POLITECNICO DI TORINO

Master's Degree in Electrical engineering

Master's Degree Thesis

Assessment of the Photovoltaic Plant Performance in the Equatorial Area at North Kinangop Hospital Kenya

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And so, I would like to acknowledge everyone I have feelings for because they have been essential in getting through these five years, especially my mother who is now in heaven has always been happy of me.

Abstract

Nowadays, the world and in particular the energy field is turning in the direction of distributed and renewable resources (solar photovoltaic, wind, hydroelectric etc ...) in the main purpose of limiting pollution, eco-sustainability and for reason of cheaper and more convenient energy production from renewable sources.

The thesis focuses on one of the renewable sources: solar photovoltaics. First of all, it is specifically proposed to analyze, using appropriate measuring instruments and software, the possibility of installing a photovoltaic system in North Kinangop Hospital Kenya near to the equator. Due to a particularity of geographical location (over 2500 meters above sea level and close to very high mountains), the region is characterized by the high variability of the meteorological parameters, subsequently reliable measurements of solar irradiance are needed. During the thesis, I travelled to Kenya to install a solar Data Logger and manage a continuous acquisition of solar parameters measurements.

After the analysis of the hospital’s energy consumption, a PV plant has been designed to cover the demand of hospital ward such as oxygen production.

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1 Introduction

1.1 Goals

The purpose of this work was to analyze the potentialities of the North Kinangop Hospital zone, in order to understand if it's possible to install a photovoltaic plant there, with suitable performance and economically convenience during the years for the Hospital. Since the Kinangop Hospital is located on the equator (over 2500 meters above sea level and close to very high mountains), it has the very high variability of the meteorological parameters then the first objective was to evaluate the solar parameters of the Kinangop Hospital area continuously for a few months through the installation of a special measuring device retrieving data measured after a specific period. The second objective was, using the solar parameters provided by the devices, and after making comparisons with the solar data of the PVGis database, design the photovoltaic plant in order to cover the oxygen production Demand of the Hospital.

1.2 Renewable concepts and international cooperation in the energy field

The concepts about renewable energy and distributed energy resources (Solar photovoltaic, Wind, hydroelectric and other green energy…), actually are more discussed in the energy field and there are many institutions, research schools and universities which are involved into an international cooperations about these topics. In particular ''Politecnico di Torino'' focuses its research, student's internship in a company and thesis of students in the country or abroad, in that directions in order to perform it well. Therefore, it organises and allows continuously for students and researchers respectively, written thesis (in the country or abroad), and research in that field, as like for example this project under consideration among Kenya country and ''PoliTo'', for the study and if possible, the construction of a solar photovoltaic plant for the North Kinangop catholic hospital Kenya.

2 Performance evaluation of a photovoltaic system

The evaluation of the performance of a PV plant relies often on the availability of solar databases whose accuracy is well tested in most locations. For the case being it was mostly advised to gather experimental results on the main quantities of interest.

2.1 Quantities to be measured

The are many parameters which characterize the performance of the photovoltaic system such as: irradiance, daily global radiation

2.1.1 Irradiance

The total power, received by a unitary area from a radiating source, is called irradiance G, measured in watt per square metre (W/m^2).

2.1.2 Daily Global radiation

The daily global radiation represents the total energy received by unitary area from a radiating source. It's measured in watt hour per square meter (Wh/m^2).

2.2 Solar Atlants and devices used for measurement

The are many software and devices which are used to measure solar parameters in a specific zone where we need to install a photovoltaic plant such as:

2.2.1 PVGis Data base

The PVGis is a software which provide the solar data of every area of the world where the solar pant needs to be installed, providing it the location and the geographical parameters of the area considered, for given azimuth and slope it shows the energy production during the year, power, and so on.

2.2.2 HD35 wireless Data Logger

2.2.2.1 Introduction to wireless data recording systems

A **data recording system** is a set of an instruments that allows you to **measure** and **store** the values of certain physical quantities, for example temperature, humidity, pressure, solar radiation, etc.

A data recording system is generally composed of:

- **Sensors**: positioned at the measurement points, they convert the values of physical quantities into analog or digital electrical signals.

- **Acquisition system**: reads and records the electrical output signals of the sensors. If the acquisition system is digital, the acquired values are kept in the system's internal memory until the memory itself is full.

- **PC**: the data transfer from a digital acquisition system to the PC allows to keep the measured values even after filling the internal memory of the acquisition system. The PC also allows you to process and analyze the acquired values.

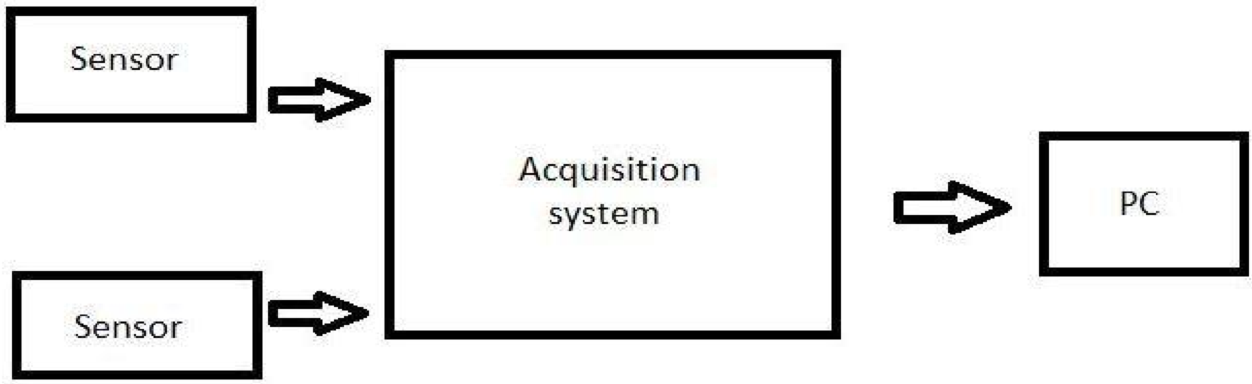


Fig. 1: Data recording system

The components of the recording system can be connected in two ways:

- **Wired connection**

- **Wireless (WIRELESS) by radio frequency transmission**.

The choice of the type of connection depends on various factors, such as: the distance between the various components of the system, ease of installation, the cost of installation, the ability to easily modify the system and electromagnetic interference present in the installation environment.

Advantages of the wireless connection:

- **quick and easy installation**: since it is not necessary to lay cables and conduits, a wireless system is installed much easier and faster than a system wired, especially when the components are at a great distance from each other

- **reduced installation costs**: the absence of cables allows a considerable saving in material and labor costs.

- **system flexibility**: the absence of fixed connections between the various parts allows the system components to be moved at any time without problems.

- **reduced maintenance**: cables are subject to deterioration over time, the absence of cables reduces system maintenance costs.

However, the operation of a wireless system can be difficult in environments with excessive electromagnetic interference (in which case a shielded wired connection may be preferable) or in particularly shielded areas that obstruct radio frequency transmission between the parts of the system.

2.2.2.2 Radio frequency transmission in wireless systems

In the case of a wireless connection, the acquisition system consists of a transmitting part and a radio frequency receiving part:

- **Transmitting part**: positioned near the sensor, it transmits the measured values to the receiving part. The transmitting part is normally integrated in the measuring instrument to which the sensor is connected.

- **Receiving part**: positioned near the PC, it receives the measured values and transmits them to the PC. The receiving party is usually referred to by the terms Base Unit or Access Point.

The transmitting part of the acquisition system can be unique for all the sensors, or there may be several transmitters, each of which transmits the measurements of part of the sensors. The receiving part of the system is unique for all sensors.

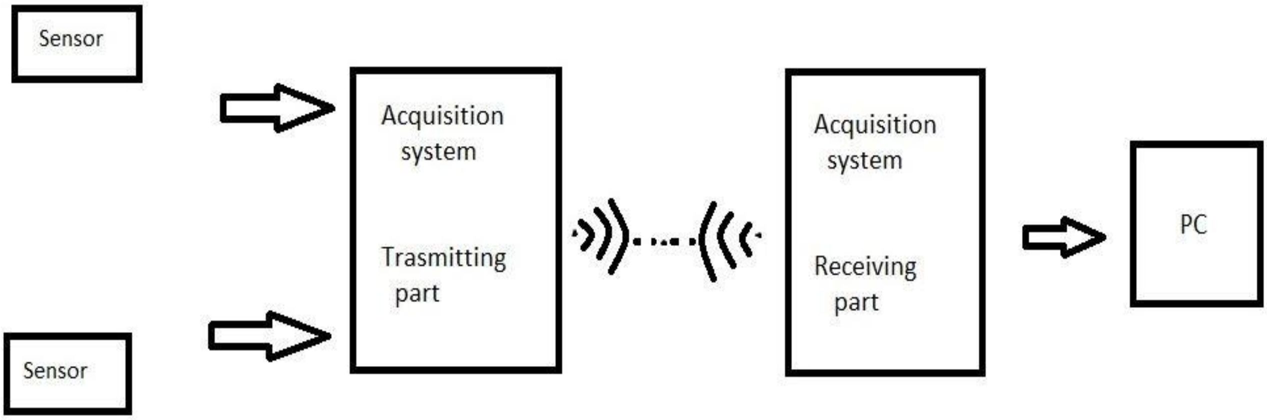


Fig. 2: Wireless data recording system

2.2.2.3 The Delta OHM wireless system

The Delta OHM **HD35 series** basic wireless system consists of:

- **One or more devices of the HD35ED series**: the HD35ED devices acquire the values measured by the integrated sensors or by the external sensors connected by cable. The data are both stored in the internal memory of the device and transmitted via radio to the receiving unit (base unit / Access Point). HD35ED devices work with a battery and require no power connections.

- **A base unit (Access Point) HD35AP**: receives the measured values from all the HD35ED devices and transmits them to the PC. The base unit HD35AP has an internal buffer battery with limited autonomy, therefore it must be powered from the outside by connecting it to the appropriate power supply (optional) or to the USB port of the PC.

- **HD35AP-S software**: to be installed on the PC, it allows you to download and view the data, to enter the data in a database and to configure the system. The basic version of the software, which allows you to download data only in the local database of the PC where the software is installed and to view them only from the same PC, is supplied free of charge with the base unit.

System configuration

The Delta OHM HD35… series wireless system can be completely configured using the basic HD35AP-S software. The radio frequency communication between the HD35ED devices and the HD35AP base unit is bidirectional, this allows the HD35AP base unit to transmit to the HD35ED devices the modifications of the operating parameters carried out through the HD35AP-S software:

- The HD35ED devices: transmit the measured values to the HD35AP base unit,

- The HD35AP base unit: transmits the changes in the operating parameters to the HD35ED devices.

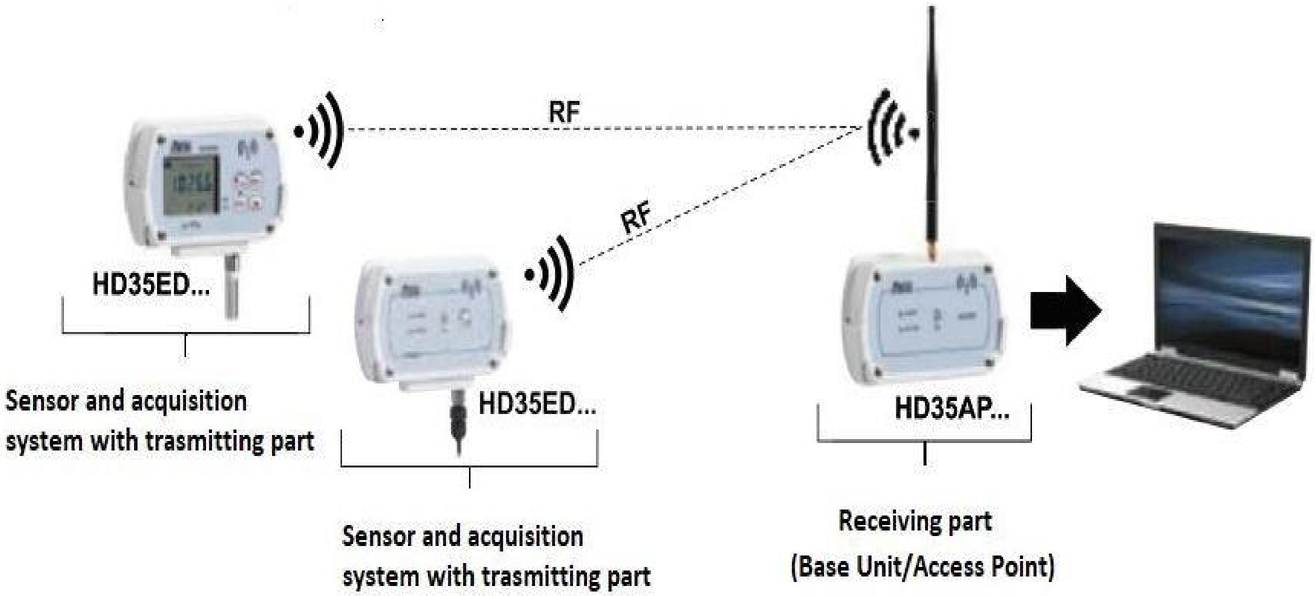


Fig. 3: Delta Ohm wireless data logging system

2.2.3 Solarimeter

LPPYRA03 pyranometer measures the irradiance on a flat surface (W/m2). The measured irradiance (Global Irradiance) is the sum of direct solar irradiance and diffuse irradiance.

Fig. 4 Pyranometer

2.2.3.1 Working principle

LPPYRA03 pyranometer is based on a thermopile sensor. The thermopile sensitive surface is coated with a black matt paint, which allows the pyranometer not to be selective at different wavelengths. The pyranometer spectral range is determined by the transmission of the glass dome type K5.

Radiant energy is absorbed by the thermopile black surface, thus creating a difference of temperature between the center of the thermopile (hot junction) and the pyranometer body (cold junction). Thanks to the Seebeck effect, the difference of temperature between hot and cold junction is converted into a Difference of Potential.

In order to grant the thermopile a proper thermal insulation from the wind and reduce the sensitivity to thermal irradiance, LPPYRA03 is equipped with a 4 mm thick dome which is 32 mm in outer diameter. The dome protects the thermopile from the dust, which might change spectral sensitivity if it lies on the black surface.

To prevent internal condensation forming on the internal side of the dome under certain climatic conditions, silica gel tablets are inserted inside the pyranometer to absorb humidity.

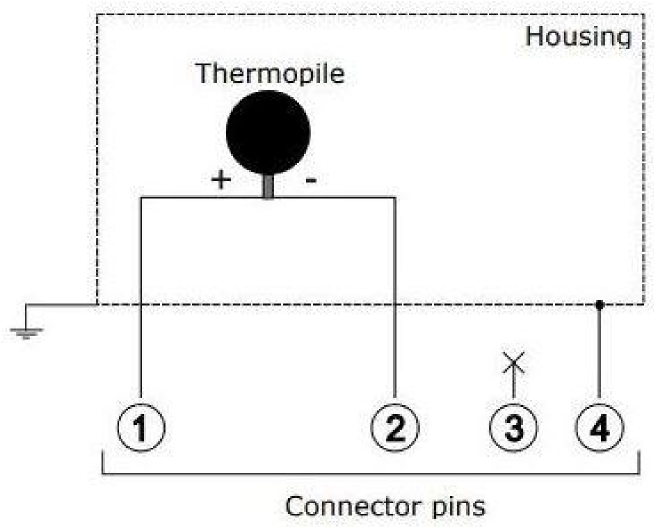


Fig. 5: Scheme of principle LPPYRA03 (Version with mV output)

2.2.3.2 Pyranometer connections

The pyranometer LPPYRA03 is passive and does not require power supply. It is to be connected either to a millivoltmeter or to a data acquisition system. Typically, the pyranometer output signal does not exceed 20 mV. In order to better exploit the pyranometer features, the readout instrument should have 1 µV resolution.

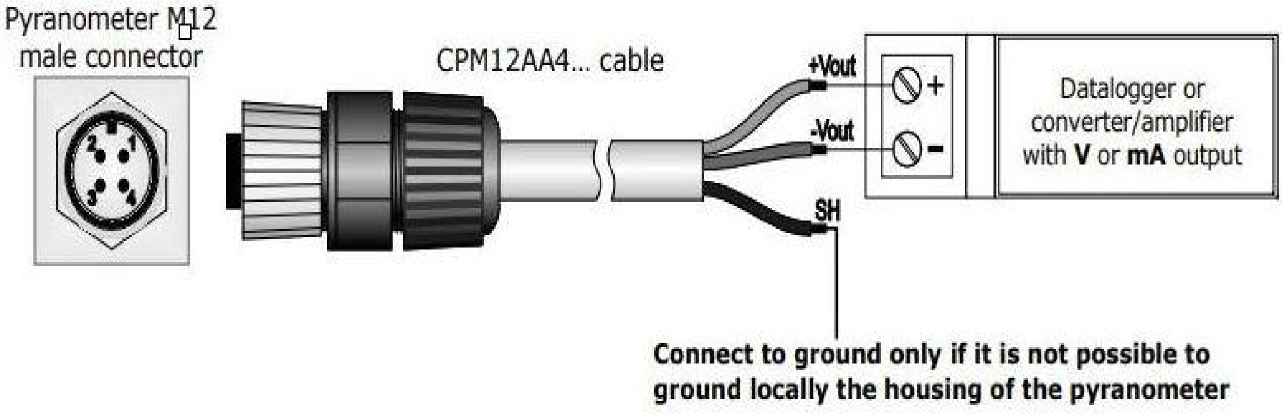


Fig. 6: LPPYRA03 connections

Connector	Function	Color
1	+Vout	Red
2	-Vout	Blue
3	Not connected	White
4	Cable shield (SH)/Housing	Black

Table 1: LPPYRA03 Connection parameters

2.2.3.3 Technical specifications

Each pyranometer is distinguished by its own sensitivity (or calibration factor) S expressed in $\mu V/(Wm^{-2})$ and shown in the label on the pyranometer (and in the calibration report).

The irradiance E_e is obtained by measuring with a multimeter the difference of potential DDP at the ends of the sensor and applying the following formula:

$E_e = DDP/S$

where:

E_e is the irradiance expressed in W/m^2;

DDP is the difference of potential expressed in μV measured by the multimeter.

S is the sensitivity of the pyranometer expressed in $\mu V/(Wm^{-2})$.

The most important technical features of the Pyranometer LPPYRA03 are resumed in the table below:

Sensor	Thermopile
Typical sensitivity	$5 \div 15\ \mu V/Wm^{-2}$
Impedance	$33 \div 45\ \Omega$
Measuring range	$0 \div 2000\ W/m^2$
Viewing angle	$2\pi\ sr$
Spectral range	$300 \div 2800\ nm$
Operating temperature/humidity	$-40 \div 80$ °C/ $0 \div 100\%$
Output	Analog in $\mu V/Wm^{-2}$
Connection	4 or 8-pole M12 connector depending on the model
MTBF	> 10 years

Table 2: Technical characteristics of the Pyranometer LPPYRA03

3 HD35 wireless Data Logger components and their features

The HD35 wireless Data Logger is a very appropriate device used in order to logging and retrieve some solar parameters useful for a solar plant analysis. It's composed of five main components each with their own function and characteristics.

3.1 HD35AP base unit

This device acts as an interface between the network data loggers that are positioned in the measurement sites, and the PC. It communicates wireless with the remote data loggers.

Fig. 7: Base unit placed between data loggers and PC

3.1.1 Working principle

The operation principle of the HD35AP base unit is described below:

1. RF antenna for transmission in ISM band

2. POWER LED: in red color, it indicates the presence of an external power supply; it blinks if the battery is recharging.

3. BATTERY LED: in green color, it indicates the internal battery charge level. When the indicator light is steady on, the battery is fully charged; as the battery is running

low, the LED blinks with a lower and lower frequency (the blink period increases of 1 second for each 10% decrease of the battery charge)

4. GSM/3G antenna cable (only HD35APG and HD35AP3G). Place the GSM/3G antenna at least 30 cm away from the RF antenna.

5. Red RF LED: it blinks to signal problems in RF transmission

6. Green RF LED: it blinks when the unit is in normal operation mode

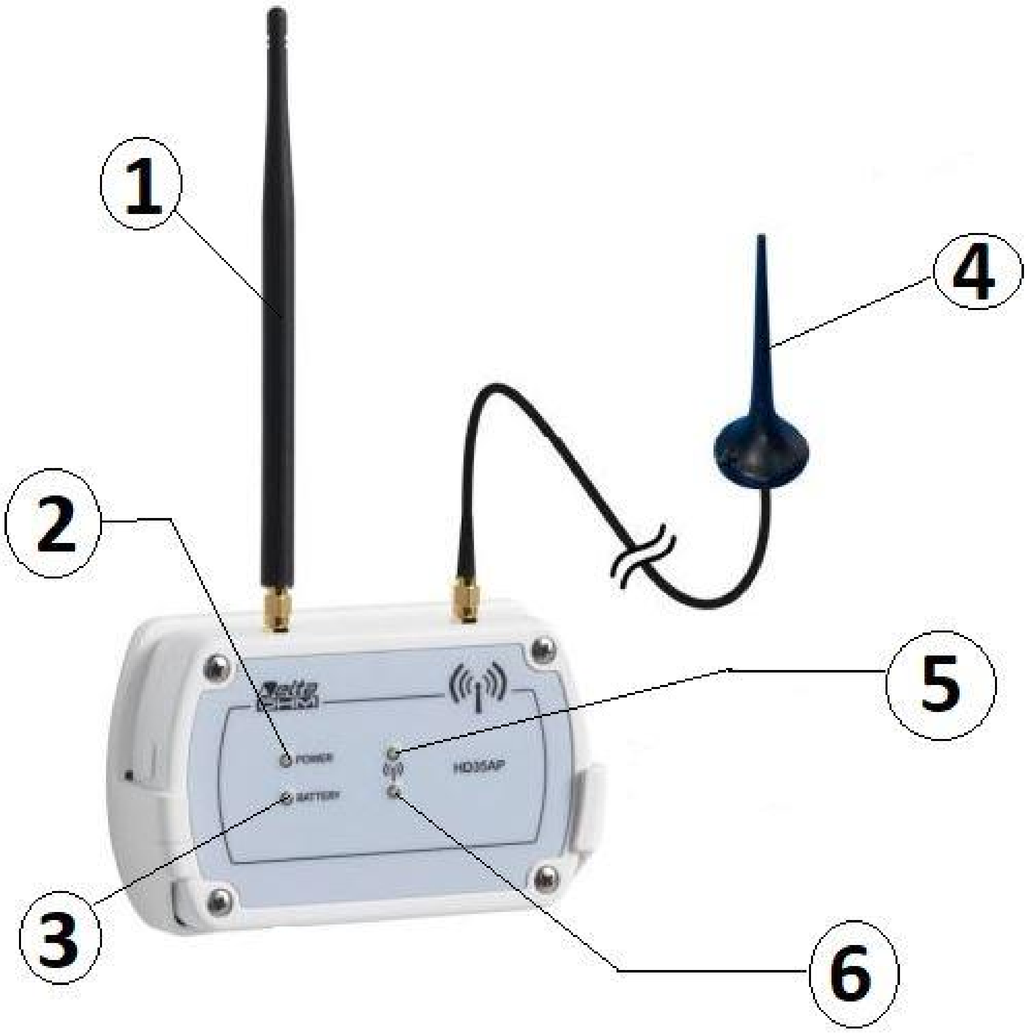


Fig. 8: HD35AP description

3.1.2 Technical specifications

Technical features most important of base unit HD35AP are resumed on the table below:

Component	HD35AP…G
Transmission frequency	868 MHz, 902-928 MHz, or 915.9-929.7 MHz
Transmission range	In open field: > 500 m (E, J, U) towards repeaters and data loggers with external antenna
Internal memory	The capacity is of 226,700 samples if a data logger record 7 quantities.
LED indicators	Presence of external power supply, battery charge level, RF communication status.

Table 3: Technical specifications of HD35AP

Furthermore, it has been used HD35AP with USB connection, then we used also the HD35APD (access point) that is connect to the PC USB inlet and communicate with the others device through the HD35AP-S software and allows to retrieve data logging from the last period which the device is left at zone analysis until the day of logging the data.

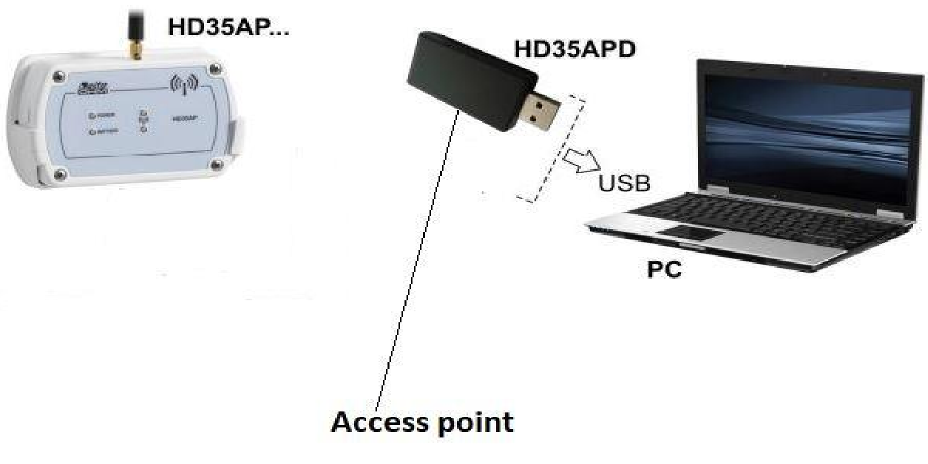


Fig. 9 USB connection with HD35APD access point

The HD35APD access point has its technical characteristics shown in table below:

Component	HD35APD access point
Transmission frequency	868 MHz or 902-928 MHz
Antenna	Internal
Transmission range	In open field: 180 m (E, U)
Output	USB with A type connector
Internal memory	The capacity is of 226.700 samples if a data logger record 7 quantities
LED indicators	RF communication status

Table 4: Technical specifications of HD35APD access point

3.2 HD35 RE repeaters

These devices are able to act as a bridge between the base unit HD35AP and the remote data loggers HD35ED, allowing the communication distance between data loggers and base unit to be increased. Several repeaters in cascade can be used.

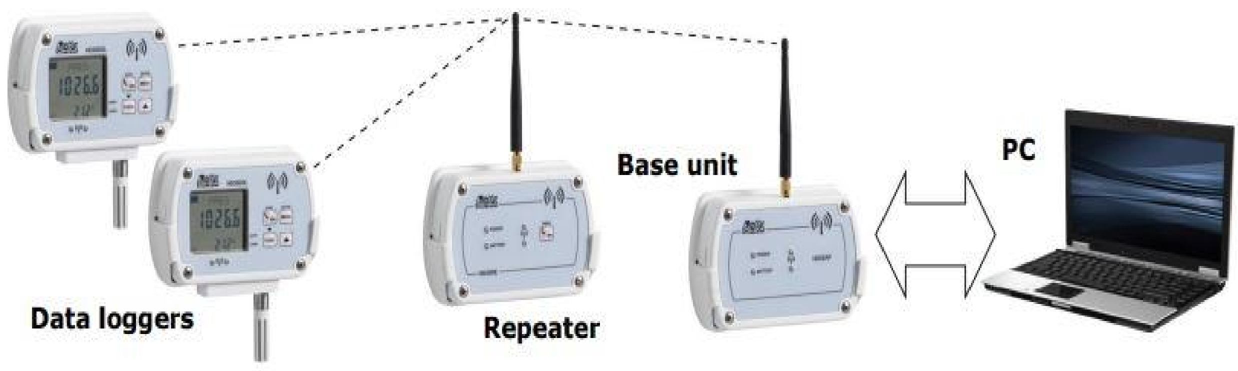


Fig. 10: Repeater placed between dataloggers and base unit

3.2.1 Working principle

The operation principle of the HD35R…W in waterproof housing is described under:

1. RF Antenna

2. BATTERY LED: green color, it indicates the internal battery charge level. As the battery is running low, the LED blinks with a lower and lower frequency (the blink period increases of 1 second for each 10% decrease of the battery charge).

3. ALARM LED: not used.

4. Red RF LED: it blinks to signal that data transmission has failed.

5. Green RF LED: it blinks if the data transmission was successful

The green and red RF LEDs blink simultaneously if the device is in error condition.

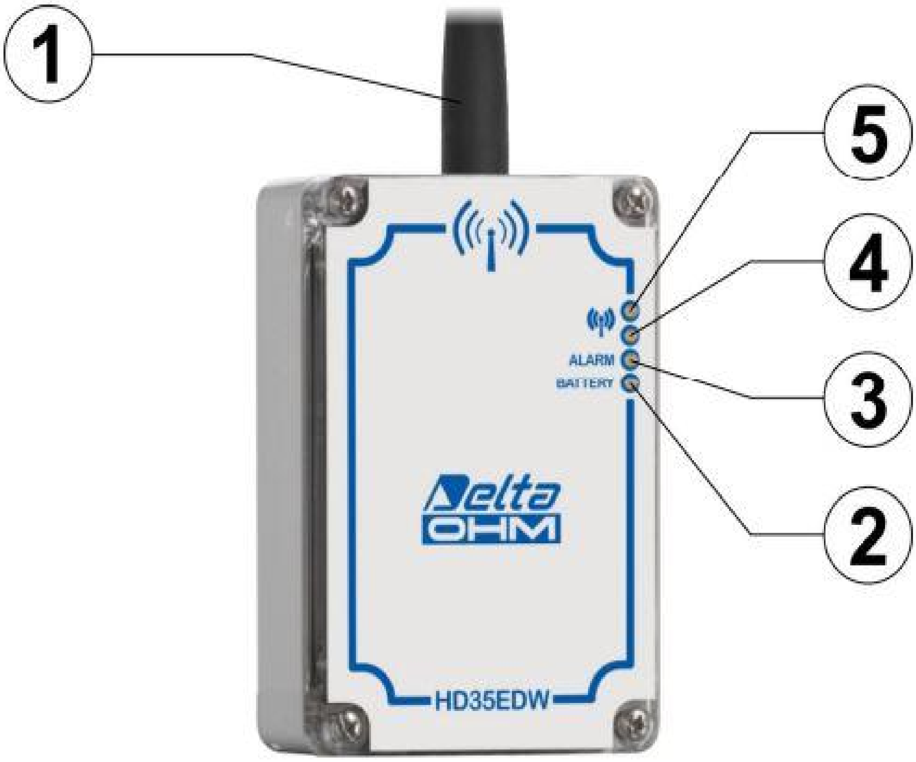


Fig. 11 HD35RE description

3.2.2 Technical characteristics

The repeater HD35RE, similarly to the HD35AP has its technical features resumed in the table under:

Component	**HD35RE…W**
Transmission frequency	868 MHz, 902-928 MHz
Antenna	External whip antenna
Transmission range	In open field: 300 m (E, J)/ 180 m (U) towards data loggers with internal antenna. > 500 m (E, J, U) towards base unit (except HD35APD), repeaters and data loggers with external antenna. 180 m (E, U) towards base unit HD35APD.
LED indicators	Battery charge level, RF communication status
Power supply	Internal 3.6 V lithium-thionyl chloride (Li-SOCl2) not rechargeable battery, capacity 8400 mA/h, size C, Molex 5264 2-pole connector
Battery life	2 years typical (repeating the signal of 5 data loggers transmitting every 30 s)

Table 5: Technical specifications of HD35RE…W

3.3 HD35 ED series of dataloggers

Remote devices with measurement probes. They are installed in the locations to be monitored. They acquire measurements, store them in the internal memory and send them automatically to the base unit at regular intervals or on request of the user. Versions with or without LCD display are available.

3.3.1 Working principle

The functionalities of a data logger end device HD35ED in particular HD35ED..W waterproof model used for this project is described below:

1. Probes and/or integrated sensors, with M12 connecter.

2. BATTERY LED: green color, indicates the charge level of the internal battery. As the battery runs low, the LED blinks with a lower and lower frequency (the blink period increases of 1 second for each 10% decrease of the battery charge).

3. ALARM LED: red color, it blinks when the measurement is in alarm condition.

4. Green RF LED: blinks if data transmission was successful.
5. Red RF LED: blinks to indicate that data transmission has failed.

6. External RF Antenna (optional). The antenna is internal by default. On request, the antenna can be external fixed or with 3 m cable.

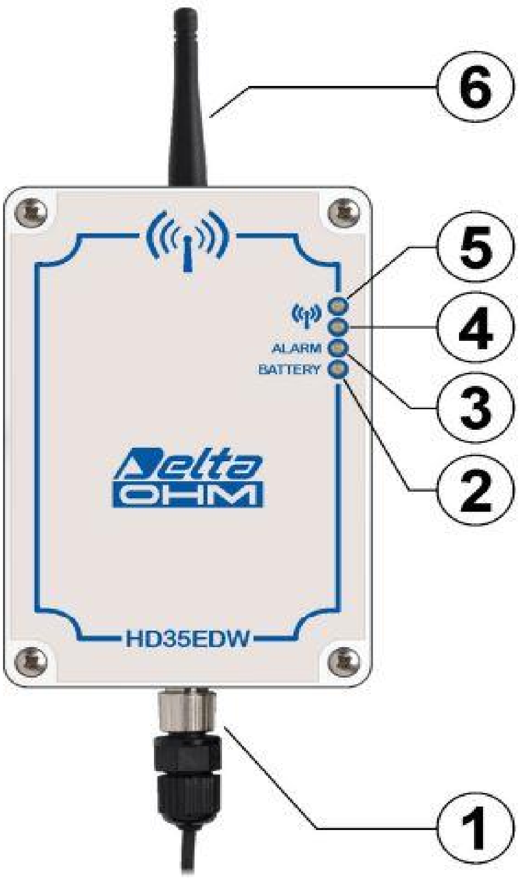


Fig. 12: Description of HD35ED..W data logger

3.3.2 Technical specifications

Same as the previous components, the HD35ED data logger has its technical features resumed in the table below

Component	HD35ED…W
Transmission frequency	868 MHz, 902-928 MHz
Transmission range	In open field: 300 m (E, J)/ 180 m (U) with internal antenna towards base unit (except HD35APD) and repeaters. 180 m (E, U) with internal antenna towards base unit HD35APD. > 500 m (E, J, U) with external antenna towards base unit (except HD35APD) and repeaters. 180 m (E, U) with external antenna towards base unit HD35APD.
Measuring, logging and transmission interval	1, 2, 5, 10, 15, 30 s / 1, 2, 5, 10, 15, 30, 60 min
Internal memory	Circular management or stop logging if memory is full. The number of storable samples depends on the number of detected Quantities (58.000 samples for one input)
LED indicators	RF communication status
Battery life	Typically, between 2 and 4 years
Power supply	Non rechargeable lithium thyonil chloride (Li-SOCl2) internal battery, 3.6 V

Table 6: Technical specifications of HD35ED

3.4 HD35ED-ALM remote alarm device

Device equipped with relay outputs that allows to activate, in case of an alarm, signalling devices (sirens, flashing lights…) or actuators.

3.4.1 Working principle

The functionalities of the HD35ED-ALM remote alarm device are described below:

1. ALARM LED: red color, it blinks to signal alarm conditions.
2. BATTERY LED: green color, it indicates the internal battery charge level. As the battery runs low, the LED blinks with a lower and lower frequency (the blink period increases of 1 second for each 10% decrease of the battery charge).
3. Relay outputs. The connection terminals are protected by a cover.
4. Green RF LED: it blinks to indicate that RF transmission was succefully.
5. Red RF LED: it blinks to indicate that RF transmission has failed.
6. Connection / PING (for testing RF) button.
7. Internal RF antenna.

Fig. 13: Description of the HD35ED-ALM remote alarm device

3.4.2 Technical characteristics

Similarly, to the other components, the remote alarm device HD35ED-ALM has its technical characteristics resumed in the table below:

Component	HD35ED-ALM
Transmission frequency	868 MHz, 902-928 MHz
Antenna	Internal
Transmission range	In open field: 300 m (E, J)/ 180 m (U) towards base unit (except HD35APD...) and repeaters. 180 m (E, U) towards base unit HD35APD.
LED indicators	Alarm condition, battery charge level, RF communication status
Relays	2 bistable relays with potential-free contact Contact: max 1A @ 30Vdc resistive load
Buzzer	Sounds cyclically when an alarm condition occurs: 1 single beep indicates that relay 1 is active 2 beeps in rapid succession indicate that relay 2 is active 3 beeps in rapid succession indicate that both relays are active
Power supply	Non rechargeable lithium thyonil chloride (Li-SOCl2) internal battery, 3.6 V, size A, 2-pole Molex 5264 connector
Keyboard	Connection / PING (for testing RF) button

Table 7: Technical specifications of HD35ED-ALM

3.5 HD35AP-S software

It's the software which is used to configure the wireless system. It must be installed on the PC. The entire wireless system can be completely set-up using this software HD35AP-S. However, the parameter of the wireless system can be modified by the user only through the software under consideration. It provided with the set of the others wireless devices from the manufacturer.

Interface of the HD35AP-S software when is installed and working well

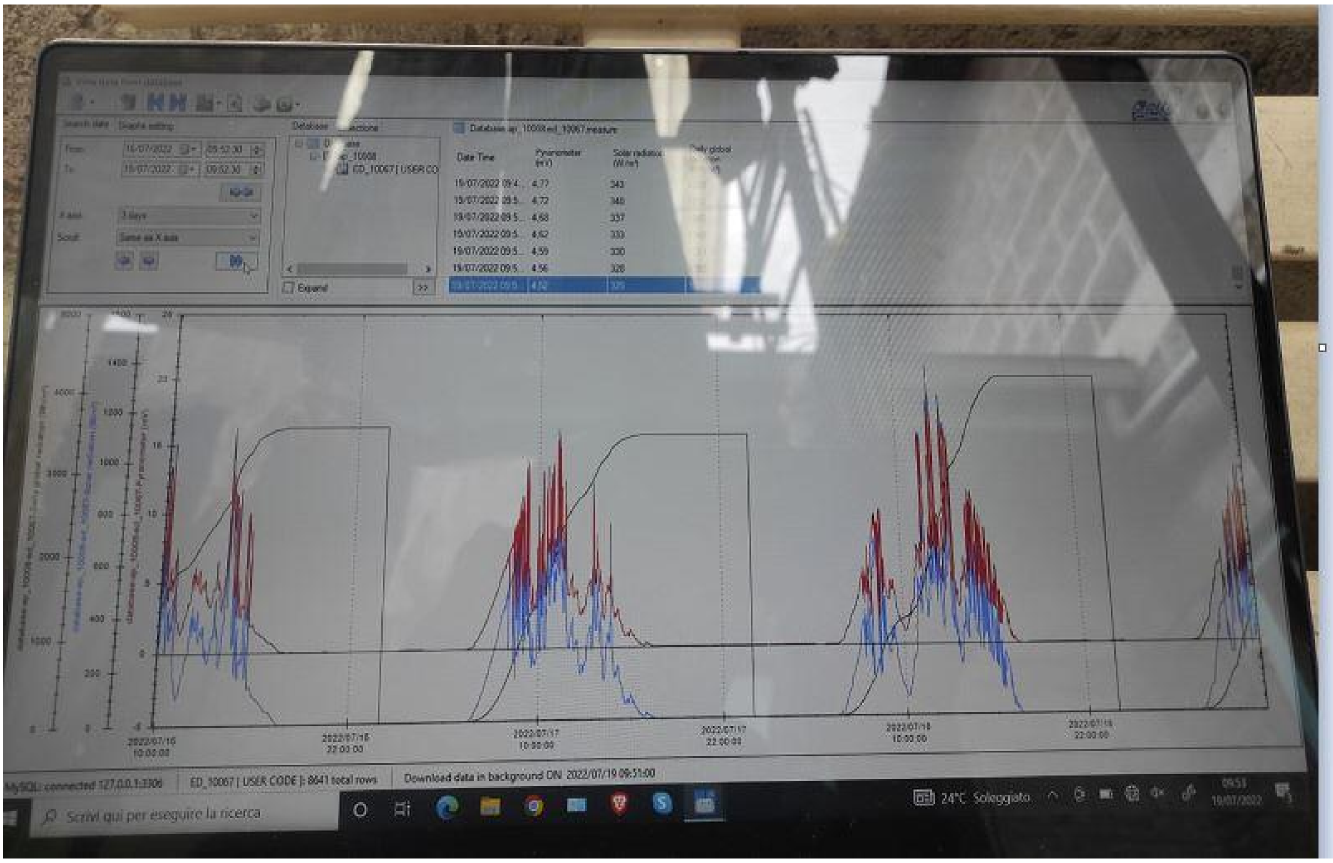


Fig. 14: Overview of the internal part of the software HD35AP-S working

4 Hospital North Kinangop Kenya

4.1 Description of the hospital and its geographical location

Located in Nduyu Njeru, a town in the Nyandarua region of Kenya, the North Kinangop hospital is situated about 300 km from Nairobi, the country's capital. About 73 thousand patients are treated per year by 330 employees including doctors, nurses, laboratory technicians, administrative and support staff. It consists of about 300 beds divided per wards: chirurgical (95 beds), medicine (80), maternity and gynaecology (60), paediatrics (medical and chirurgical) and intensive care (65). North kinangop Catholic Hospital is then the fifth most prestigious hospital in the region.

Fig. 15: Entrance of the North Kinangop Catholic hospital Kenya

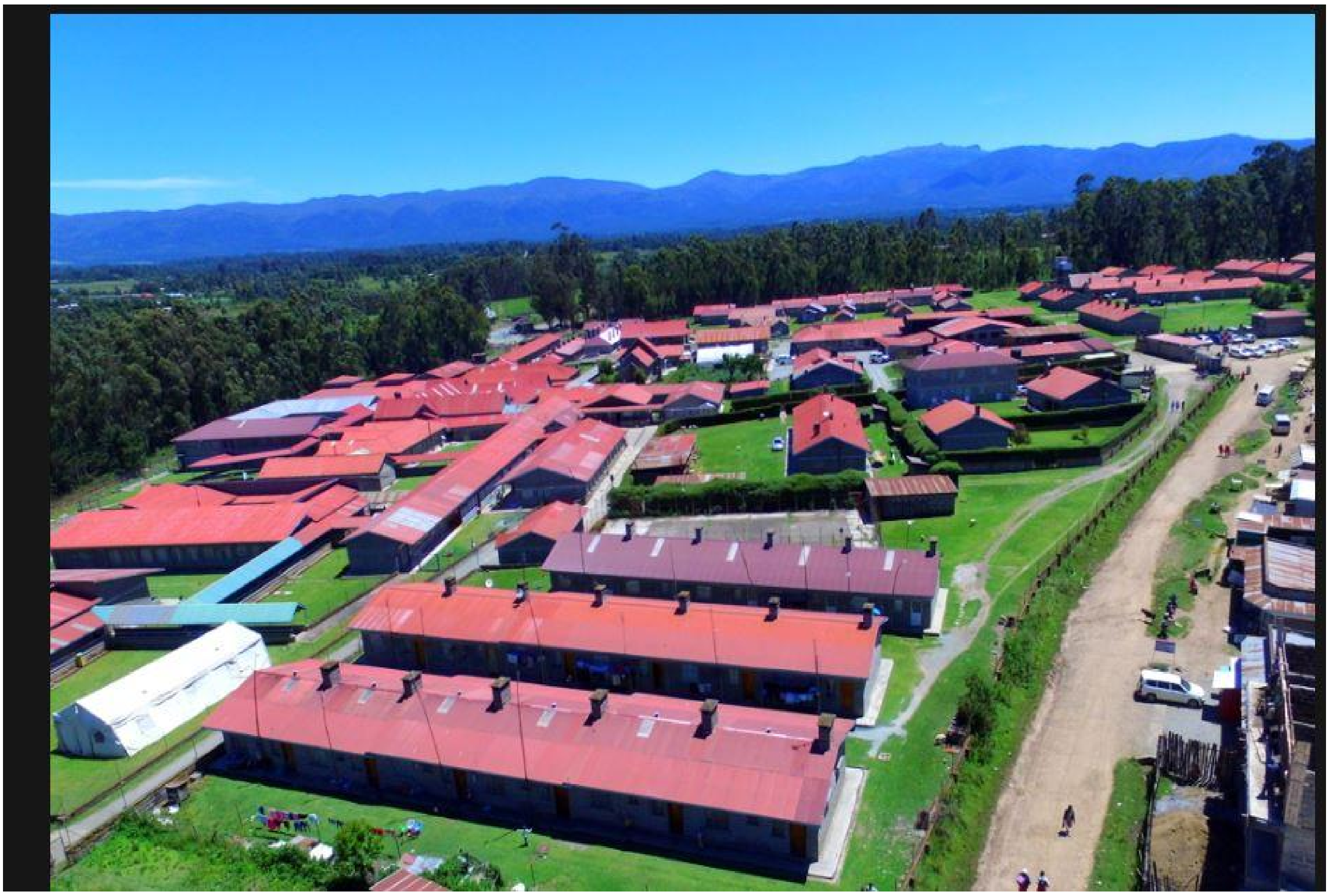


Fig. 16: Overview from above of the North Kinangop Catholic hospital Kenya

4.2 connection of Data logging system at the Hospital to measure the solar parameters

In order to connect well all the components of data logging system to measure the solar parameters of the North Kinangop hospital, the connection need to follow an appropriate procedure to work fine.

The process used for installing the Data logging system in order to check and make the system operational is shown below

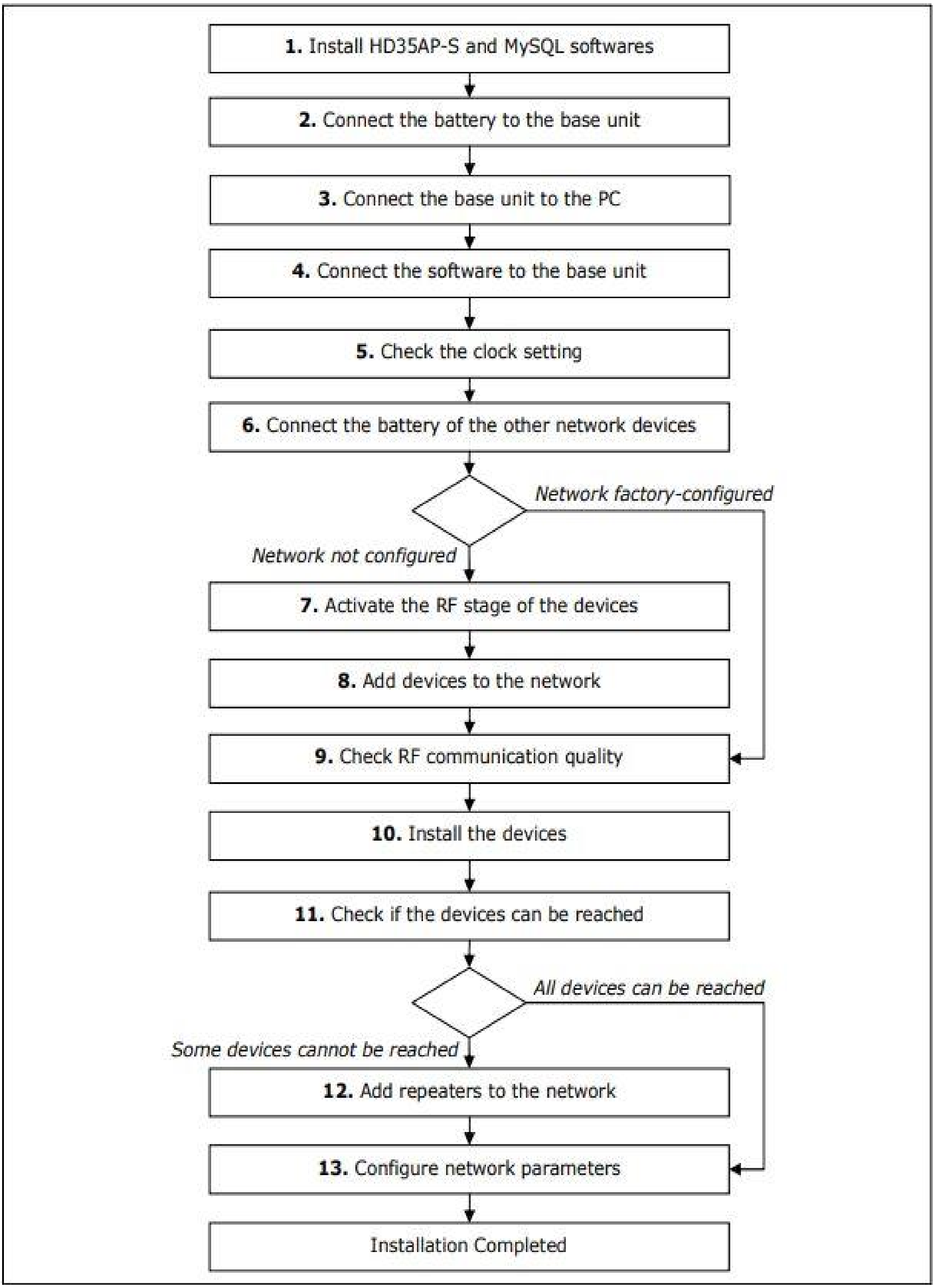


Fig. 17: System installation procedure

once everything has been set up according to the previous installation procedure, the pyranometer is mounted together with the end device data logger HD35ED connected via M12 cable on one of the hospital roofs (flat surface), the other components instead interact with them via radio frequency thanks to their antennas , the two antennas are fixed on the HD35AP base unit at about 30 cm from each other to avoid interference in the system, subsequently, the HD35APD (access Point) is connected to the PC via the USB inlet, the software being already started on the PC, by entering an appropriate code that is provided by the manufacturer and setting the system parameters, all the components of the data logging system are interconnected via radio frequency and the recording is started starting from the solarimeter to the HD35AP-S software which records every 30 seconds time intervals fixed into the software, the solar parameters (voltage, solar radiation, accumulated energy per square meters ...) of interest for the evaluation of the performance of a possible photovoltaic system on site.

Fig. 18: Data logging system mounting in Kenya

4.3 Results of measurements by the data logger system

In order to obtain the data recorded by the HD35 system, we have to follow a particular process, and then we get the results for a certain time interval fixing by the user.

4.3.1 Procedure for recording data from HD35 system

For retrieving the data by the data logging system, I have prepared this procedure to be used by technicians in North Kinangop, it's important to ensue step by step all the points shown below

1. Open the PC and start the **software HD35AP-S**

2. Open the box where you could find the device HD35AP-base unit, put that device at around **50 cm** from the PC, fix the two antennas upon the base unit device, the **stick-like antenna** should be placed near the entrance with Wi-Fi sign and the other antenna with wire into the other input. It's necessary to put the second antenna with wire at about **30 cm** from the base unit device HD35AP.

3. Insert the USB key within the USB inlet of the PC and you could find that USB key into a little box written upon **HD35APD.E**

4. After the USB key connect to the PC, and then the software HD35AP-S is opened, on the display you could see the main interface of that App, click on **connect** on the top corner left and insert the password: **9876** and then click **enter**, it will be showing a new device (HD35ED end device), with new parameters on the display.

On the top of the display, you could see **Data download from AP**, to the left click on the small triangle sign and then choose **Data background download setup**

It will be shown a small new window, further down choose **the data download starting from the last time that you downloaded the data** and also the time, so fix both of them.

Click on **Apply**, then click on **start** and then close that small window clicking on **Exit**

The download will be start and you could notice that in the blinking of the **Data download from AP** in the top of the display.

5. On the top of the display, you could see **View data**, click on and it will be appearing a new page. On the top corner left of that page you could see a small window where you could choose the slot of the date that you need to download and fixing the time from the last time to the new one corresponding to the data.

Fix also on the **X axis**, how long corresponding that period chosen before (for example if it's one month, choose one month, if the corresponding period chosen before it's 2 months, fix two months).

Before launching, wait all the download that started before finished looking down, you will be see if the download reached the day and the time that it has been fixed for the end. If it's the case process clicking down in that small window with two triangles attached.

On the top corner left used before, on the right side click on **ED_10067** and then click the two triangles attached, it will be displaying the graphs of pyranometer(mV), solar radiation (W/m^2) and daily global radiation (Wh/m^2).

6. **Download the Excel file of the data**

On the top corner right click on the **green button (with the cross)**, then click on **Export File text** (it's an excel file of the data).

On the desktop of the PC, downstairs click on ''**Explore file**'', in the folder **HD35AP-DATA** check if you find that excel file uploaded before. If you find it **Ok**.

At the end you must copy it and save it in one folder that you should create.

7. **Download of the graphs**

On the top of that page always, near to the green button used before, moving on the left side, there is another button called **print report (blue button)**, click on and it will be appearing a new window called **Report setup:**

On the top corner left of that window skip the two first points and choose the third point called **Measure settings.**

On the right, click only on:

- **Print statistics**

- **Daily statistics**

And then down, click on **Execute**.

It will be displaying ''**Doc_date of the day_''** (name of the report in PDF).

Same as before, you must check if the **report PDF** has been downloaded well.

To do that you must:

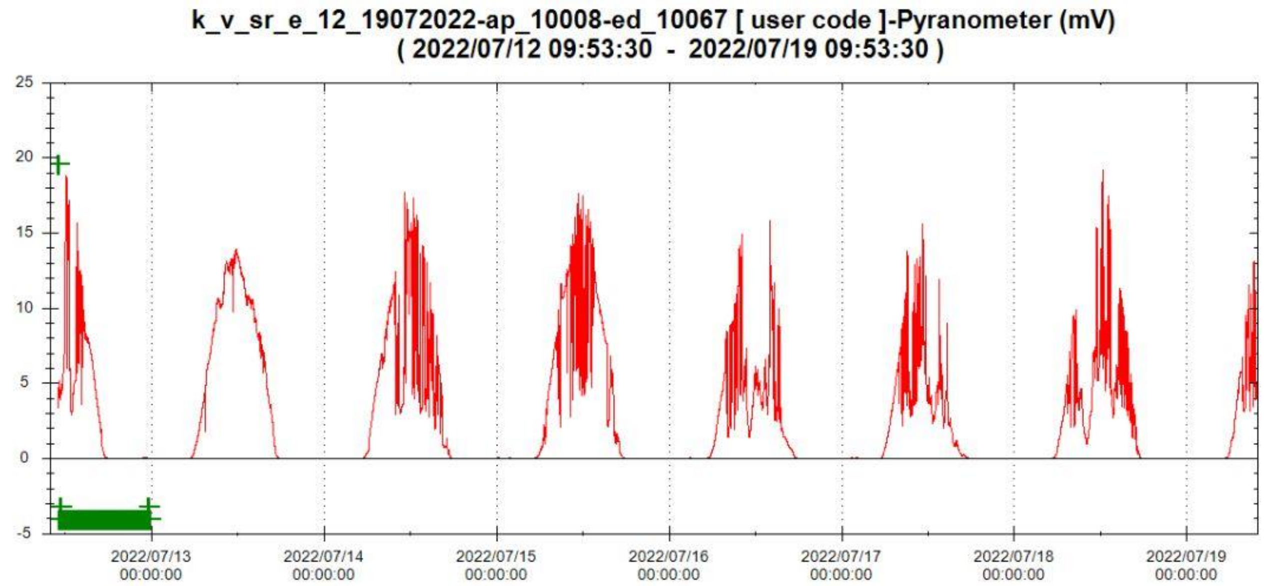
Going down of the desk of the PC click on ''**Explore file**'', in the folder **HD35AP-S**, check the name of that PDF report (looking as before today's date…), copy it and save it in the same folder created before where it's has been put the last one excels file.

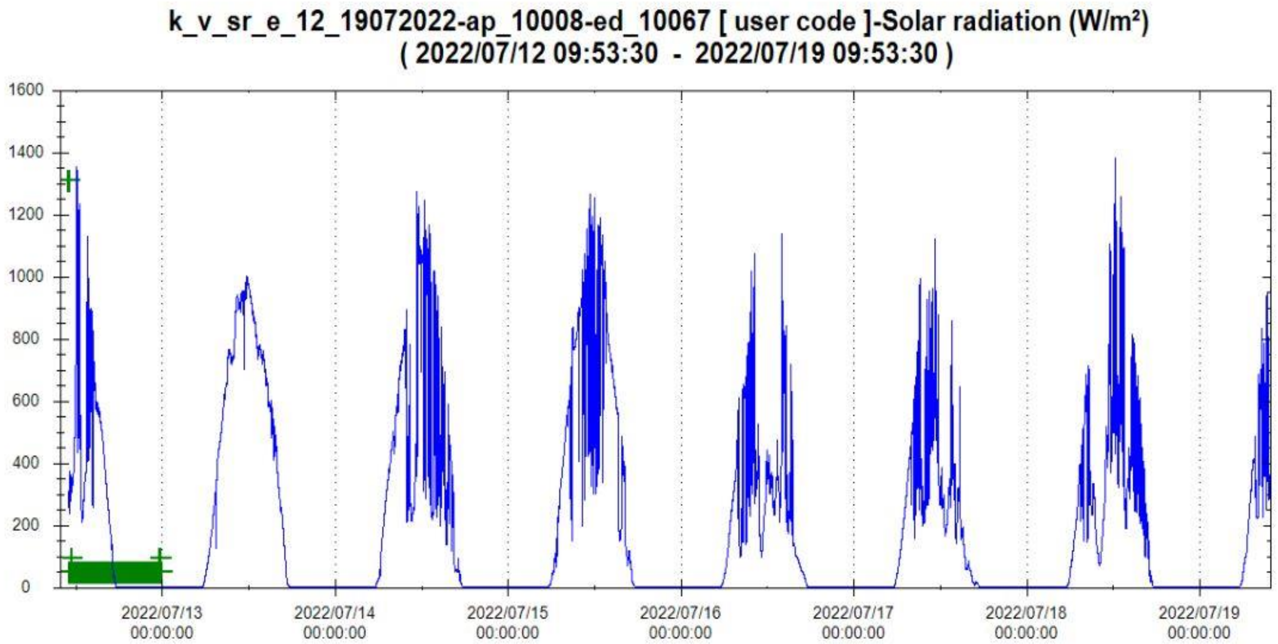
8. At the end of the process remove each component (USB key, antennas…) and then put everyone into its own box and put the set in the bag for the next time.

4.3.2 Results of measurements

For our interest, the outputs data's which are provided by the data logging system for a solar analysis are typically: Voltage (mV), Solar radiation (W/m^2) and Daily global radiation (Wh/m^2). The data logging system provide, the graph in the time of every quantity mentioned before, with their average value, maximum value, minimum value, excel file of variations of these quantities during everyday analysis and so on.

The results of every quantity registered in different time intervals (after one week, one month, two months…) are shown in the figures below


k_v_sr_e_12_19072022-ap_10008-ed_10067 [user code]-Pyranometer (mV)
(2022/07/12 09:53:30 - 2022/07/19 09:53:30)
25
20
15
10
5
0
-5
2022/07/13 00:00:00
2022/07/14 00:00:00
2022/07/15 00:00:00
2022/07/16 00:00:00
2022/07/17 00:00:00
2022/07/18 00:00:00
2022/07/19 00:00:00


k_v_sr_e_12_19072022-ap_10008-ed_10067 [user code]-Solar radiation (W/m²)
(2022/07/12 09:53:30 - 2022/07/19 09:53:30)
1600
1400
1200
1000
800
600
400
200
0
2022/07/13 00:00:00
2022/07/14 00:00:00
2022/07/15 00:00:00
2022/07/16 00:00:00
2022/07/17 00:00:00
2022/07/18 00:00:00
2022/07/19 00:00:00

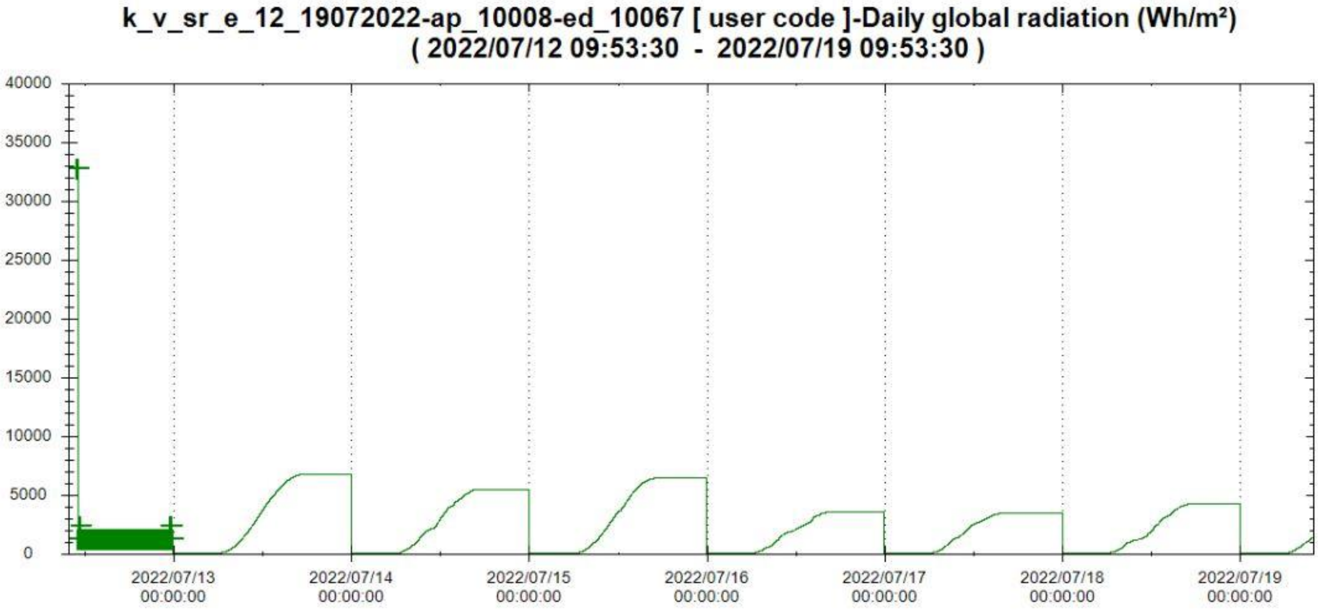
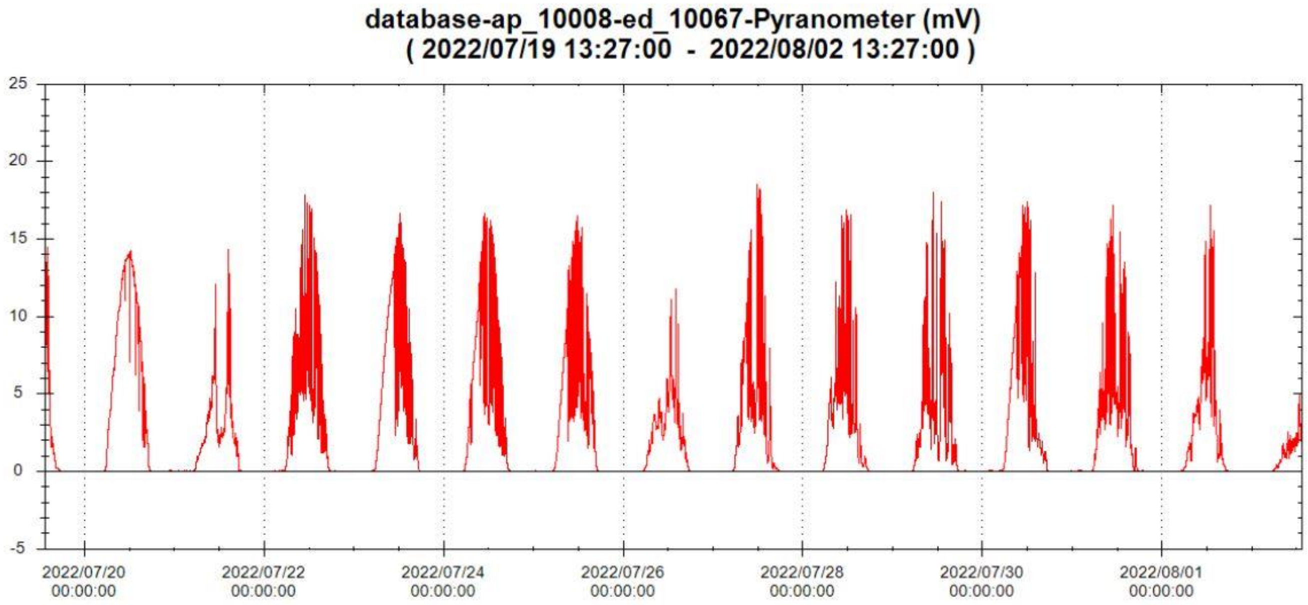
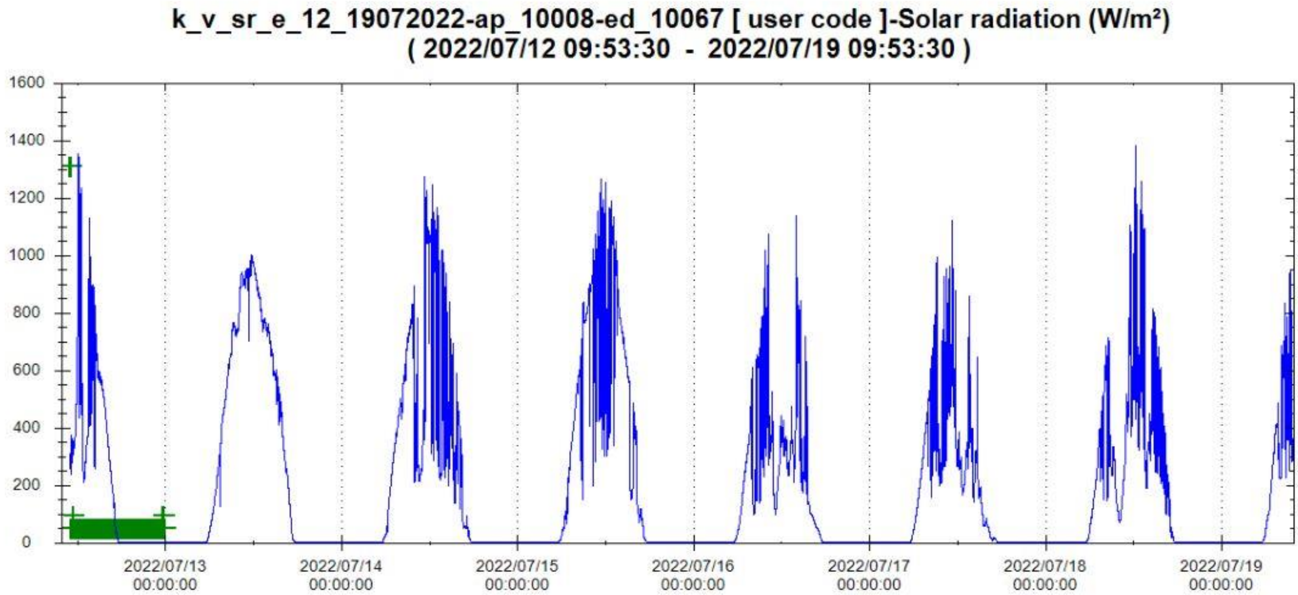


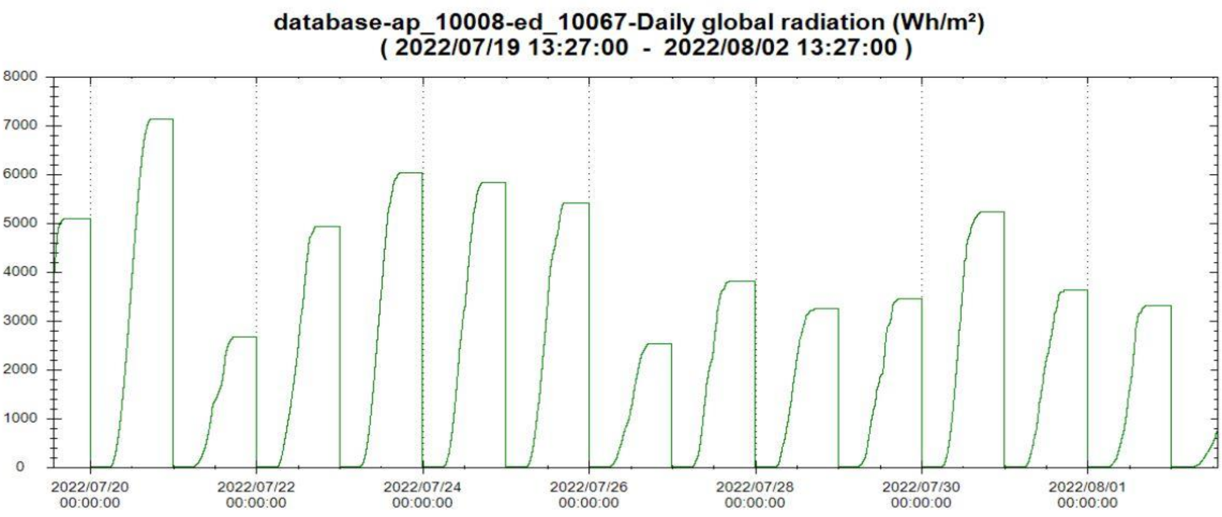
Fig. 19: Global statistics of quantities after one week

Name	MIN	MAX	AVG	STD	MKT	MAX-MIN	MAX-AVG	AVG-MIN
ap_10008\ED_10067 [USER CODE] MEAS_1	-0,05	19,2	2,82	4,1004		19,25	16,38	2,87
ap_10008\ED_10067 [USER CODE] MEAS_2	0	1382	204,1	294,5397		1382	1177,9	204,1
ap_10008\ED_10067 [USER CODE] MEAS_3	0	32746	2327,8	2351,1972		32746	30418,2	2327,8

Fig. 20: Trend of the solar parameters after one week in Kenya


database-ap_10008-ed_10067-Pyranometer (mV)
(2022/07/19 13:27:00 - 2022/08/02 13:27:00)
25
20
15
10
5
0
-5
2022/07/20 00:00:00
2022/07/22 00:00:00
2022/07/24 00:00:00
2022/07/26 00:00:00
2022/07/28 00:00:00
2022/07/30 00:00:00
2022/08/01 00:00:00

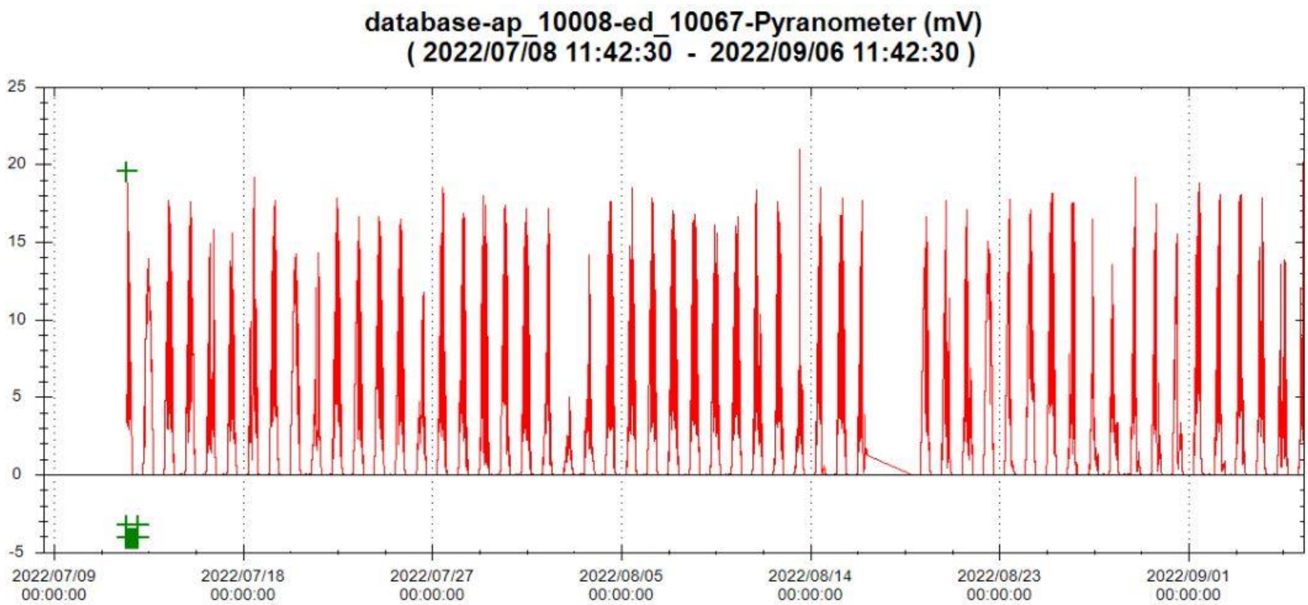

k_v_sr_e_12_19072022-ap_10008-ed_10067 [user code]-Solar radiation (W/m²)
(2022/07/12 09:53:30 - 2022/07/19 09:53:30)
1600
1400
1200
1000
800
600
400
200
0
2022/07/13 00:00:00
2022/07/14 00:00:00
2022/07/15 00:00:00
2022/07/16 00:00:00
2022/07/17 00:00:00
2022/07/18 00:00:00
2022/07/19 00:00:00

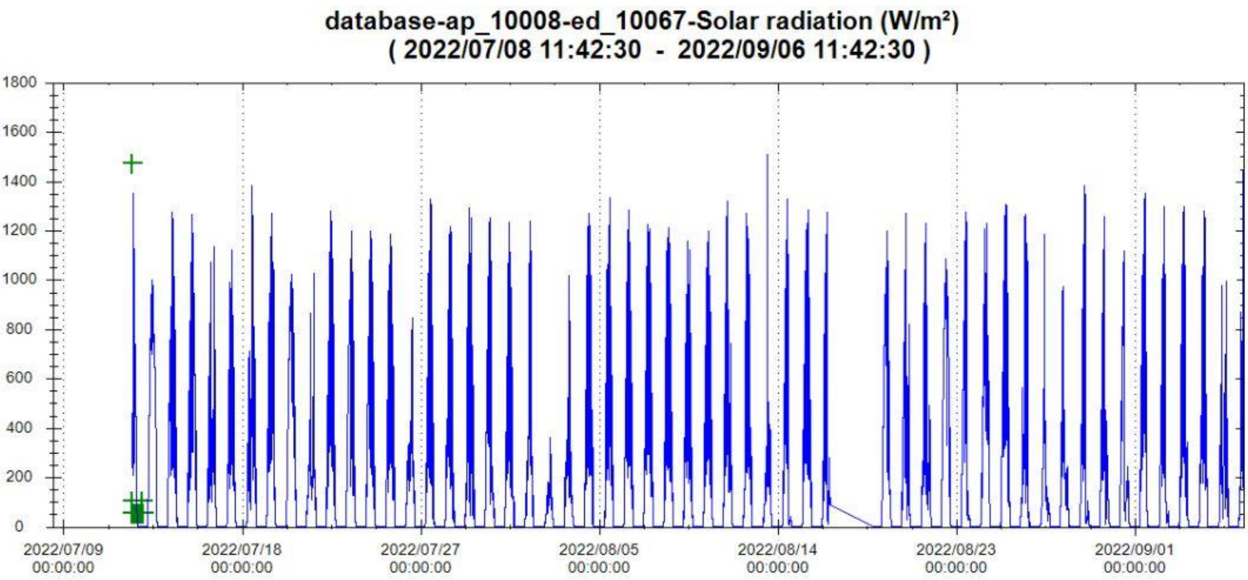

database-ap_10008-ed_10067-Daily global radiation (Wh/m²)
(2022/07/19 13:27:00 - 2022/08/02 13:27:00)
8000
7000
6000
5000
4000
3000
2000
1000
0
2022/07/20 00:00:00
2022/07/22 00:00:00
2022/07/24 00:00:00
2022/07/26 00:00:00
2022/07/28 00:00:00
2022/07/30 00:00:00
2022/08/01 00:00:00

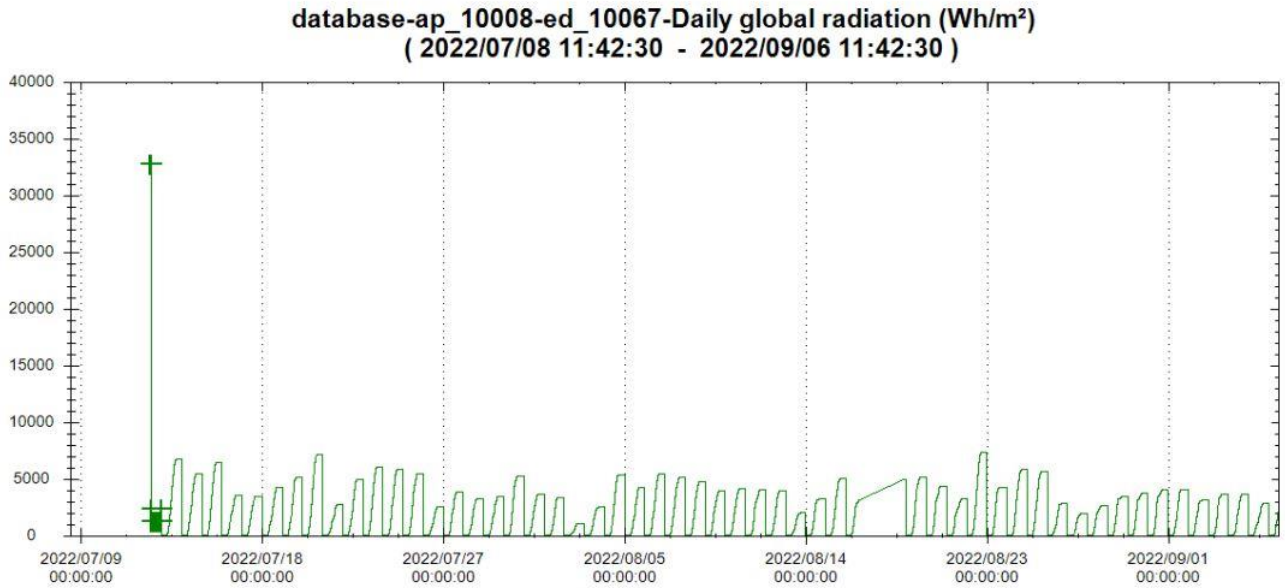
Global statistics

Name	MIN	MAX	AVG	STD	MKT	MAX-MIN	MAX-AVG	AVG-MIN
ap_10008\ED_10067 [USER CODE] Pyranometer	-0,06	18,47	2,43	3,9101		18,53	16,04	2,49
ap_10008\ED_10067 [USER CODE] Solar radiation	0	1330	176,02	281,0078		1330	1153,98	176,02
ap_10008\ED_10067 [USER CODE] Daily global radiation	0	7126	2286,85	2165,3886		7126	4839,15	2286,85

Fig. 21: Trend of the solar parameters after one month in Kenya







Global statistics

Name	MIN	MAX	AVG	STD	MKT	MAX-MIN	MAX-AVG	AVG-MIN
ap_10008\ED_10067 [USER CODE] Pyranometer	-0,06	20,99	2,41	3,8906		21,05	18,58	2,47
ap_10008\ED_10067 [USER CODE] Solar radiation	0	1511	174,44	279,6135		1511	1336,56	174,44
ap_10008\ED_10067 [USER CODE] Daily global radiation	0	32746	2171,92	2044,3602		32746	30574,08	2171,92

Fig. 22: Trend of the solar parameters after two months in Kenya

<u>Observations</u>:

Looking the graphics of every quantity and the global statistics in outcoming from the data logging system, we may notice that the mean value of voltage registered is around $2{,}42\ mV$, the recorded solar radiation average value is about $175\ W/m^2$, and the average value of the daily global radiation is around $2175\ Wh/m^2$.

4.4 Comparison between the measurements made by the HD35 system and PVGis data base

In this part, it has been made the comparison among the measures carried out in the month of August 2022 through the HD35 system at Kinangop hospital Kenya and those provided by the PVGis data base for a town Gilgil located at a few kilometers from the Kinangop hospital, as it shown by the graphics below

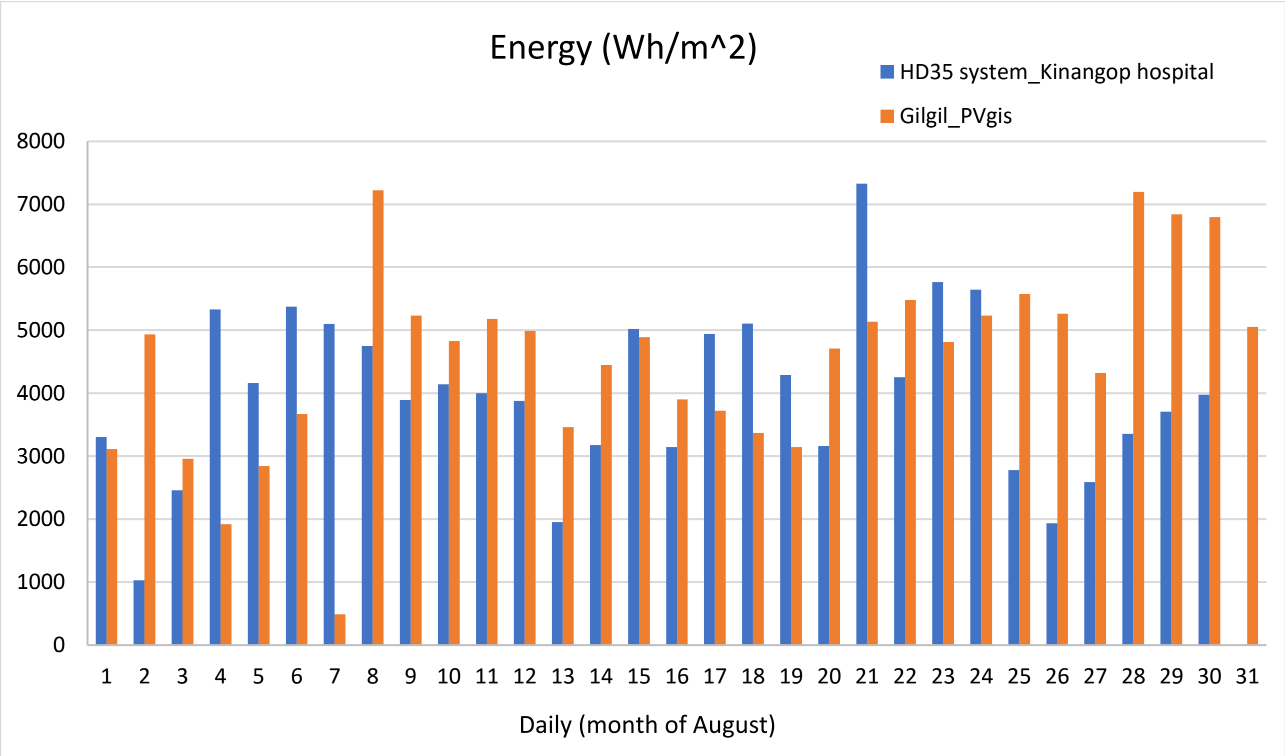


Fig. 23: Confrontation energy measured by HD35 system and PVGis

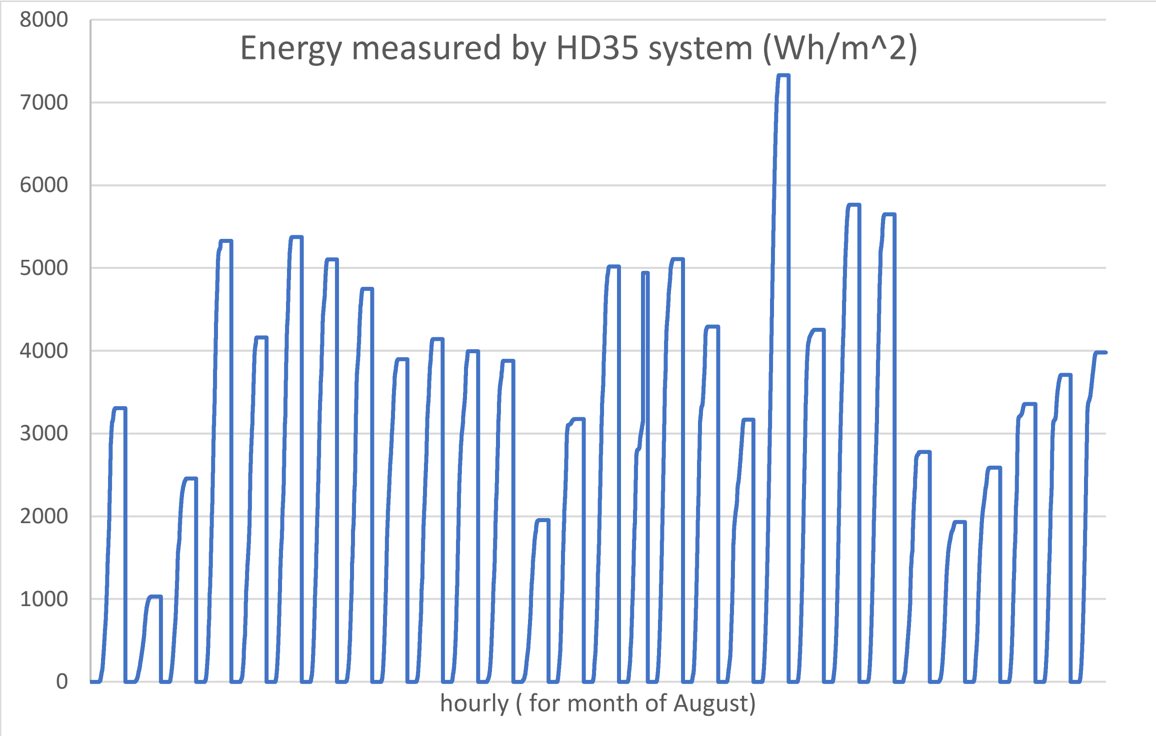


Fig. 24: Hourly energy measured by the HD35 system at Kinangop hospital

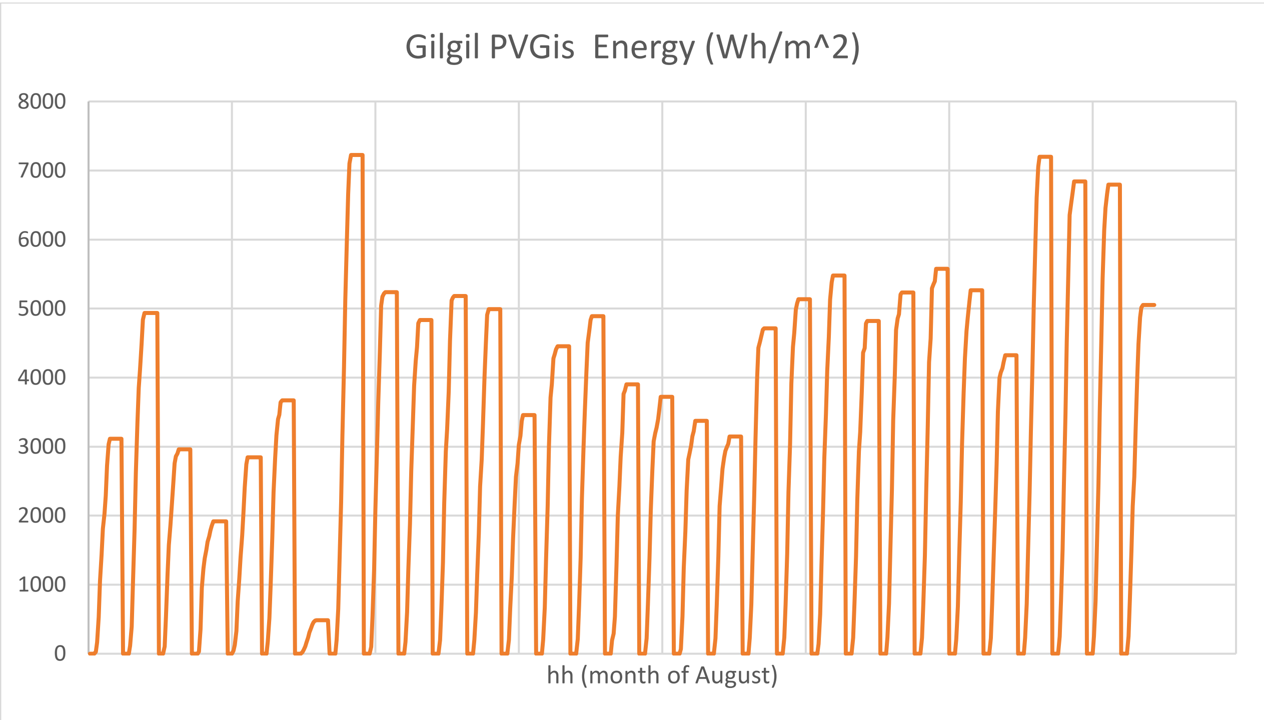


Fig. 25: Hourly energy Gilgil town provided by PVGis data base

Observations:

Observing the measures carried out at Kinangop hospital by the HD35 system-measurement which provided the average monthly energy around $3985\ Wh/m^2$ and those provided by the PVGis data base for Gilgil town at a few kilometers of Kinangop hospital with average monthly energy about $4540\ Wh/m^2$, we could notice a bit difference about 14% which can be acceptable because the PVGis data base for the Africa provides approximate data. Even if there is sensible difference between measured and estimated values, they are comparable and that means that after one month of measures the Kinangop hospital could be adapted to receive a PV plant installation.

5 Sizing of the photovoltaic plant to cover one part of the North Kinangop Hospital Kenya

In order to design in the well direction, the solar photovoltaic plant for the North Kinangop hospital, we made first the analysis about the annual electricity consumption of the hospital.

5.1 Analysis of the Hospital's energy consumption

Starting from the monthly and annual energy consumption data of the North Kinangop hospital provided by the bills, energy consumption graphs were plotted as a function of month, also the energy consumption has been distributed per ward for a more adequate analysis as shown right away

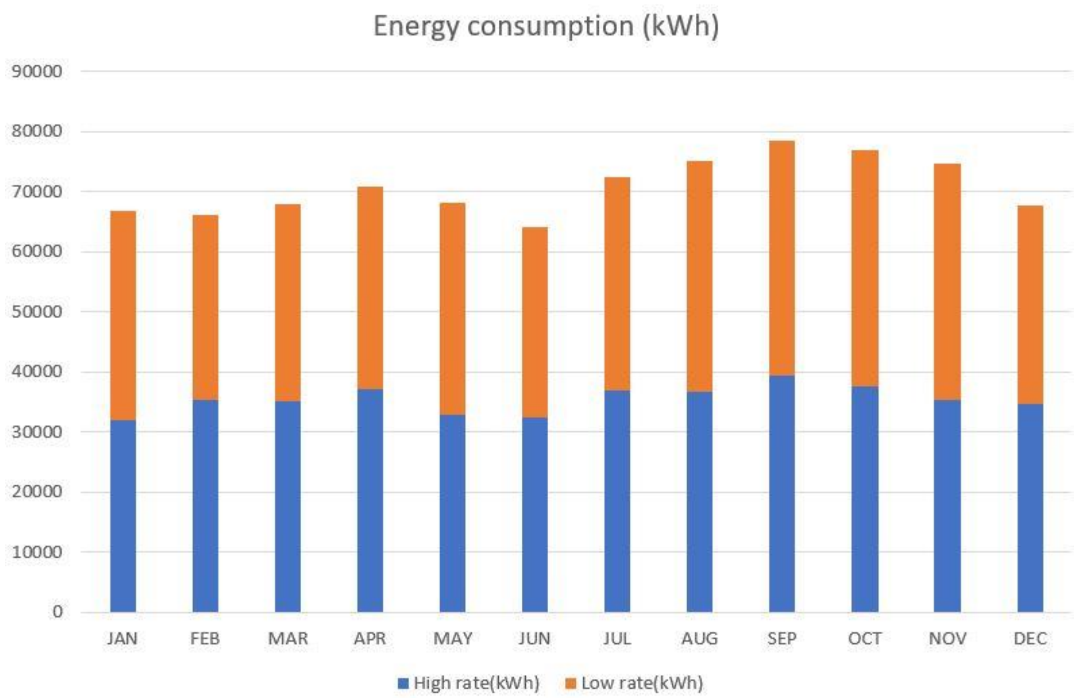


Fig. 26: Energy consumption of the North Kinangop Hospital (year 2021)

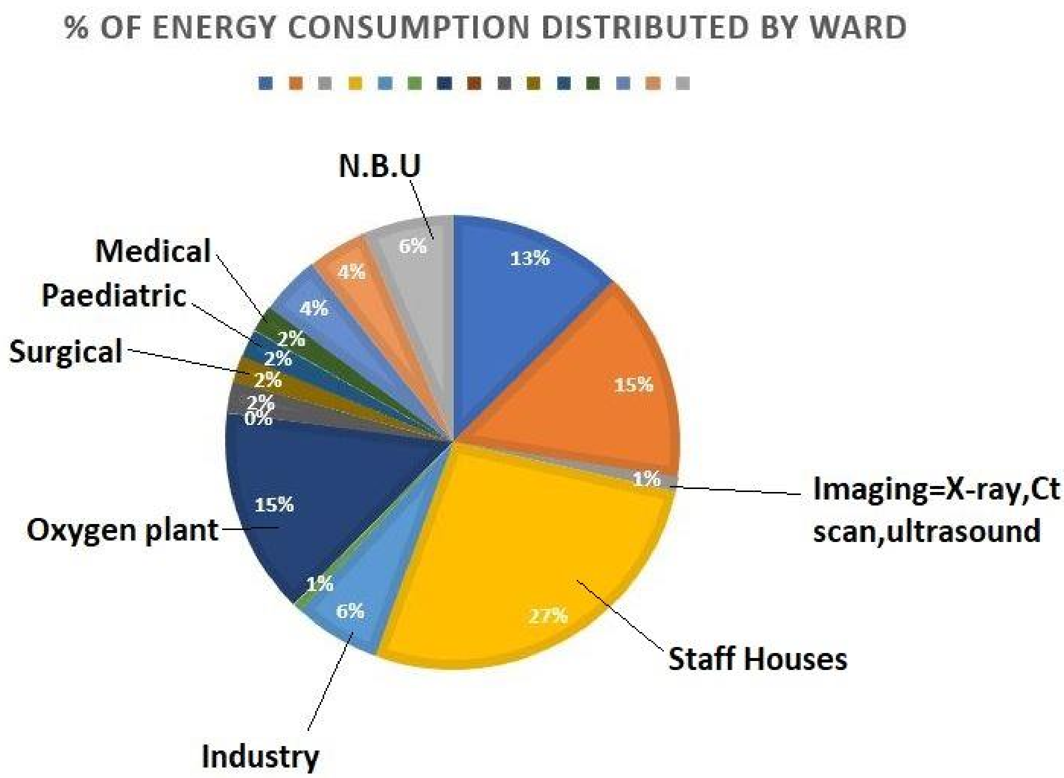


Fig. 27: % of Energy consumption per hospital ward

At the light of what has been done, due to the high energy consumption of the hospital around $842447 kWh$ (Total annual energy consumption) per year, thus around 75 MWh per month, are largely exceeding what a feasible PV plant could be provide and more excessive than how the solar device could provide by month (around $2175\ Wh/m^2$ average value), it has been decided to size the solar plant to cover the demand of one of the most important ward of the hospital (oxygen plant) which its demanded is about 15% of total annual energy consumption of the hospital.

5.2 Sizing of a photovoltaic plant for a hospital ward: Oxygen plant

The oxygen plant is the most important ward of the hospital, and medicinal oxygen is used by almost all the other wards of the North Kinangop hospital. Starting from that assumption, it has been decided to sizing the photovoltaic plant in order to cover the energy demand of that hospital ward.

5.2.1 Description of the medicinal oxygen production

The production of the medicinal oxygen gas O_2 can be divided into primary and secondary production. The process includes the various steps: compression, drying, expansion, fractionation, storage, and filling of the cylinders.

During the primary production, the oxygen manufacturing process occurs in factories where there are plants called "fractionation columns". With these systems, the fractionation of the air taken from the environment is applied: it is compressed, dried, and cooled down to $-183°C$ liquefaction temperature at which the oxygen gas becomes liquid and then with a distillation the O_2 is separated from the nitrogen. Its purity is around 99%.

The process of secondary production and packaging of the finished product (compressed and liquefied gases) is carried out at the factories in ventilated and suitable areas, equipped with bottling plants. Furthermore, gases for medicinal, food and technical use are produced in the same plants. A further method of obtaining oxygen O_2 from the air employs molecular sieves that capture it by letting the nitrogen pass through. In this case, the oxygen obtained is not very pure but is still adequate for medical needs, reaching a purity of $93\ \%$.

5.2.2 Design of a photovoltaic plant for the oxygen production plant

In the North Kinangop hospital, there are two medicinal oxygen plants, which consumes around $14{,}6\%$ of the total annual energy consumption of the hospital around $122\ MWh$ per year, with a rated power of 37 kW (each of them). In order to cover the power and energy of both of the oxygen plants, it has been decided to design one solar plant which will cover 78 kW in power, leaving a bit excess part which takes under consideration losses etc…

Using the software PV*SOL and choosing the roofs close to the oxygen production plants reducing cost of installation in that mode, having chosen in appropriately mode the inverters of its characteristics adapted for that PV plant, the modules economically convenient (Si monocrystalline), the inclination of the roof, fixing the rated power which we need to cover etc…, we made the sizing of the solar plant as will be shown below.

PV*SOL software provides in output the area in square meter where all the modules around $436\ m^2$ for the PV plant can be placed and the other performance parameters of the PV plant shown below.

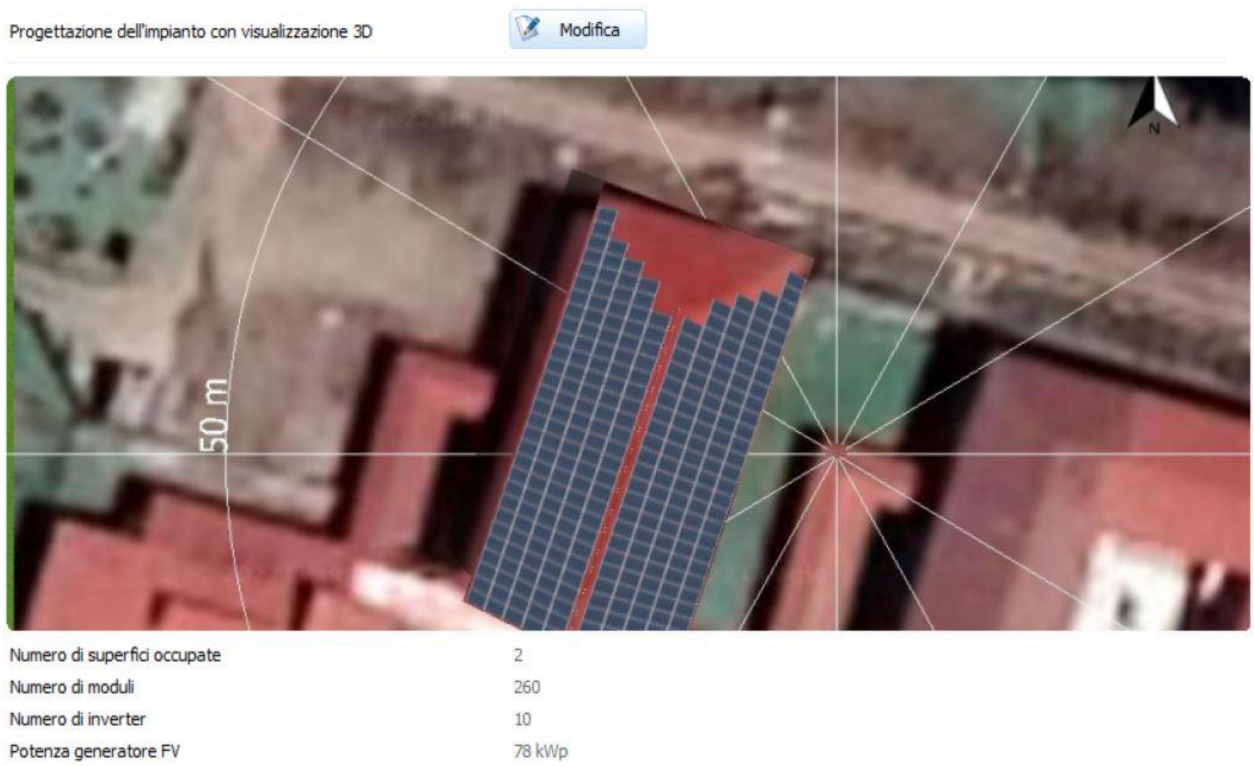


Fig. 28: Design of the photovoltaic plant over on the hospital roof

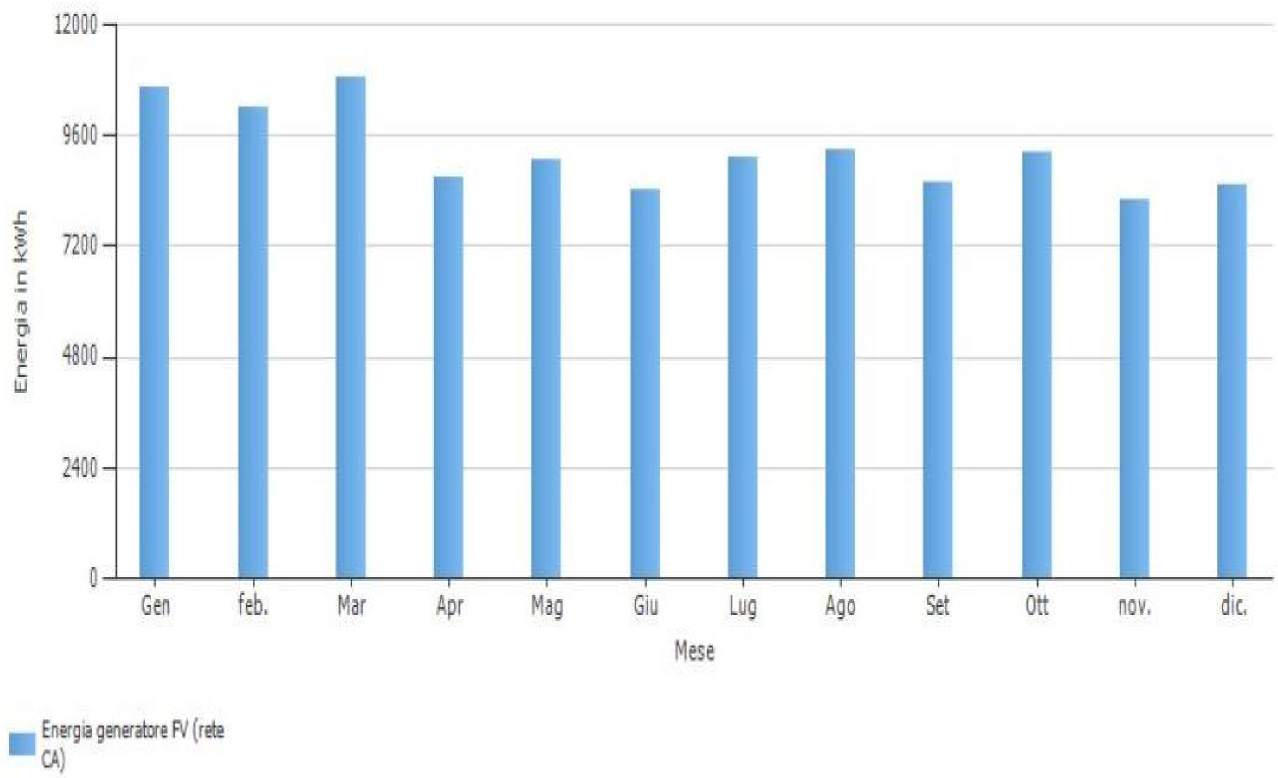


Fig. 29: Annual energy yield forecast PV plant

Technical quality	**PV plant**
PV generator energy (CA grid)	$110.860\ kWh/year$
Specific annual annuity	$1.418{,}18\ kWh/kWp$
Performance (PR)	$75{,}6\ \%$
Total area covered	$436\ m^2$

Table 8: Technical qualities of the PV plant

5.2.3 Economic analysis for the Kinangop hospital electricity bill

Kenya Power

COPY

ELECTRICITY BILL: Ksh 1,588,785.03

ACCOUNT NUMBER: 15332489

Issue Date : 01/08/2022

Due Date : 15/08/2022

Kenya Postage Paid

HOSPITAL NORTH KINANGOP C.

0

Invoice Number: 202208DC0014770796

Supply Location: PLT ENGINEER TOWN

Maximum Authorized Load(kVA): 127

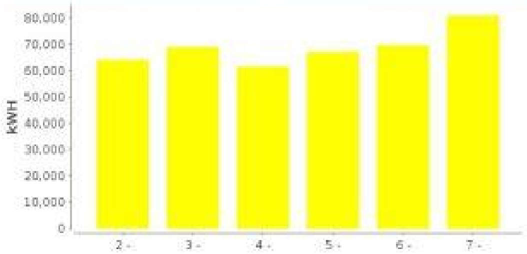
CONSUMPTION DATA

Meter Number	Previous Reading	Current Reading	Reading Type	Cons.	Cons. Type
040016117698	0	246	Real	246	Demand KVA
040016117698	0	242	Real	242	Demand KW
040016117698	1683133	1721977	Real	38844	High Rate
040016117698	1581625	1623818	Real	42193	Low Rate

Consumption Period: 02/07/2022-01/08/2022

Method of Charge: C1-3 Commercial-Industrial Method CI1 -

CONSUMPTION TREND



MESSAGES

Total VAT 16% = ksh 200487.36
Notice is hereby given that if this bill is not paid within 14 days from 01/08/2022, on 15/08/2022, your supply shall be liable for disconnection without any further notice to you.
Should the supply be disconnected, in addition to settling the outstanding amount, you will be required to pay a reconnection fee and an additional deposit which is equal to 2 times your average consumption.
The Reconnection (RC) fees (inclusive of a 16% VAT charge) are as follows:
*ksh 580 for cut-out RC
*ksh 3,828 for pole RC
*ksh 13,920 for service line RC

BILLING DETAILS

Billing Concepts		Amount (Ksh)
Bill-202208BC0013617491		
Energy		
HighRateConsumption	38844kWh x 8.7	337,942.80
LowRateConsumption	36681kWh x 8.7	319,124.70
LowRateConsumption	5512kWh x 4.35	23,977.20
MaximumDemandKVA	246kVA x 800	196,800.00
Fuel Energy Cost	81037kWh x 4.63	375,201.31
Total Energy		1,253,046.01
Levies and Adjustments		
Forex Exchange Adj. (FERFA)	81037kWh x 0.7314	59,270.46
Inflation Adj. (INFA)	81037kWh x 0.47	38,087.39
ERC Levy	81037kWh x 0.03	2,431.11
REP Levy	681044.7 x 5	34,052.24
WRA Levy	81037kWh x 0.0174	1,410.04
Total Levies and Adjustments		135,251.24
Rounding Adjustment		0.39
V.A.T.	1253046.01 x 0.16	200,487.36
Total Monthly Bill		1,588,785.00
BALANCE BROUGHT FORWARD		1,398,451.03
APPLIED CREDIT		-0.00
Payment by Cheque		-498,451.00
Payment by Cheque		-900,000.00
TOTAL AMOUNT PAYABLE		1,588,785.03

OWER Central Office - Stima Plaza Kolobot Road P.O. Box 30099-00100 Nairobi. Tel: 3201000 Fax: 3514485 VAT Reg. No.: 0010608 PIN: P000591096X

Fig. 30 Electricity bill of Kinangop hospital

As we can see on the Kinangop hospital electricity bill above, the cost of the energy consumption takes into account the High Rate Consumption, Low Rate Consumption, also takes into account the cost of the maximum Demand kVA and the fuel energy cost.

Similar to the Kinangop hospital energy consumption analysis made before, where through the annual energy consumption graphs considering High and low Rate, it’s clear that division make in Kenya consumption help to follow and getting a good appreciation and understanding the energy consumption cost.

Furthermore, after a little economic analysis about the electricity cost and savings, emerges that installing the 78 kW of a PV plant at Kinangop hospital to cover the oxygen production, it’s possible to save around 3.000.000 Ksh by year that means around 26.000 € by year.

6 Conclusions

This report analyzes the procedure that allowed to study the North Kinangop hospital area to understand its capacity in term of a PV solar plant installation. The key contributions of the Thesis are:

i) Wireless Data Logging System: system of devices used to measure and store the solar parameters of the North Kinangop Catholic Hospital zone, for evaluation of the ability of that zone to receive a PV plant installed

ii) PV*SOL: software used in order to design in appropriate and economically convenient way the PV plant for the most important ward of the North Kinangop hospital Kenya (medicinal oxygen production plant)

iii) PV plant: the North Kinangop hospital Kenya in this mode, with the Solar plant installed could reach to decrease the annual energy consumption by paying its electricity bills less.

iV) Source of energy generation: ''solar'', the hospital contributes to the eco-sustainable item.

Potential future developments:

- Exploit the wind potential of the North Kinangop hospital area
- Construction of a possible hybrid green energy plant
- Exploit the hydroelectric potential of the water pipes that bring water to the hospital from the mountains.

Bibliography

1. https://www.today.it/foto/esteri/kenya-l-ospedale-di-north-kinangop/(fig

2. https://www.aifa.gov.it/sites/default/files/11-192014_Presentazione_Fulfaro_19-11-2014_Produzione_Gas_Medicinali_Rev%201.pdf

3. https://www.certifico.com/chemicals/documenti-chemicals/221-documenti-riservati-chemicals/12021-gas-medicinali-quadro-normativo

4. https://webthesis.biblio.polito.it/20172/1/tesi.pdf

5. https://www.deltaohm.com/product/hd35-wireless-data-logger-system/

6. https://www.deltaohm.com/manuale_HD35-wireless-data-logger/

7. https://re.jrc.ec.europa.eu/pvg_tools/en/

8. https://valentin-software.com/en/products/pvsol-premium/

9. https://re.jrc.ec.europa.eu/pvg_tools/en/