater site was assumed with regard to the size and value of the proposed photovoltaic project, which should be designed in the first phase up to 2 MW of installed capacity.

Each parameter mentioned in the chapter 1 was associated with a proper measurement instruments and a range and accuracy were defined. The additional equipments are data-logger for the data registration and a GSM unit for automatic data transmission (Fig. 10).

In a first step after range and accuracy comparison, the energy consumption of each instrument was determined. This was later used for the power supply decision. These parameters together with the price factor were evaluated and the overall suitability out of consideration to the site conditions was advised. Each instrument must be also 100% compatible with the data logger. This task was verified by a supplier with a method instrument by instrument comparison but only for the suggested instruments.

Parameter	Instrument type	Range	Accuracy
Weather			
Wind Speed	Anemometer	0 / 50 m/s	+/- 0.5 m/s
Wind Direction	Wind Vane	0 / 360°	+/- 5°
Ambient Temperature	Thermometer	-20°C / +60°C	+/- 0.5%
Humidity (relative %)	Humidity Meter	10% / 95%	+/- 2%
Rain Precipitation	Rain Gauge	1 tip max. 0.254 mm	+/- 5%
Solar			*Non-linearity*
Total Radiation – horizontal	Pyranometer	0 / 1200 W/m2	3%
Total Radiation - 20° tilt	Pyranometer	0 / 1200 W/m2	3%
Direct Radiation	Pyrheliometer vs. Pyranometer	0 / 1200 W/m2	3%

Fig. 10 Parameters and associated instruments and equipments

3.2.1 Weather Instruments

After request for proposal with defined type of instruments, accuracy and limits several suppliers answered, though only complex proposals were considered. Some of the suppliers offered the same instruments (the same manufacturer), in this case the best price was the crucial point.

As shown in the Fig. 11 below, some of the chosen instruments for measuring of the weather conditions have associated functions, but the sensors are separate. I such case the range, resolution and accuracy limits were evaluated separately, but the energy consumption and the price just for the first time of consideration.

Measurement of the wind parameters is indirectly related to the tilt of the photovoltaic power panels seeing that the surface will be exposed to the wind conditions and there is a potential hazard of overturning or damage.

The supplier Texas Electronics, Inc. (TEI) offered own anemometer and also wind wane, unfortunately the anemometers accuracy was out of the desired limit and the price in compare to the other suppliers was to high.

Campbell Scientific offered one instrument 03001. Both wind direction and wind speed will be measured by two sensors combined in one instrument manufactured by the company RM Young. The accuracy and range by both sensors are within the limit.

NRG System offered an anemometer with the best accuracy and much higher range as required. The wind wane was considered as fair.

All of the introduced sensors for measuring of wind parameters have only negligible power consumption.

The relative humidity and temperature are parameters measured for the reason of better understanding of the general weather conditions as they can have direct affect on the photovoltaic power cells, which can also partially influence the momentary energy production.

The TEI and Campbell Scientific offered own set of these sensors, both within the range and accuracy limits however the energy consumption during processing by the sensors from TEI was 2.35 times higher. The NRG System offered the sensors separately, unfortunately, both of them out of the limits.

Parameter/Supplier	Manufacturer/Type	Range/Resolution	Accuracy	Energy consumption		Price	Suitability
				Quiescent	*Active*		
Wind Speed	**Anemometer**	0 - 50 m/s	± 0.5 m/s	mA	mA		
Texas Electronics, Inc. (TEI)	TV-114	0 - 44.7 m/s	± 0.9 m/s	negligible	negligible	$ 734.00	N
Campbell Scientific, Inc.	RM Young / 03101 (part of 03001)	0 - 50 m/s	± 0.5 m/s	negligible	negligible	$ 588.00	Y
NRG Sytems	190 NRG #40C	1 - 96 m/s	± 0.1 m/s	negligible	negligible	$ 285.00	Y
Wind Direction	**Wind Vane**	0 / 360°	± 5°				
Texas Electronics, Inc. (TEI)	TD-104-5D	0/360°	± 3°	negligible	negligible	$ 760.00	Y
Campbell Scientific, Inc.	RM Young / 03301 (part of 03001)	0/360°	± 5°	negligible	negligible	set	Y
NRG Sytems	1904 NRG #200P	0/360°	± 3.6°	negligible	negligible	$ 205.00	Y
Ambient Temperature	Thermometer	-20°C / +60°C	± 0.5%				
Texas Electronics, Inc. (TEI)	TTH 1315 set	-40°C / +60°C	± 0.3°	negligible	4	$ 949.00	Y
Campbell Scientific, Inc.	CS215 set	-40°C / +70°C	± 0.3°	negligible	1.7	$ 354.64	Y
NRG Sytems	1906 NRG #110S	-40°C / +52.5°C	± 0.33°	negligible	0.3	$ 195.00	N
Humidity (relative %)	Humidity Meter	10% / 95%	± 2%				
Texas Electronics, Inc. (TEI)	TTH 1315 set	0-100%	± 1.5%	set	set	set	Y
Campbell Scientific, Inc.	CS215 set	0-100%	± 2%	set	set	set	Y
NRG Sytems	NRG/RH-5	5% / 95%	± 5%	negligible	1.2	$ 345.00	N
Rain Precipitation	Rain Gauge	max. 0.254mm	± 5%				
Campbell Scientific, Inc.	TEI/TE525WS-L	0.254 mm	± 1%	negligible	negligible	$ 394.50	Y
NRG Sytems	Tipping Bucket 2226	0.254 mm	± 2%	negligible	negligible	$ 595.00	Y

Texas Electronics, Inc. (TEI)	TV-114 + TD-104-5D + TTH-1315 + TE525WS-L	negligible	4.0	$ 2,837.50	N
Campbell Scientific, Inc.	**0301 + CS215 + TE525WS-L**	**negligible**	**1.7**	**$ 1,337.14**	**Y**
NRG Systems	190NRG#40C + 1904NRG#200P + 1906NRG#110S + RH-5 + 2226	negligible	1.5	$ 1,625.00	N

Fig. 11 Evaluation of weather sensors and instruments by the defined resolution, accuracy criteria, energy consumption and a price factor

Better understanding of the precipitation conditions on the site will give as a better idea about the number of rainy days, typical length of the rain and about the amount of rainfall. In respect to the obtained information from the nearby weather station in Fallon, about the negligible snowfall conditions in this area, we decided not to install an optional heater, which is usually the biggest energy consumer.

The Campbell Scientific offered the same rain gauge TE525TS-L as Texas Elektronics, Inc., manufactured by TEI, but for a better price. The characteristics in compare to the second rain gauge from NRG Systems were comparable. The energy consumption by both instruments is negligible only.

Due to the evaluation of the weather sensors aforementioned in the Fig. 11, the complex suitability of all instruments was documented only by the products offered by Campbell Scientific.

3.2.1.1 Wind Speed and Direction Sensor

The chosen 03001 Wind Sentry Set Anemometer/Vane (Pic. 5) supplied by Campbell Scientific, Inc. is used to measure horizontal wind seed and direction.

Wind speed is measured with three cup anemometer. Rotation of the cup wheel produces an AC sine wave frequency proportional to wind speed.

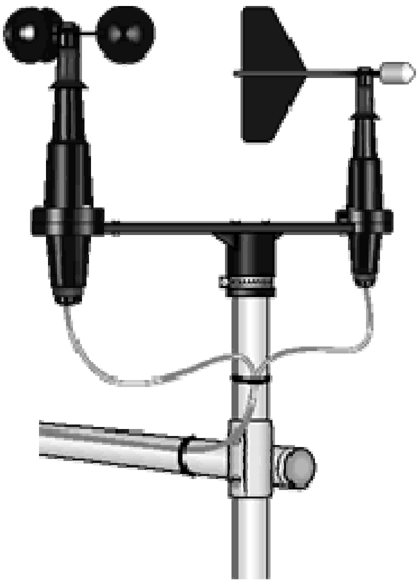
Vane position is transmitted by 10K ohm potentiometer. With a precision excitation voltage applied, the output voltage is proportional to wind direction.

Additionally, together with the instrument was also ordered a ¾ fitting and a cross-arm for easy installation on the pole. (Fig. 12)

Wind Speed (Anemometer)	**Specification**
Range	0 to 50 m/s (180 km/h), gust survival 60 m/s (215 km/h)
Sensor	12 cm diameter cup wheel assembly, 40 mm diameter hemispherical cups
Accuracy	± 0.5m/s (1.76 km/h)
Turning Factor	75 cm
Distance Constant (63% rec.)	2.3 m
Threshold	0.5 m/s
Transducer Output	AC sine wave signal induced by rotating magnet on cup wheel shaft 100 mV peak-to-peak at 60 rpm; 6 V peak-to-peak at 3600 rpm
Output Frequency	1 cycle per cup wheel revolution; 0.75 m/s per Hz
Cup Wheel Diameter	12 cm diameter
Weight	113 g

Wind Direction (Vane)	Specification
Range	360° mechanical, 355° electrical (5° open)
Sensor	Balanced vane, 16 cm turning radius
Accuracy	±5°
Damping Ratio	0.2
Delay Distance (50% recovery)	0.5 m
Threshold	0.8 m/s at 10° displacement; 1.8 m/s at 5°displacement
Transducer	Precision conductive plastic potentiometer; 10 kohm resistance; 0.5% linearity; life expectancy 20 million revolutions. Rated 1 watt at 40°C, 0 watts at 125°C.
Transducer Output	Analog dc voltage proportional to wind direction angle with regulated excitation voltage supplied by the data-logger
Vane Length	22 cm
Vane Weight	170 g
Wind Sentry Assembly	**Specification**
Operating Temperature	-50°C to +50°C assuming non-riming conditions
Overall Height	32 cm
Cross-arm Length	40 cm between instruments (center-to-center)
Mounting Diameter	26.7 mm, mounts on standard 3/4 in. pipe

Fig. 12 Technical specification of selected 03001 Wind Sentry Set Anemometer/Vane (Campbell Scientific, 2007)



Pic. 5 03001 Wind Sentry Set Anemometer/Wind Vane

3.2.1.2 Temperature and Relative Humidity Probe

The selected CS215 supplied from Campbell Scientific, Inc. uses the Sensirion SHT75, a combined relative humidity and temperature element, to provide accurate, stable measurements (Fig. 13). Each element is individually calibrated with the calibration corrections stored on a chip.

The probe is fitted with a low-cost sintered plastic filter to minimize the effects of dust and dirt on the sensor. The filter is lightweight and hydrophobic, thereby minimizing the effect of the time response of the sensor.

To avoid the direct exposure of the sensor to sunlight, the CS215 will be housed in a 41303-5A radiation shield (Pic. 6).

Pic. 6 Combined CS215 Temperature and Humidity Probe (left) and a radiation shield 41303-5A (right)

Relative Humidity	Specification
Measurement Range	0 to 100% RH (-20° to +60°C)
Accuracy (at 25°C)	±2.0% (10-90% range), ±4.0% (0-100% range)
Temperature Dependence	better than ±2.0% over -20° to +60°C
Short-Term Hysteresis	<1.0% RH
Typical Long-Term Stability	better than ±1.0% RH per year
Response Time with Filter	<10 s (63% response time in air moving at 1 m/s)
Temperature	**Specification**
Measurement Range	-40° to +70°C
Accuracy	±0.4°C (+5° to +40°C), ±0.9°C (-40° to +70°C)
Response Time with Filter	120 s (63% response time in air moving at 1 m/s)
Output Resolution	0.1°C
General	**Specification**
Supply Voltage	6-16 Vdc (typically powered by datalogger's 12 V supply)
Typical Current Consumption	70 µA quiescent, 1.7 mA during measurement (takes 0.7 s)
EMC Compliance	tested and conforms to BS EN61326:2002
Communication Standard	SDI-12 V1.3 (responds to a subset of commands)
Operating Temperature	-40° to +70°C
Weight	150 g (w/3 m cable)
Diameter	1.2 cm at sensor tip, 1.8 cm at cable end
Length	18.0 cm including cable strain relief
Housing Material	anodized aluminum
Cable Type	low-temperature cable with Santoprene outer jacket

Fig. 13 Technical specification of selected Relative Humidity and Temperature Probe (Campbell Scientific, 2008)

3.2.1.3 Tipping Bucket Rain Gage

The TE525WS-L series tipping bucket rain gage is supplied by the Campbell Scientific and measure in 0.01 inch increments (Pic. 7).

These gage funnel precipitation into a bucket mechanism that tips when filled to a calibrated level. A magnet attached to the tipping mechanism actuates a switch as the bucket tips (Fig. 14).

Pic. 7 TE525WS-LTipping Bucket Rain Gage

Rainfall	Specification
Sensor type	Tipping bucket/magnetic reed switch
Material	Anodized aluminum
Temperature	0° to +50°C
Resolution	1 tip
Cable	2-conductor shielded cable
Rainfall per tip	0.254 mm
Orifice diameter	20.3 cm
Height	26.7 cm
Weight	1.1 kg
Accuracy	Up to 1 inch/hr: ±1%
	1 to 2 inch/hr: +0, -2.5%
	2 to 3 inch/hr: +0, -3.5%

Fig. 14 Technical specification of selected Rain Gage (Campbell Scientific, 2008)

3.2.2 Solar instruments

The instruments for the solar measurement are the most important and the biggest concentration was focused on their proper selection in respect to the defined criteria (Fig. 15). All of the suppliers offered instruments within the expected resolution and non-linearity as the percentage deviation of sensitivity from sensitivity at 500 W/m2 due to a change in irradiance level within the range from100 to 1000 W/m2.

Parameter/Supplier	Manufacturer/Type	Range/Resolution	Non-Linearity	Energy consumption		Price	Suitability
				Quiescent	*Active*		
Total Radiation	Pyranometer	0 / 1200 W/m2	3%				
Kipp&Zonen	CMP3	0 - 2000	2.50%	negligible	negligible	$ 878.00	Y
Kipp&Zonen	CMP11	0 - 4000	0.20%	negligible	negligible	$ 2,663.00	Y
Eplab	PSP	0 - 2800	0.50%	negligible	negligible	$ 2,300.00	Y
Direct Radiation	Pyrheliometer/Pyranometer	0 / 1200 W/m2	3%				
Eplab	NIP (Pyrheliometer)	1400	0.50%	negligible	negligible	$ 2,350.00	Y
	ST-1 (tracker)					$ 2,625.00	
Kipp&Zonen	CH1 (Pyrheliometer)	4000	0.20%	negligible	negligible	$ 3,390.00	Y
	SOLYA2 (tracker)					$ 14,250.00	
Dynamax	SPN1 (Pyranometer)	2000	<1%	negligible	2	$ 5,750.00	Y

Kipp&Zonen	2xCMP3 + CH1 + SOLYA2	negligible	negligible	$ 19,396.00	N
Kipp&Zonen II.	2xCMP11 + CH1 + SOLYA2	negligible	negligible	$ 22,966.00	N
Eplab	2xPSP + NIP + ST-1	negligible	negligible	$ 9,575.00	Y
Kipp&Zonen + Dynamax	**2xCMP3 + SPN1**	**negligible**	**2**	**$ 7,506.00**	**Y**

Fig. 15 Evaluation of solar sensors and instruments by the defined resolution, accuracy criteria, energy consumption and a price factor

In this process were considered several solutions. The main difficulty was caused by the inquiry to have the station automated as much as possible. This difficulty was especially bold in the selection process of the instrument for the direct radiation. One possibility was to install on the site the pyrheliometer together with a tracker, unfortunately only these two components together costs around $17,600.-, which was not possible in respect to our budget in a total amount of $15,000.-.

The other option was to buy one pyranometer and a shadow ring. With this solution it would be possible to measure the diffuse radiation only. A value of the direct radiation would be a difference between the total and diffuse radiation. Unfortunately, this solution requires an adjustment of the shadow ring every 10 days, which is not in coincidence with the request for fully automated solar-weather station.

The Sunshine Pyranometer SPN1 manufactured by the company Delta-T Devices Ltd. and in the USA offered by the company Dynamax was a product found after a comprehensive research on this topic. The Sunshine Pyranometer uses an array of seven miniature thermopile sensors and a computer-generated shading pattern to measure the direct and diffuse components of incident solar radiation. The SPN1 computes direct radiation by subtracting the diffuse from the total radiation.

For the measurement of the total radiation horizontal and angle-wise 20° three pyranometers were compared, and however the CMP3 from Kipp&Zonen has the highest non-linearity and lowest spectral range, the defined criteria for selection were executed.

In a final version for the solar measurements the combination of two CMP3 pyranometers and one SPN1 pyranometer were selected.

The energy consumption of the instruments is usually only negligible however the SPN1 pyranometer offers also a heating option under conditions below 0°C. This function of the pyranometer will be not used because of already mentioned modest snowfall condition during the winter on the location and also because of high energy consumption of the heater, which would require additional energy source as discussed later.

3.2.2.1 Total Radiation

A pyranometer is used to measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density (in watts per meter square) from a field of view of 180 degrees. They essentially comprise two hemispherical glass domes, a black metal plate as an absorber surface, the thermo-elements located bellow this, and a white metallic housing. Solar radiation falls through the hemispherical glass domes onto the absorber surface, warming it up. Since the amount of warming directly depends upon the irradiance, the difference in temperature between it and the environment allows the irradince to be calculated. (Deutsche Gesellschaft für Sonnenenergie, 2008)

The selected Kipp & Zonen's CMP3 pyranometer is designed for continuous outdoor use (Pic. 8). Due to its flat spectral sensitivity form 300 to 3000 nm, it can be used in natural sunlight, in greenhouses or buildings, and inverted to measure reflected solar radiation.

Pic. 8 Pyranometer CMP3

The CMP3 pyranometer consists of thermopile sensor, housing, dome, and cable. The thermopile is coated with a black absorbent coating. The paint absorbs the radiation and converts it to heat. The resultant temperature difference is covered to a voltage by the cooper-constantan thermopile. The thermopile is encapsulated in the housing in such a way that it has a field of view 180 degrees and the angular characteristics needed to fulfill the cosine response requirements. (Fig. 16)

CMP3 Pyranometer	Specifications
Light Spectrum Waveband	310 to 2800 nm
Maximum Irradiance	2000 W/m²
Sensitivity	5 to 20 µV W-1 m²
Operating Temperature	-40° to +80°C
Temperature Dependence	±5% (-10° to +40°C)
Non-linearity (0 to 1000 W/m²)	<±2.5%
Tilt Response (±80°)	<±2% at 1000 W/m²
Dimensions	7.9 cm width x 6.7 cm height; 3.2 cm dome diameter
Weight (with cable)	600 g
ISO Classification	Second Class

Fig. 16 Technical specification of the selected pyranometer CMP3 (Campbell Scientific, 2008)

For a programming and proper data recording with the data-logger, the pyranometer must be calibrated and co called calibration certificate submitted:

Kipp & Zonen
SINCE 1830

Kipp & Zonen B.V.
Delftechpark 36, 2628 XH Delft
P.O. Box 507 2600 AM Delft
The Netherlands

T +31 (0)15 2755 210
F +31 (0)15 2620 351
E info@kippzonen.com
www.kippzonen.com

CALIBRATION CERTIFICATE
PYRANOMETER

PYRANOMETER MODEL	:	CMP 3
SERIAL NUMBER	:	080305
SENSITIVITY at normal incidence on horizontal pyranometer	:	13.13 μV/W/m^2
IMPEDANCE	:	36 Ohm
CALIBRATION PROCEDURE	:	The indoor calibration procedure is based on a side-by-side comparison with a reference pyranometer under an artificial sun fed by an AC voltage stabiliser. It embodies a 150 W Metal-Halide high-pressure gas discharge lamp. Behind the lamp is a reflector with a diameter of 16.2 cm. The reflector is 1 m above the pyranometers producing a vertical beam. The reference and test pyranometers are mounted horizontally on a table, which can rotate. The irradiance at the pyranometers is approximately 500 W/m². During the calibration procedure the reference and test pyranometer are interchanged to correct for any non-homogeneity of the beam. The dark offsets of both pyranometers are measured before and after the interchange and taken into account.
REFERENCE PYRANOMETER	:	Kipp & Zonen CMP 3 sn 071176 active from 01/01/2008.
hierarchy of traceability	:	This pyranometer was compared with the sun and sky radiation as source under mainly clear sky conditions using the “continuous sun-and-shade method”. The readings are referred to the World Radiometric Reference (WRR) as stated in the WMO Technical Regulations. The measurements were performed in Davos (latitude: 46.8143°, longitude: -9.8458°, altitude: 1588 m above sea level). The inclination of the receiver surfaces versus their horizontal position were set to 0.0 degrees, the instrument signal wire to the north. During the comparisons, the instrument received global radiation intensities from 637 to 1093 with a mean of 867 W/m^2. The angle between the solar beam and the normal of the receiver surface varied from 25.2 to 49.9 with a mean of 33.9 degrees. The instrument temperature ranged from +16.6 to +25.7 with a mean of +22.6 °C. The sensitivity calculation and the single measurements deviation (σ) are based on 346 individual measurements. The obtained sensitivity value and its expanded uncertainty (95% level of confidence) are valid for similar conditions and are: 11.07 ± 0.36 μV/W/m^2 (but is corrected by Kipp & Zonen to 11.20 μV/W/m². See "correction applied" below.) Dates of measurements: 2007 July 13-18. Global radiation data were calculated from the direct solar radiation as measured with the absolute cavity pyrheliometer PMO2 (member of the WSG, WRR-Factor: 0.998618, based on the last International Pyrheliometer Comparison IPC-2005) and from the diffuse radiation as measured with a continuous disk shaded pyranometer Kipp & Zonen CM 22 sn020059 with sensitivity 8.91 (ventilated with heated air, instrument-wire to the north).
correction applied	:	+1.1 % This correction was necessary to correct for the mean directional errors of the reference CMP 3 in Davos. This error is estimated at Kipp & Zonen measuring the cosine error for the mean angle of incidence at azimuth S-30° and S+30°. The reference CMP 3 now measures the vertical directed beam of the indoor calibration facility more correctly.
IN CHARGE OF TEST	:	F. de Wit, Date: 18 April 2008 Kipp & Zonen, Delft, Holland

Notice
The calibration certificate supplied with the instrument is valid from the date of shipment to the customer. Even though the calibration certificate is dated relative to manufacture or recalibration the instrument does not undergo any sensitivity changes when kept in the original packing. From the moment the instrument is taken from its packaging and exposed to irradiance the sensitivity will deviate with time. See also the 'non-stability 'performance (max. sensitivity change / year) given in the radiometer specification list.

3.2.2.2 Direct Radiation

The selected Sunshine Pyranometer SPN1 (Pic. 9) from Delta-T Devices Ltd. measures total and diffuse radiation and sunshine duration in one instrument. The direct radiation is computed by subtracting the diffuse from the total radiation.

The Sunshine Pyranometer uses an array of seven, miniature thermopile sensors and a computer-generated shading pattern to measure the direct and diffuse components of incident solar radiation.

The shading pattern and thermopiles are arranged so that at least one thermopile is always fully exposed to the solar beam, and at least one is fully shaded from it, regardless of the position of the sun in the sky.

All seven thermopiles receive an equal amount of diffuse light. From the individual thermopile readings, a microprocessor calculates the global and diffuse horizontal irradiance and from these values an estimate of sunshine state is made.

The WMO threshold for bright sunshine is 120 W.m-2 in a plane perpendicular to the direct solar beam. The SPN1 uses an algorithm based on the ratio of direct to diffuse radiation, combined with their absolute values, to estimate sunshine duration to within a few percent of the WMO standard.

The Sunshine Pyranometer provides two analogue voltage outputs for global and diffuse radiation, and a digital output for sunshine duration, which can be connected to data loggers, such as the DL2e and GP1.

The Sunshine Pyranometer needs no routine adjustment or polar alignment and works at any latitude (Fig. 17).

Pic. 9 Pyranometer SPN1

SPN1 Pyranometer	Specification
WMO Classification	Matches “WMO Good Quality Pyranometer” classification
Overall Accuracy Global (Total) and Diffuse radiation	±5% Daily integrals, ±5% ±10 W/m² Hourly averages, ±8% ±10 W/m² Individual readings
Resolution	0.6 W.m-2 = 0.6 mV
Range	0 to >2000 W.m-2
Analogue Output Sensitivity	1 mV = 1 W.m-2
Analogue Output Range	0-2500 mV
Sunshine Status Threshold	120 W.m-2 in the direct beam
Accuracy Sunshine Status	±10% sun hours with respect to the threshold
Accuracy Cosine Correction	±2% of incoming radiation over 0-90° Zenith angle
Accuracy Azimuth Angle	±5% over 360° rotation
Temp Coefficient	± 0.02% per °C typical
Temperature Range	-20 to + 70°C
Recalibration / Stability	Factory recalibration recommended every 2 years.
Response Time	< 200ms
Spectral Response	400 – 2700nm
Spectral Sensitivity Variation	10% typical
Non-linearity	<1%
Tilt Response	Negligible errors
Zero Offsets	<3 W/m² for a change of 5°C/hr in ambient temperature <3 W/m² dark reading
Latitude Capability	-90° to +90°
Environmental	IP67 sealing
Sunshine Status Output	No sun = open circuit, Sun = short circuit to ground
Power Requirement	2mA (excluding heater power), 5V – 15V DC
Heater Power	12V – 15V DC, up to 1.5A
Heater Control	Continuously variable up to 20W output for external temperatures below 0°C
Lowest Snow & Ice Free Temperatures (w/heater in use)	-20°C at 0 m/s wind speed -10°C at 2 m/s wind speed
Mounting Options	3 x M5 tapped holes in base; 108mm pcd, 120° spacing
Size & Weight	140mm dia x 100mm (h), 940g

Fig. 17 Technical specification of selected pyranometer SPN1 (Wood, 2007)

3.3 Data

The resolution of a system for recording, transmission and processing of measured data was the next step in the process of the solar-weather station dimensioning. Because the request for a fully automated solar-weather station was applied to the data transmission equipments as well, an automated digital cellular modem was ordered.

The whole system consists in our case from a data-logger which records the data over time or in relation to location via external instruments and sensors, from an instrument for a data transmission (modem) and a data receiver (PC) (Fig. 18).

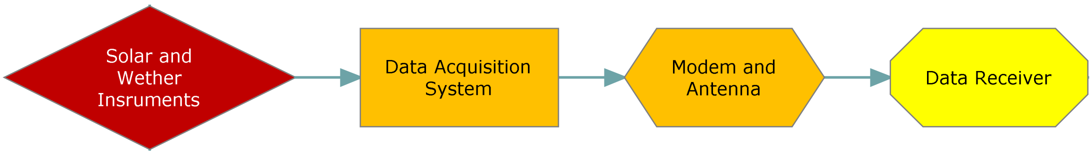


Fig. 18 Schema for data recording and transmission

3.3.1 Data Acquisition System

For a data acquisition system is a 100% compatibility with the instruments required. As a solution from Campbell Scientific was a CR 1000 offered. After verification of compatibility with the pyranometer CMP3 and pyranometer SPN1 from the manufacturers was the number of analog and counter sensors totaled and compared with the capacity of the data logger. (Fig. 19)

Instrument	Supplier	Type	Measurent Units	Counter	Analog
Anemometer	Campbell Scientific	RM Young Wind Sentry Set	m/s	✓	
Wind vane			° to North		✓
Thermometer	Campbell Scientific	CSL Temperature/RH Probe	° C		✓
Humidity meter			%		✓
Rain Gauge	Campbell Scientific	Texas Electronic Rain Gauge	mm	✓	
Pyranometer	Dynamax	SPN1	W/m²		✓
Pyranometer - 20° tilt	Kipp&Zonen	CMP3	W/m²		✓
Pyranometer - horizontal	Kipp&Zonen	CMP3	W/m²		✓
TOTAL				**2**	**6**
Data logger	Campbell Scientific	CR 1000		2	16

Fig. 19 Specification of counter and analog sensors in comparison to the data logger capacity

The CR1000 (Pic. 10) supports also several options for communication, including direct connect via its two serial communications ports (CS I/O and RS232), standard telemetry options (RF, phone, etc.), and TCP/IP (with an NL100, NL115, or NL120 peripheral device). It consists of a measurement and control module and a wiring panel. Standard operating range is -25° to +50°C; an optional extended range of -55° to +85°C is available (Fig. 20).

The data storage consists of 4 MB SRAM, with additional storage using CFM100 Module with a Compact Flash card.

Pic. 10 Data-logger CR-1000

CR1000 Data-logger	Specification
Analog inputs	16 single-ended or 8 differential, individually configured
Pulse counters	2
Switched voltage excitations	3
Control/digital ports	8
RS-232 port	1
CS I/O port	1
Scan rate	100 Hz
Burst mode 1500 Hz	1500 Hz
Analog volt. Resolution	to 0.33 uV
A/D bits	13
Programming	CRBasic
Data Storage	Table
Telecommunications	PakBus

Fig. 20 Tech. specification of the data-logger CR-1000 (Campbell Scientific, 2008)

3.3.2 Digital Transmission

Selection of a modem for the data transmission was strongly affected by the presence of any cellular network provider. In the area are three providers active: Alltel, AT&T, Verizon, but only Alltel was confirmed directly on the Stillwater site and appertaining modem RavenXTA was selected.

The chosen RavenXTA is a full-duplex Airlink modem (Pic. 11) with a wireless data-transmission to the local cellular tower using a Code Division Multiple Access (CDMA) network. A PC typically retrieves the data from the cellular tower via the Internet (1xRTT/EVDO). Internet communications provide faster communication rates and eliminate dialing delays and long distance fees.

Selected Omni-directional Antenna 18285 1 dBd covers both the 800 MHz and 1.9 GHz bands. It includes a mounting bracket for attaching the antenna to a cross-arm, tripod, tower, or pole. For a connection to the modem a cellular phone antenna cable 21847 with a length of 3,65m was ordered (Fig. 21).

Pic. 12 Cellular digital modem AirLink Raven XTA

RavenXTA Airlink CDMA Digital Cellular Modem	Specification
Technology	CDMA 1xRTT, EVDO Rev. A, CDMA IS-95
Bands	800 MHz Cellular, 1900 MHz PCS
Transmit Frequency	1850 to 1910 MHz and 824 to 849 MHz
Transmit Power	1.0 W for 1900 MHz; 0.8 W for 850 MHz
Receiver Frequency	1930 to 1990 MHz and 869 to 894 MHz
CDMA Th roughput	up to 80 kbps
RS-232 Data Rates	1200 bps to 115.2 kbps
Serial Interface	RS-232, DB9-F
Serial Protocols	AT Commands, PPP, SLIP, UDP/IP, TCP/IP
RF Antenna Connector	50 Ohm SMA
Input Current Range	50 to 250 mA
Typical Current Drain (at 12 Vdc)	50 mA dormant (idle for 10 to 20 seconds), 120 mA transmit/receive
Input Voltage Range	6 to 28 Vdc
Operating Temperature Range	-30° to +70°C
Operating Humidity Range	5% to 95% RH non-condensing
Status LEDs	Power, Network, Signal, Activity
Dimensions	3”W x 1”D x 4”L (7.6 x 2.5 x 10 cm)
Weight	<1 lb (<0.5 kg)

Fig. 21 Technical specification of the selected cellular modem (Campbell Scientific, 2008)

3.4 Power

Whereas the solar-power station is located out of any grid connection point and a construction of a special line from the nearest building will be technically very complicated and financially to expensive, the only possible solutions is using batteries. Because classical alkaline batteries needs to be changed and the solar-weather station should be as automated as possible, the rechargeable batteries in combination with a charging source – solar panel were selected.

For a proper dimensioning of the powering system is necessary to calculate the total power consumption. The power consumption of a system is the sum of the data-logger, sensors, and peripheral equipments average current drains.

The average current data loggers drain can be calculated by determining the time spent in an active versus the time spent in a "quiescent" state. This relationship is primarily affected by the data loggers scan rate (Fig. 22) and the length of the data logger program.

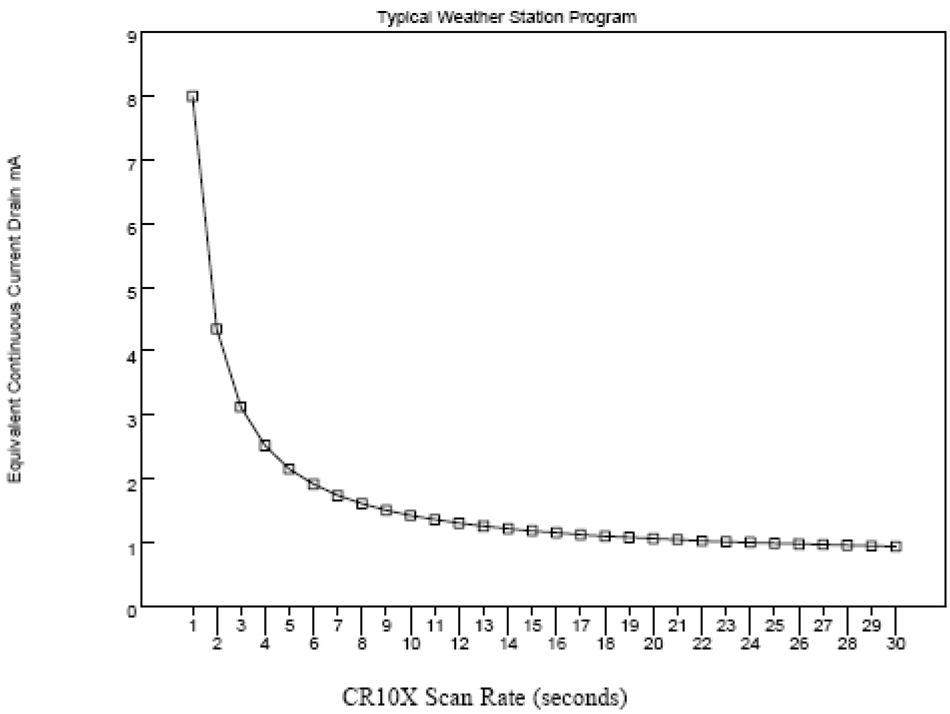


Fig. 22 Short scan rates by the data logger CR 1000 dramatically affect the current drain of a system (Campbell Scientific, 2004)

The current drain of sensor is determined by its current drain during quiescent and active states, which is also affected by the data loggers scan rate. Most sensors have only negligible consumption.

The biggest energy consumer is the data-logger together with the digital cellular modem. From the sensors, the temperature and humidity probe and the pyranometer SPN-1 were considered. (Fig. 23).

Instruments	Type	Status	Frequence	Duration (sec.)	Consumption (mA)
Temperature and Humidity Probe	CS215 set	quiescent		9.3	Negligible
		procesing	every 10 sec.	0.7	1.7
Pyranometer	SPN-1	quiescent		9.8	negligible
		procesing	every 10 sec.	0.2	2
Data Logger	CR 1000	quiescent		9.77	1.5
		procesing	every 10 sec.	0.03	13
		procesing	1x per day	300	13
		Analog measurement	every 10 sec.	0.2	46
Modem	Raven XTA	quiescent		86100	50
		procesing	1x per day	300	120

Fig. 23 Power consumption of weighty instruments

The energy consumption of the modem depends from the number of data transmissions during a day. For this reason only one transmission per day and the sensors scan rate every 10 seconds is programmed. (Fig. 24)

Instruments	Type	Frequence	Consumption (mA)
Data Logger + Instruments	CS215 set + SPN-1 + CR 1000	every 10 sec.	2.58
Modem + Data Logger	CR 1000 + Raven XTA	1x per day	50.38
TOTAL (mA)			**52.96**
TOTAL (A)			0.0530

Fig. 24 Calculation of the total power consumption of the solar-weather station

3.4.1 Rechargeable Battery

By using a solar panel and rechargeable battery to power the solar-weather station was important to recalculate the capacity under worst case conditions, because the rechargeable battery must be able to power the station also during period of low light. If the weather station is at latitude of 30 to 50° N, recommended reserve time is between 288 to 336 hours. Because the station in located at 39.4 ° N, reserve time of 312 hour was considered. (Campbell Scientific, 2004)

Required battery capacity = (systems current drain)*(reserve time)/0.8 (Ahr)

The 0.8 value is to limit the battery depth of discharge to 80%. This assumes the worst conditions.

Required battery capacity = 0.053*312/0.8 = 20.26 Ahr

For this solar-weather station a rechargeable battery 12V with 24 Ahr and a 12 V charging regulator to connect the battery with charging source must be employed.

3.4.2 Solar panel

Solar panels charge batteries by converting sunlight into direct current. The panels can source current on cloudy days but not at nigh. Dirty panels, shadows, inversion, ice and trees may reduce the solar panels charging power.

Solar panel size for the solar-weather station was calculated by using this equation:

Solar panel current > ((system Ahr/day) x 1.2)/(hrs of light)

The 1.2 was taken into account because for solar system losses and the number of hours were suggested the worst case conditions. The shortest day on the Stillwater site is the 21st of December when time difference between the sunrise and the sunset is only 9 hours and 24 minutes. Because of the poor irradiation conditions in the very early morning and in the very late evening, only 6 hours of sunshine were taken into calculation, but first we need to calculate the station's average amp hours per day:

Ahr/day = (0.053 A)*(24 hr/day) = 1.272 Ahr/day

Assuming the solar panels source current for six hours per day, the panels must produce:

(1.272 Ahr/day)* 1.2)/6 hr = 0.2544 A

The Campbell Scientific as a major supplier offered in their proposal also a solar panel SP20 with 1.19 A current at peak, however an SP 10 10-Watt Solar Panel with 0.59 A current at peak will be enough. For reliability reasons the SP20 was chosen. The solar panel will be installed on the main tower in a height of 3 meters with a 30° tilt (Pic. 12).

The powering system is dimensioned with a reserve and will be able to work also during days with not sufficient solar irradiation. The only function which is prohibited is the heater installed inside the pyranometer SPN1, because the heater by him self will need up to 1.5 A.

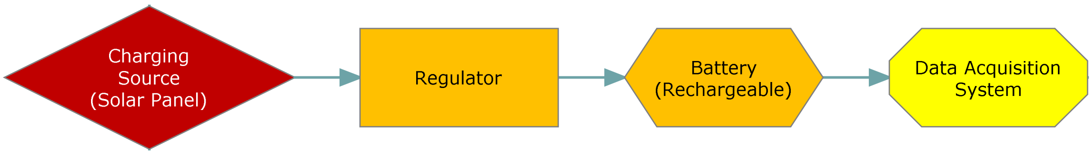
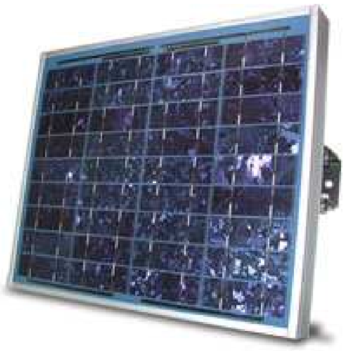


Fig. 25 Schema for independent power supply secured by the solar panel



Pic. 12 Solar Panel SP20

4 Description of results

4.1 Solar - Weather Station Positioning

The solar-weather station positioning within the parcel owned by Enel North America at the Stillwater site after consideration of all of the obstacles, barriers as well as opportunities was quite unambiguous (Fig. 26).

The first and also the biggest barrier located in the north-eastern part of the parcel, is created by a new geothermal power plant. The power plant has a total size of 10 acres and the only concern was about the water vapor created in a process of the binary cycle operation. The only possible solution for positioning of the solar-weather station in this case is a distance of at least 50 m. With regard to the localization of the power plant on the north-east, any shielding by positioning anywhere on the south will have zero impact on the solar instruments.

Another negative factor by positioning of the solar-weather station is a dusty road on the east and north of the parcel. The easiest solution by positioning of the station in this case is again a distance of at least 20 m.

One additional road is also dividing the parcel in the middle into two parts. This road is momentary not in use and for the future can be utilized as an access road to the solar-weather station. On the end of the road is an area of approximately two acres where is growing only a sparse vegetation of bushes.

The last limitation by the solar-weather station positioning is a planned photovoltaic power plant which should be located in the middle part of the parcel with a southern limitation on the additional route described in the upper paragraph.

After considering of all of the aforesaid conditions, the best positioning for the designed solar-weather station will be the middle part of the parcel, bellow from the additional route and on the south from the area with the sparse vegetation of bushes. The route will be at the same time used as an access route with utilization only for the purpose of station maintenance.

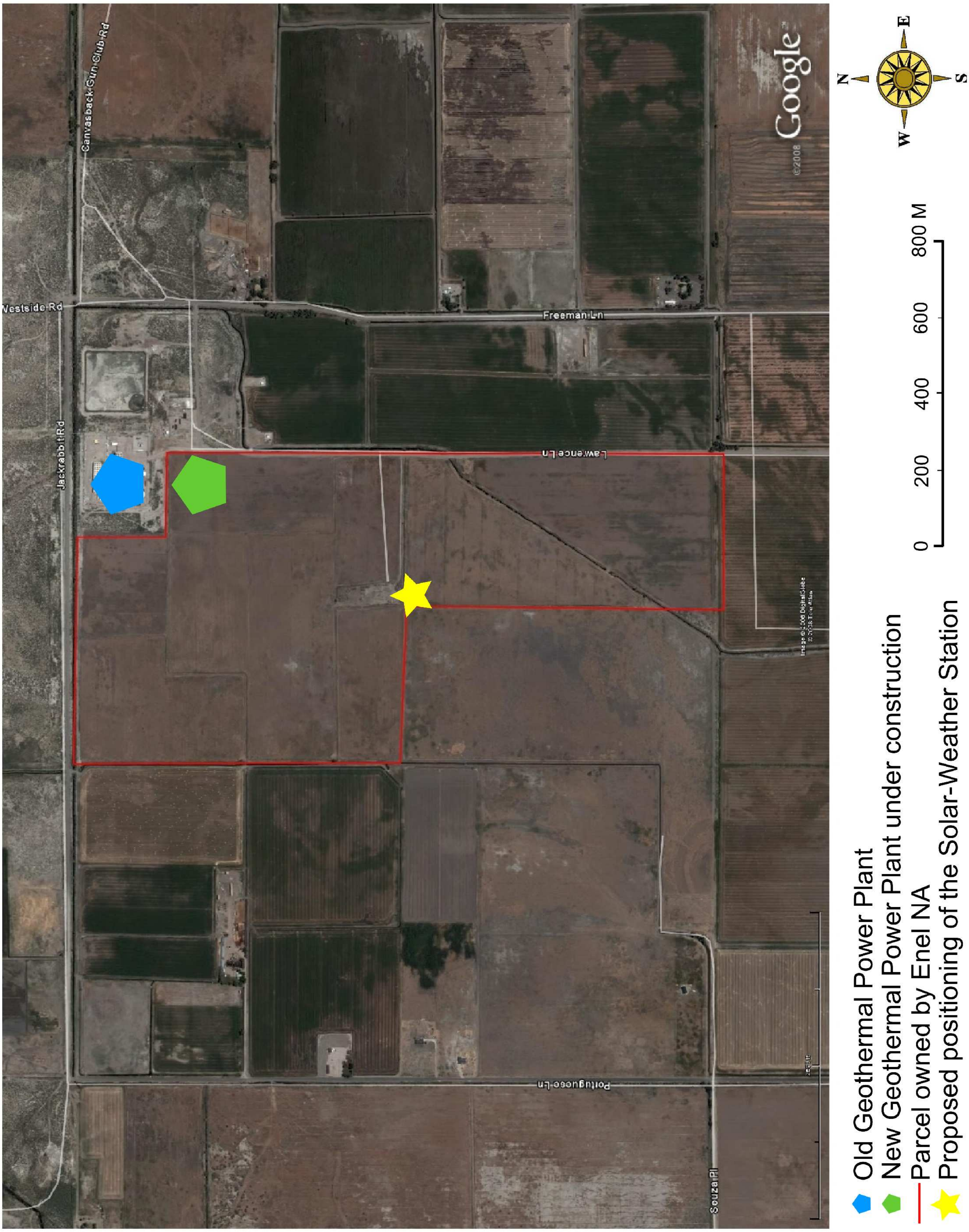


Fig. 26 Proposed positioning of the Solar-Weather Station with the parcel owned by Enel North Amrica at the Stillwater site in Nevada, USA

4.2 Solar - Weather Station Protection

The price of the equipments and also their sensitivity are good reasons for keeping it save and secure. Because of the positioning in the middle of a parcel where the nearest buildings are located 600 m far away, the biggest concern arose about vandalism and wild animals.

For the protection against vandalism or stealing a fence around the station will be build. This wire fence will consist of nine fence rails, deployed in a shape of a square with a dimension of 6,6 x 6,6 metres. In the north part of the fencing an entrance door will be installed and locked. Whereas the lowest pyranometer will be installed on a pole in a high of 1.5m, the fencing can not be higher, because in other case a shielding will be caused. For this reason a cattle wire will be placed on the top.

Additional suggested protections are warning signs placed on the fencing. The signs should inform about private character of the property with No Entry.

Further recommendations against vandals from Campbell Scientific (2001) as followed:

- Camouflage the station.
- Disguise enclosure boxes to look like rocks or unimportant objects.
- Put “Warning” stickers on enclosures.

The fencing around the solar-weather station should serve as a protection against wild and other large animals as well.

Other jeopardy for the instruments and wiring is denoted by rodents. Against rodents are recommended following actions:

- Placing of moth balls or crystals along the wires to prevent rabbits or other rodents from chewing on wires.
- Routing of wires through flexible metal or plastic conduit to isolate censor cables from the environment and secure the ends with Adum heat shrink.
- Running of wires through PVC pipes that terminate in “rodent free” areas.

- Wearing gloves, wipe wires or flexible conduit with a thick cloth soaked in rubbing alcohol or deer/rodent repellent.

Protections against birds consist of preventing of landing on the sensors or cables. The cables should be twisted around the poles and the sensors protected with a spiny belt around.

The last recommended protection is against insects. A method introduced by Campbell Scientific consists in placing of moth balls or crystals in enclosure to prevent fire ants, wasps, spiders and other insects from nesting.

4.3 Solar - Weather Station Design

The design of the solar-weather station is one the most important outputs of the thesis. The introduced arrangement of instruments is considering the interacting between individual equipments and the influence of the installed poles as well.

The solar and weather instruments will be placed on three poles. Two of the poles are suggested with a concrete bed just the main tower will be fixed via iron tower base and four anchors. The anchors must be cemented in a distance of 4,6 m from the tower base. This concrete bed will be used also for the corner fence rails. Additional fence rails must be cemented in the middle of the sides. The main tower will be fixed with eight guy wires connecting the tower with the anchors in two heights (Fig. 29). Southwest Windpower (2008)

The poles are arranged in a line with a course north-south. The first pole with the concrete bed will have a height of 1,8 m above the terrain and will host two pyranometers. The first pyranometer CMP3 for measuring of a total solar radiation with a tilt of 20° will be placed on a mounting rod in a height of 1,5 m above the terrain. The second pyranometer SPN1 will be fixed on a leveling base plate on the top of the pole.

The main tower will be supplied by the company Southwest Windpower and the total height of the tower will be 8,8 m above the ground. The distance between the pole 1 and the tower will be 1,5 m. The tower is designed without any shadow impact on the pole Nr. 1 (Fig. 27). From the top to the bottom following instruments and equipment will be installed:

- Wind Wane and Anemometer (8,8m)
- Solar Panel (3m)
- Temperature and Humidity Probe (2m)
- Cellular Antenna (1,8m)
- Weather Resistant Enclosure for the Battery, Data-logger and Modem (1,5m)

The last pole will be delivered together with the rain gauge and will be fixed into a concrete bed 1,0m behind the main tower. The rain gauge will be installed on the top of the pole (Fig. 28).

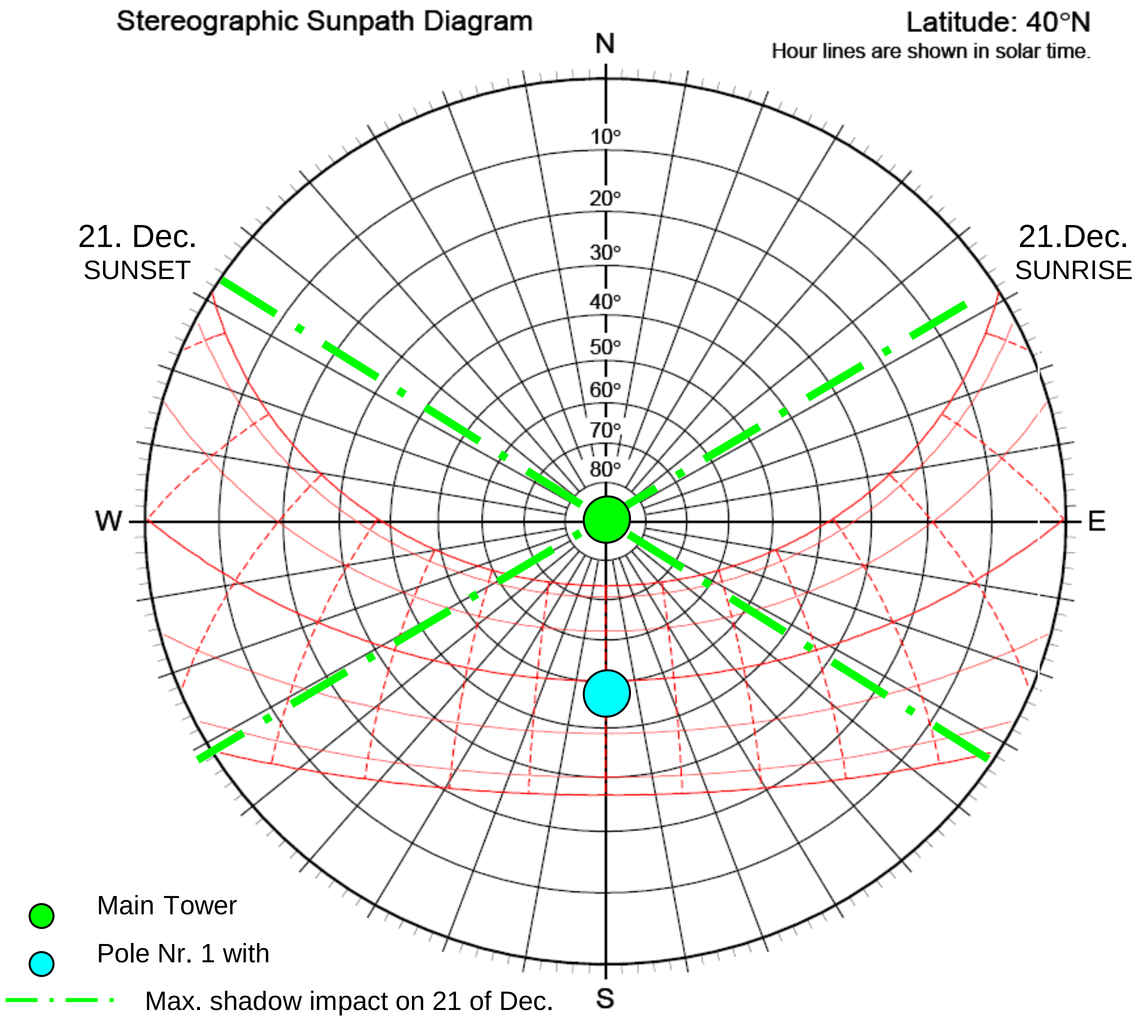


Fig. 27 Stereographic Sunpath Diagram for the Stillwater location (Luxal, 2007)

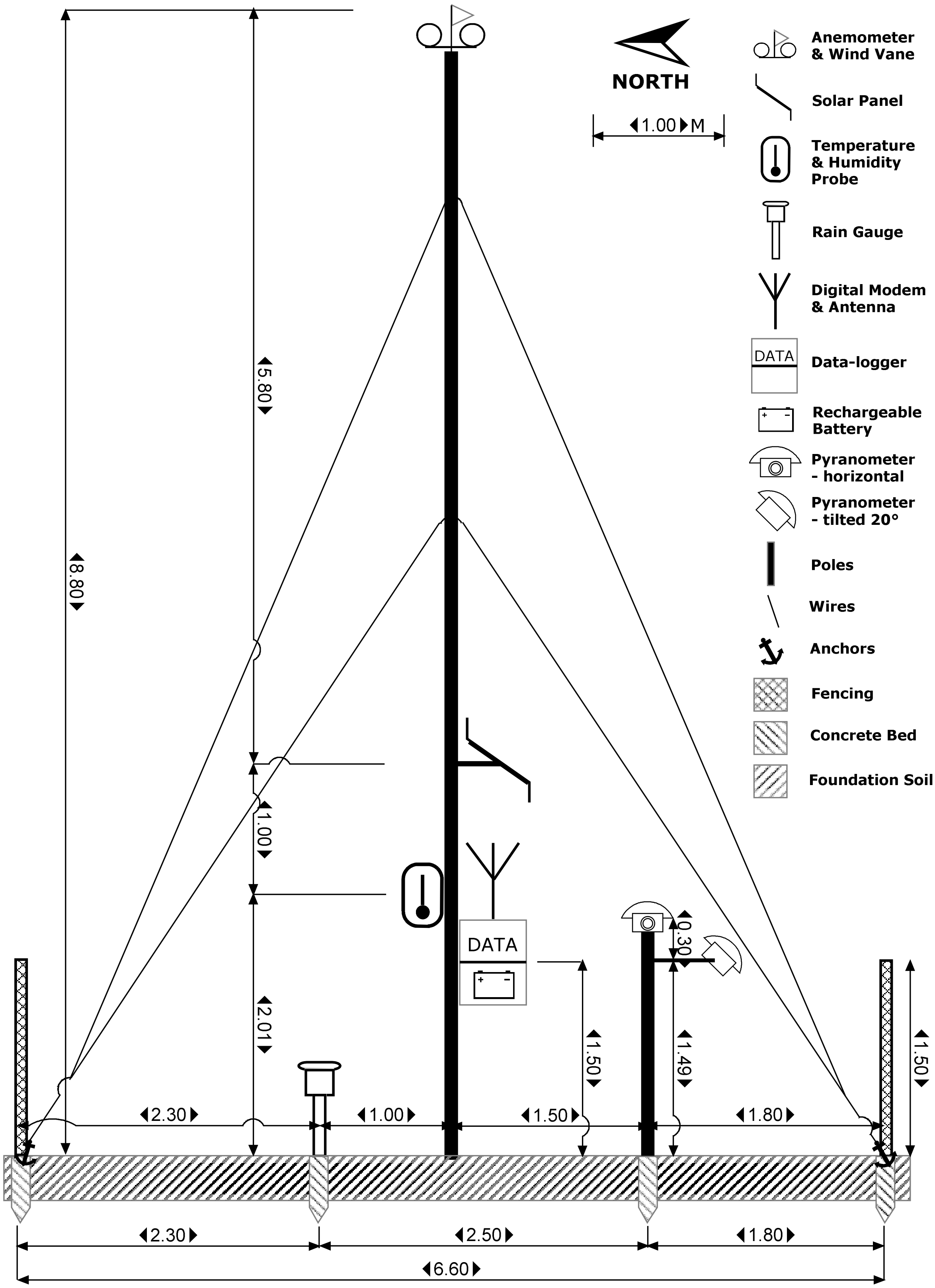


Fig. 28 Solar-Weather Station design in profile

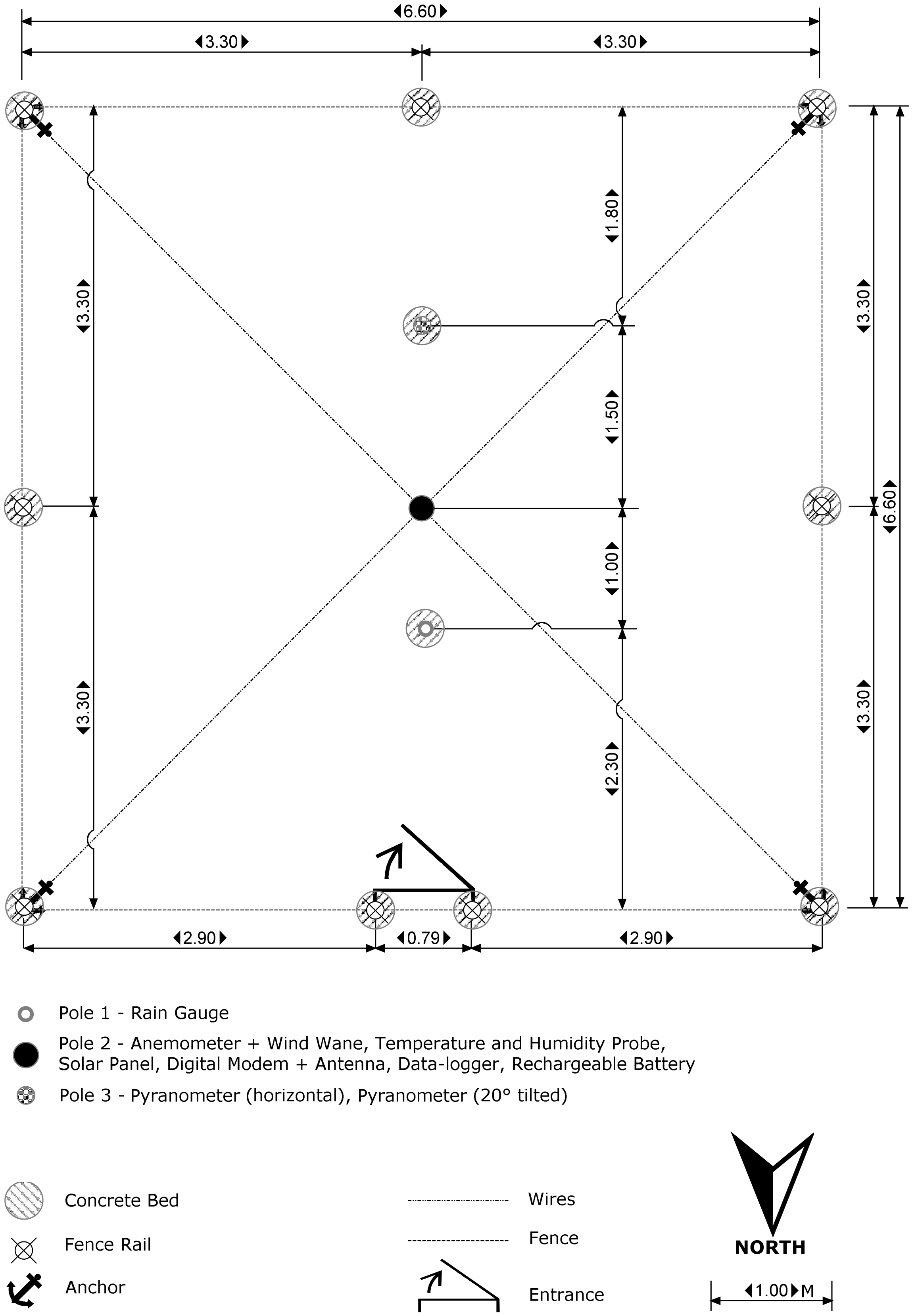


Fig. 29 Solar-Weather Station design in perspective

Conclusions

The process of designing of the solar-weather station started in June 2008 short after my ingoing to Enel North America as my first task and was ended in December 2008 with the erection of the system, unfortunately without my presence at the Stillwater site because of my comeback to Europe.

For all that I think that my role in the process was brought into a successful end and all of the requirements from the start were executed:

a) The defined range limits and inquiry for resolution and accuracy are by all selected instruments adhered. The price limit of $15.000 was unbroken. After totaling of all of the items and addition 10% for contingency (postal charges, insurance, fencing) the sum ended at $14,662.05 (Fig. 30).

b) The instruments with a significant power consumption were defined and the consumption of the solar-weather station rated at 0.053 A. A solution with rechargeable battery and a solar panel as charger was adopted. The defined consumption is adequate for a battery capacity with 20.26 Ahr. The nearest applicable has 24 Ahr. The expected solar panel should have a source current at least 0.2544 A. The selected SP20 with 1.19 A has a big enough reserve for charging the battery also during cloudy winter days.

c) The data processing will be secured by a data logger CR 1000 with verified compatibility with the other instruments and enough wiring capacity for all of the sensors. For the data transmission a cellular modem Raven XTA was employed and the only present provider Alltel stipulated.

d) The solar weather station was placed within the parcel owned by Enel North America with consideration of all of the obstacles as well as future plans for the area. The design of the station is providing a solution where none of the instruments or equipments is influencing the others. Positioning for the designed solar-weather station will be the middle part of the parcel, bellow from the additional route and on the south from the area with the sparse vegetation of bushes. The route will be at the same time used as an access route with utilization only for the purpose of station maintenance. Possible influence of any obstacles will be on this position delimited.

Weather Instruments	Supplier	Type	Price
Anemometer	Campbell Scientific	RM Young Wind Sentry Set 03001-L	$588.00
Wind vane			
3/4 x 1 inch NURAIL Fitting			$18.00
Sensor Cross-arm			$83.00
Thermometer	Campbell Scientific	CSL Temperature/RH Probe CS215-L	$354.64
Humidity meter			
Radiation Shield			$115.00
Rain Gauge	Campbell Scientific	Texas Electronic Rain Gauge TE525WS-L	$394.50
Monting Pole			$95.00
Subtotal			**$1,648.14**
Solar Instruments	**Supplier**	**Type**	**Price**
Pyranometer	Dynamax	SPN1	$5,750.00
Mounting Rod			$71.00
Leveling Base Plate			$250.00
Pyranometer - 20° tilt	Kipp&Zonen	CMP3	$878.00
Mounting Rod			$71.00
Subtotal			**$7,020.00**
Power Instruments	**Supplier**	**Type**	**Price**
20W Solar Panel	Campbell Scientific	SP20	$410.00
12V Charger			$180.00
12V Battery (24Ahr)			$180.00
Subtotal			**$770.00**
Data logger & Modem	**Supplier**	**Type**	**Price**
Measurement & Control Datalogger	Campbell Scientific	CR1000	$1,390.00
Support Software			$565.00
Custom Program and documentation			$350.00
Water-Resistant Enclosure	Campbell Scientific	ENC14/16	$315.00
GPRS Cellular Digital Modem	Campbell Scientific	RavenXTA	$545.00
Mounting Kit			$22.00
Data Cable			$4.00
800Mhz 1dBd Omni Cellular Antenna			$110.00
Cellular Phone Antenna Cable			$40.00
Subtotal			**$3,341.00**
Tower	**Supplier**	**Type**	**Price**
EZ Tower	SW Windpower	AIR EZ Tower 29 ft.	$550.00
TOTAL			**$13,329.14**
Contingency 10%			$1,332.91
SUM			***$14,662.05***

Fig. 30 The costs summary of the single instruments and sensors with added contingency

Whereas this designing task was the first of this kind by Enel North America experience and contacts will remain and they can be used again by any similar project of a measuring station. Also the mistakes and complications can be reduced.

The primary purpose for the design of this solar weather station was to obtain input data for an intended photovoltaic power plant at the Stillwater site, but on the other hand, the outputs can be after request used also as a regular weather data for any others activities in the area.

ACKNOWLEDGEMENT

The topic of the thesis was selected as an opportunity to learn something new from the other part of renewable energy projects preparation and on the other hand as a part of a new field in my professional career, the solar energy. However the thesis is not a real scientific work, but a full-scale technical processing description of a solar-weather station design for a special purpose in desert conditions, the process and the results are applicable for any other case studies and I hope that they will help also others freshmen in this field.

On the face of it the topic should be an easy assignment, but after several weeks spent only collecting proposals with lists of instruments, they were completely new to me and I did not have any idea about the parameters I found very helpful the advices from my former superior Alberto Iliceto who was always ready for any consultation. He was also the only one who defined the criteria for instruments selection and who send me to the Stillwater far a site visit and analysis.

The results were completed and the instruments already ordered when I wrote the first version of the thesis, unfortunately because of the time pressure I forgot about some important milestones to mention. From this point of view the strict ranking from my supervisor Werner Weiss was very helpful and impel me to review the whole process and to describe deeper the steps they were absolved during the assembly of the solar-weather station. Thanks to this review I found out many hidden patterns and for example better understood the dependences between sensors and data logger.

At last but not at least I would to say many thanks to my wife Veronika for all of the weekends and evenings spend with writing and considering the thesis. I hope that I will find a way how to compensate it.

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