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Basic photovoltaic system (PV) design requirements

Introduction

The design of a photovoltaic (PV) system must reflect a transparent trade-off between quality, reliability and price. The supplier should clearly explain the reliability of the PV system both in terms of the system sizing and in terms of the quality of the system components.
The sizing of the PV system should be based on the relevant reliability factors and on a simulation of the behaviour of the PV system under the given circumstances on site.
The PV system components should require a minimum of maintenance during the operating life.
This specification states the minimum requirement for the sizing, design, engineering, manufacture, assembly, installation, commissioning and maintenance of solar photovoltaic (PV) power systems. Such a system consists of solar module(s), control equipment, battery bank, mechanical support and ancillary components.

Abbreviations

DDOD	Daily Depth of Discharge
IMR	Inspection, Maintenance and Repair
PV	Photovoltaic
SOC	State of Charge
SPS	Solar Power System
STC	Standard Test Conditions
VDRL	Vendor Data Requirement List

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Definitions

1 General Definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, assembly, installation, testing, commissioning/management of a project. The Principal may undertake all or part of the duties of the Contractor.

The **Sub-Contractor** is the party, which is appointed by the Contractor to carry out part of all the work.

The **Manufacturer/ Supplier** is the party, which manufactures or supplies equipment and/or services to perform the duties specified by Contractor. Manufacturer/Supplier and Contractor may be the same party.

The **Principal** is the party, which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

2 Specific Definitions

Certificate	Document issued by a recognised authority certifying that it has examined a certain type of apparatus and, if necessary, has tested it and concluded that the apparatus complies with the relevant standard for such apparatus.
Daily Depth of Discharge	The quantity of charge taken from the battery on a daily basis expressed as a percentage of the nominal capacity of the battery.
Hazardous area	An area in which an explosive gas atmosphere is, or may be expected to be, present in quantities such as to require special precautions for the construction, installation and use of electrical apparatus.
Insolation	Radiant power incident upon a unit area of surface (Wm^{-2}).
Standard Test Conditions	The Standard Test Conditions (STC) are: (1) Cell temperature: 25 +/- 2^0C. (2) Insolation: 1000 Wm^{-2} . (3) Air mass: 1.5, representing the sun at 45^0
Autonomy	The number of full days the PV system can supply the specified load under Worst Case conditions.
Worst Case conditions	The day/week/month with the designed minimum battery capacity available to supply the load(s) during the defined number of days of autonomy.

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3 BASIC REQUIREMENTS

3.1 General

The solar power system shall comply with the requirements of IEC 60904-1, 2 and 3.

The PV system shall be suitable for continuous operation at full load within the specified service conditions. The PV system shall be designed for a **minimum** expected lifetime of:

- 5 years for lead acid batteries
- 20 years for solar modules
- 10 years for other PV system components

The specified lifetime of the assembly shall be met by means of scheduled maintenance programmes.

3.2 Operating principle

The specified performance requirements shall be based on the following basic operating principle of the SPS:

- The system consists of an array of solar modules, a controller system and a battery system.
- DC output from the modules is regulated for storage in the battery system and, if applicable, for direct supply to the load.
- Batteries are charged during the day to achieve a full state of charge (SOC) condition. During periods of darkness or little sunlight the load is supplied from the batteries.
- Additional battery capacity may be required to ensure that the load is supplied with at least the minimum voltage during periods of insufficient charge from the solar array.

3.3 Operational requirements

The SPS will be used to power a range of various applications and shall be suitable for reliable operation in an environment specified by the Principal.

The SPS shall be suitable for unattended operation at onshore and offshore sites as specified.

The equipment and all its accessories shall be suitable for the area classification as specified in the requisition.

4 DESIGN AND CONSTRUCTION

4.1 General requirements

The solar PV power system shall be designed for satisfactory operation under site and load conditions as specified by the Principal.

Individual components of each sub-system, which form the complete system, shall be completely compatible and well proven through field duty similar to the specified operational requirements.

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All components shall be suitably protected for operation in a tropical climate, and they shall be moisture-proof and fungus-proof.

All exposed hardware hinges, etc. shall be AISI 304 stainless steel.

The solar PV power system shall be designed to be adaptable for extension and have a degradation level of the solar module output of not more than 20% over 20 years.

The overall system, which includes all system components, shall be protected against discharge of the battery through the modules (reverse current protection).

The system shall be protected against reverse polarity of modules and battery.

The system voltage, nominal and maximum current shall be clearly stated

4.2 Basic issues

The SPS shall be designed to supply a nominal 12Vdc or 24Vdc or 48Vdc output, or other as specified.

The size of the SPS shall be such that the energy requirement of the load can be met directly or via storage in the battery bank under all “normal” meteorological conditions. Conditions as specified by the Principal, under which the energy requirements will not be met, shall be notified by the Manufacturer/Supplier.

The battery bank shall be designed to supply the load under conditions that the solar modules alone cannot meet the energy requirements.

The size of the SPS shall be such that at any moment the state of charge will be at least 20% and/or the daily depth of discharge will not be more than 20%.

The controller, monitoring, indication and ancillary circuits shall be installed in an enclosure suitable for the operational and ambient conditions. The enclosure shall be suitable for wall-mounted operation and maintenance. The wall of the building or location where the enclosure is installed shall not be considered as part of the enclosure. Internal cooling shall be by natural ventilation or as specified by Principal. The temperature of internal components shall not have a detrimental effect on any other components within the enclosure.

4.3 Insolation data

The design of the SPS shall preferably be based on insolation data provided by the Principal. When not available insolation data from internationally recognised sources shall be used.

Manufacturer and/or Contractor shall submit detailed information on his source(s) together with his design of the SPS to the Principal.

4.4 SPS parameters

Contractor shall submit the following system parameters prior to commencement of detailed engineering:

- Number of solar modules and the average output of each solar module under STC conditions;
- Same for the expected operational and environmental conditions;
- The physical size of each module;

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- The effective module current;
- The battery capacity at c/10 and at c/100 rate, and even higher C/xxx values if applicable and available, as well as the discharge rate during its autonomy period of minimum four (4) consecutive days;
- The physical size and weight of the batteries;
- Battery charge factor (efficiency);
- Battery recovery time at end of autonomy period (seasonal storage for high latitude);
- Tilt angle of the modules;
- The maximum and minimum terminal voltage supplied to the equipment after wiring, diodes, circuit breakers, etc. during the day and night and also the mean voltage;
- System losses and de-rating factors due to:
  - charge efficiency of the batteries
  - degradation
  - dust deposit
  - environmental conditions (temperature, wind, sandstorms, hail)
  - insolation variation due to normal year to year statistical changes
  - quiescent current of control equipment, metering, alarm
  - system losses in control equipment, wiring, fuses, diodes, circuit breakers
  - mismatch losses due to modules in series

Contractor shall submit evidence of satisfying the basic issues as mentioned in paragraph 4.2 by means of a computer aided design and system simulation print-out, taking into account all parameters as mentioned in this paragraph 4.4.

Principal shall submit the following parameters:

A) Specifications of the load

- Type of application (load)
- Power consumption in Watts or Amps
- Nominal operating voltage and operating voltage limits of the load(s)
- Current (average, min. and max.)
- Load pattern (hrs/day/week/year)
- Days autonomy required (see par. 4.2)
- Inspection/maintenance intervals
- Required IP rating for protection of components
- Hazardous area classification, if any
- Type of “load cable” (outside diameter, number of cores, core dimensions)

Please note: The magnitude of some loads (e.g. cathodic protection) is difficult to determine because of the changing circuit parameters. In systems where load fluctuations are anticipated, the Principal shall provide the Contractor with the upper value of load current.

B) Ambient conditions

- Location (latitude, longitude, altitude)
- Ambient air temperature (max., min., average)
- Relative humidity (max., min., average)
- Airborne particles (e.g. sand, salt, corrosive agents, hail)
- Wind velocity ($msec^{-1}$)
- Site situation/condition (e.g. access limits)
- Available space for installation

4.5 Specific load requirements regarding telecommunications

The positive terminal and system should be earthed.

To avoid unacceptable levels of noise in the connected equipment, smoothing of the DC output is required achieving

- less than 50 mV rms over the range 10 Hz to 10 MHz;
- less than 1 mV rms psophometrically weighted (800 Hz centre of frequency)

4.6 General construction features

4.6.1 Where specified, all components and accessories specified shall be certified suitable for installation in classified hazardous area zone 1 or zone 2 according to ATEX standards.

4.6.2 The degree of protection (IP-rating) of each enclosure shall be specified by the client.

4.6.3 The equipment and all its accessories shall be suitable for altitudes up to 2000m.

5 SYSTEM REQUIREMENTS

5.1 Solar array

5.1.1 The solar array shall comprise a suitable number of series and parallel connected solar modules to give a nominal 12Vdc, 24Vdc, 48Vdc or other output as specified.

5.1.2 The solar modules shall meet the requirements of:

- The Photovoltaic Modules Test specification IEC 61215.
- Repetitive humidity-freezing cycling Test between +85°C, 85% humidity and -40°C.
- The salt spray test according to IEC 68-2-11 (test Ka).

(These are all basic tests that simulate the climate in as far as it affects the working of the solar module)

5.1.3 The solar module efficiency shall be higher than 12.0% (cell efficiency shall be higher than 14.0%).

5.1.4 The solar module(s) shall be mounted on a supporting structure constructed from corrosion resistant material and suitable for installation at the specified site.

5.1.5 The solar module support structure shall be able to resist wind speeds of up to 150 km/h.

5.1.6 Cable ducts shall be integrated in the solar module support.

5.1.7 The solar module support shall be designed for tilting for optimum absorption of solar energy and also for creating a self-cleansing washing effect on the solar modules when it rains. Tilt angle should be fixed.

5.1.8 The solar module support structure shall be designed in such a way that a battery enclosure could be placed underneath.

5.1.9 The solar modules shall not be shaded.

5.1.10 The solar module's own frame shall be supplied with holes or slides for mechanical attachment and be made of corrosion resistant material.

5.1.11 Electrical connection shall be made on a sturdy terminal bloc in an IP65 junction box (or better) in which two (2) by-pass diodes shall be incorporated to prevent hot spots.

5.1.12 Electrical characteristics of the solar modules shall be stated with the solar parameters, and be listed on a non-removable sticker on the backside of the solar module.

5.1.13 Solar module shall have an IP65 rated junction box with cable glands and a terminal block that are fit for cables of minimum of 4 mm^2

5.1.14 Solar module should have an individual serial number behind the front glass.

5.1.15 If the modules are installed at a significant distance from the load and/or battery, attention shall be given to the selection of the output voltage and/or diameter of the cabling to avoid unacceptable energy losses.

5.1.16 Provisions should be made to prevent a current drain from the batteries through the solar array.

5.1.17 Normal engineering principles shall be applied to ensure that the modules and mountings are adequately strong to withstand the local environmental conditions.

5.1.18 Where requested the solar modules shall be certified for use in a zone 1 hazardous area in accordance with the ATEX Standards.

5.1.19 Site and panel temperatures shall be taken into account for the performance of the solar modules(s).

5.3 PV charge regulator

5.2.1 The function of the charge regulator shall be to control the energy flow between the solar array, the battery bank and the load. To ensure a healthy battery condition voltage regulation is essential. Care is required in the establishment of the charge regime if the system target design life of minimum 20 years is to be achieved.

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5.2.2 A charge/discharge regulator shall ensure proper charging and discharging of the batteries through the following functions:

- Overcharge protection of the battery by switching off the solar array from the system if the battery is already fully charged. The regulator must be of the type series or on/off regulation. Shunt regulators are not permitted.
- Battery protection by switching off the load from the system if the voltage drops below a limit voltage with optional an alarm contact for display of low voltage.
- Temperature compensation on maximum charge voltage.
- Prevention of overnight discharge of the batteries through the solar module (blocking diode function).

5.2.3 The PV-charge regulator shall be protected against reverse polarity of batteries and solar modules.

5.2.4 The charge regulator shall apply a temperature compensated boost-charge and float-charge principle in order to boost-charge the battery in the beginning of a charge cycle. This boost-charge allows the electrolyte of the battery to be mixed. It prevents stratification of part of the electrolyte. It enhances a very efficient beginning of a charge cycle. It utilises the maximum available charge capacity during sun hours.

The boost-charge and float-charge level shall be field adjustable.

5.2.5 For medium size- and large size PV systems, multiple sub arrays should be used, in order to disconnect the solar modules in parts from the batteries to prevent overcharge.

(This allows a gradual change in the voltage when the maximum state of charge of the battery is nearly reached and results in optimal charging behaviour.)

5.2.6 For medium size- and large size PV systems a master-slave configuration for the charge regulator should be available. This allows the PV system to be extended modularly in case a higher system load is required during the lifetime of the PV system.

5.2.7 An external temperature/voltage sense shall be available. This external temp/volt sense shall be connected to the battery for an optimal measurement of battery temperature and battery voltage and consequently an optimal adjustment of charge voltages during charging.

(The battery voltage is used as an indication of the state of charge of the battery. The relation between the voltage and the state of charge is temperature dependent. The battery voltage must be measured on the battery electrodes. If the battery voltage is measured in the regulator then the voltage drop is not taken into account and the voltage is not measured correctly.) In case of damage of the sensor, a fall back mechanism must be available to keep the set points with in a save range.

5.2.8 The minimum number of alarms for each PV system shall be:

- High battery voltage (If the battery voltage is high, the system should stop charging.)
- Pre-warning low battery voltage.

- Low battery voltage
- Load disconnect (due to a low voltage of the battery) should preferably have two levels: one for the essential loads and one for the none-essential loads (If the battery voltage will become too low then the load will be switched off to prevent permanent damage to the battery.)

5.2.9 The regulator shall have a working range of:

- Temperature between -10º C and +55º C
- Humidity between 0 and 100%

5.2.10 The print circuit board (PCB) shall be able to resist adverse weather conditions (by means of a conformal coating).

5.2.11 Remote monitoring of the alarms should be available with voltage free contacts.

5.2.12 The following LED indicators shall be available on the regulator:

- The status of the sub arrays (connected/ disconnected)
- Pre-warning low voltage
- General alarm load disconnected

5.2.13 The internal voltage drop of the regulator should be less than 400mV

(If the voltage drop is too high then the batteries cannot be charged properly.)

5.2.14 Regulator's terminals shall allow adequate core sizes of cables. For solar module cable the terminals shall allow a minimum of 4 mm^2 and for the battery a minimum of 16 mm^2.

5.2.15 The mean time between failures (MTBF) should be higher than 50.000 operating hours.

5.2.16 Test switches for the regulator's most critical alarms i.e. battery low voltage, load-disconnect and load reconnect, sub array disconnect and reconnect (if applicable), shall be available to allow testing of these functions.

5.2.17 For outside mounting the charge regulator and other related electronic parts should be housed in a stainless steel or GRP box with ingress protection IP 65 to protect the regulator from rain, moisture and dust.

5.2.18 IP 65 cable glands with strain relief should be used to connect the wires to the regulator.

5.3 Battery banks

5.3.1 The following types of batteries, which should be marked as solar batteries, will be allowed:

- Sealed lead-acid

These batteries are “maintenance free” (no topping up of electrolyte required).

The average charge factor shall be at least 1.15

- Open lead-acid

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These batteries require maintenance. The level of electrolyte shall be visible to determine the proper functioning of the batteries.

The charge factor should be at least 1.15

- NiCad (Nickel-Cadmium)

These batteries are almost maintenance free.

The charge factor for these batteries should be at least 1.4

5.3.2 The expected lifetime of the battery shall be at least 5 years. Minimal state of charge and the daily depth of discharge and the maximum operating temperature shall be taken into account for determination of the expected lifetime of the battery.

5.3.3 If installed outside the batteries shall be placed in a (preferable isolated) housing to protect them against rain, moisture and dust. Direct exposure to sun and heat should be avoided.

5.3.4 The selection of battery type should be carried out on a case-by-case basis, largely on a Total Cost of Ownership screening, using the following criteria for each battery option:

- Initial purchase and installation
- Life cycle
- Projected replacement cost
- Operational cost (e.g. logistics, maintenance, downtime)
- Disposal costs

5.3.5 The battery bank, specially designed for photovoltaic applications, suitably sized for the system, shall comprise the required number of batteries. Where requested it shall be certified together with its enclosure for use in hazardous areas. Preference is given to lead-acid batteries.

5.3.6 Site temperature limits must be taken into account in the selection of the battery type due to the effect on available capacity and lifetime expectancy.

5.3.7 The batteries shall be mounted in a corrosion (preferable isolated) resistant enclosure or assembled in acid proof racks. Battery housing shall be well ventilated and lockable.

5.3.8 The batteries shall be arranged to facilitate access for maintenance purposes. Intercell connectors shall be provided. The use of parallel arrangements should be avoided. Where batteries are connected in parallel, steps shall be taken to ensure equalisation between branches.

5.4 Ancillary equipment (to be specified by Principal)

5.4.1 A Central Control and Distribution box may be provided, containing the control equipment, an on/off switch to be controlled from the outside of the enclosure, fused terminals for the load(s), and (certified) cable glands corresponding with the installation cables.

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5.4.2 The interconnection between the solar array and the Central Control and distribution box may be made via a plug and socket unit. This arrangement facilitates the electrical isolation of the solar array from the system for repair/replacement purposes.

5.4.3 The interconnection between the battery box and the Central Control and Distribution box may be made via a plug and socket unit. This arrangement facilitates the electrical isolation of the battery bank from the systems for IMR purposes.

5.5 Cables and Accessories

5.5.1 All interconnecting cables between the electrical components shall be of a type conforming to the requirements imposed on installation cables.

5.5.2 Cable glands for terminating the cables shall be properly sized for wire diameter. The same applies to adaptors, if used.

5.5.3 Sufficient space should be left in the system for cable routing.

5.5.4 One terminal for each wire shall be used.

5.5.5 All wiring, terminals and connection points shall be permanently labelled with the same notation shown in the Manufacturer/Supplier hook-up sketch and drawing.

5.5.6 Ground cable should be steel wire armed.

5.5.7 Cables that, under normal conditions, carry a load of more than 5 A, shall be fused. (Module cables do not require fuses).

6 System sizing

The basic principle for system sizing is that the defined load can be supplied in the given climate and site conditions, with the required autonomy and with a long life-time expectancy of the battery.

The right number of modules and the right battery size are calculated.

6.1 For long battery life-time expectancy the following requirements shall be met:

- The maximum daily depth of discharge of the batteries shall not exceed 20% of its capacity under normal conditions.
- The minimum state of charge shall not be less than 20% of its capacity.

Note: the battery lifetime is dependent on the number of discharge cycles and the depth of discharge.

6.2 The Principal should supply the site information and preferably climate data. If available the insolation data at or near the location, which forms the basis of the system sizing.

If the supplier makes use of his own data, it shall be based on an internationally recognised source. In this case the source should be stated clearly. Such in order to make a fair comparison between the different contractors.

6.3 The system sizing program shall take the following aspects of the climate into account:

- The sun's insolation in kWh/m^2

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- Albedo effect (light reflection by the earth's objects) (see table 1)
- Percentage of diffuse light (light scattering by sky's objects)
- Average ambient temperature

These factors influence the quantity of light. The quantity of light is the most influencing element in the generated output of the solar modules.

The temperature affects the output of the solar modules.

6.4 Consider following factors to determine the performance of the solar modules:

- Degradation of solar modules
- Solar module de-rating due to dust (see table 2)
- Azimuth (East- or Westward deviation of ideal orientation)
- Reduction on insolation (Maximum reduction in % of average insolation in kWh/m^2)
- Mismatch loss due to series and parallel connection of solar modules.

(Because two modules generally don’t have the same power characteristics, there is a small efficiency loss, if they are placed in series and / or in parallel.) (see table 3).

6.5 The reliability of the system or the probability that the system is supplying the required energy (Ah) in %. (E.g. 99% means that the system is able to supply the load for 99% of the time.)

6.6 In case the load is disconnected because of low voltage disconnect, the system shall be designed for recharging the battery to fully charged state within 30 days.

6.7 Minimum autonomy of industrial systems shall be 4 days. By definition:

$$\text{autonomy} = \frac{C_{eff} * (100\% - (\min SOC + \max DOD))}{\text{Daily load in Ah}}$$

C_{eff}= effective capacity in Ah,

min. SOC= minimum State Of Charge of the battery

max. DOD= maximum Depth of Discharge of the battery in the month with the lowest insolation under normal conditions.

6.8 The efficiency losses of all equipment shall be taken into account. This also includes the losses from inverters or DC-DC converters, cables and switching equipment. This efficiency shall be stated clearly.

6.9 The percentage of time that the load is supplied from the battery only (i.e. during the night) shall be taken into account and mentioned.

6.10 The average charge factor, which is the amount of Ah generated by the solar modules divided by the amount of Ah used during a charge/ discharge cycle, shall be more than 1.15 for lead acid batteries and more than 1.4 for NiCad batteries.

6.11 The calculations justifying the sizing of the system in terms of battery size, number of solar modules, tilt angle of the solar modules and type of charge regulator, shall be made available. This shows the State Of Charge (SOC) and the Daily Depth Of Discharge (DDOD) in every month and that the battery is optimally charged.

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6.12 All relevant safety margins that are taken into account in the system sizing calculation shall be clearly explained.

7 Documentation

Manufacturer/Contractor's proposals shall include the following:

- data sheets and listing of all components
- main and control circuit diagrams including connection diagrams
- installation materials
- recommended spare parts list
- commissioning, operating and maintenance instructions, fault finding procedures
- any other documentation/information as required per attachment(s)

All documents shall be in English.

8 Inspection and Testing

8.1 A quantitative check shall be made to assure that all items in specified quantities are present according to the purchase order and the packing list.

8.2 A visual inspection shall be made to assure finish, workmanship and good practice were maintained through fabrication and assembly.

8.3 A functional test (solar modules simulated) with the exact sub-assemblies interconnected to achieve desired system operation shall be made and a test certificate should be made available.

8.4 The Principal reserves the option to have a representative present during testing and inspection. The Contractor shall notify the Principal two (2) weeks prior to start of final inspection.

9 Drawings and Data

Drawings and data required for Principal's evaluation, approval and record shall be submitted in accordance with the Vendor Data Requirement List (VDRL).

10 Exceptions to Specifications

10.1 If in the Contractor's opinion, an exception to any detail of this specification would be to Principal's benefit, the exception may be quoted as an alternative provided that:

a) The exception and its justification are fully described in the quotations.
b) A firm difference in price and/or performance and/or quality between the specified item and the alternative is included in the quotation.

10.2 All exceptions and deviations to specifications shall be stated clearly in an attachment to this proposal.

10.3 Non-listing of exceptions or deviations shall be considered as the proposal being in full compliance with the specifications.

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Appendix I

Table 1 Albedo for direct insolation

Clay ground	20
Sand ground	30
Grass land	20
Woods	15
Water	20
Snow	60
Clouds	50
Average earth surface	35

Table 2 Modules de-rating due to dust

	Frequent maintenance	Little maintenance
Little dust and dirt	2.5 %	5 %
A lot of dust and dirt	5 %	10 %
Dry open sand grounds	10 %	20 %

Table 3 Mismatch loss in %

modules in series	Strings in parallel	
	1 - 4	5 and more
1	0 %	1 %
2	1 %	2 %
3	2 %	2 %
4	2 %	3 %

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Appendix II Site specific data

EXAMPLE

Location site: 1 º South 10 º East

	Monthly average Insolation on horizontal plane kWh/m^2
January	4.39
February	4.91
March	5.21
April	5.03
May	4.29
June	3.71
July	3.35
August	3.96
September	4.27
October	4.47
November	4.83
December	4.50