PV System Monitoring Plan

1. Introduction

Energy plus houses are characterized by low energy consumption and generating more electricity than they consume. According to (Jones et al., 2017), energy positive buildings achieve positive energy performance when the total energy generated over the year from building integrated renewables is greater than the energy used. SOLCER house is a good illustration of these houses, since it is the first energy plus house in UK.

This report proposes a monitoring plan for the PV system performance of the SOLCER house. Performance monitoring plays an important role in addressing PV system issues and malfunctions. Moreover, monitoring is fundamental for initial system evaluation, and continuous output optimization (Yahya, 2008). Consequently, monitoring solar panels behavior contributes to reduce maintenance costs and to avoid energy output losses.

The first section of this report investigates the monitoring questions that will be examined. The second section explains the monitoring plan criteria followed by the techniques that could be used to assess the PV system.
Moreover, a detailed plan of evaluation and analysis for the monitored data is discussed, in addition to the data analysis methods and results.

The main objectives of this monitoring plan are:

- To estimate the energy output and performance ratio of a 4.3 kWp PV roof system.
- To develop and analyse problems causing the inefficiency of the PV system
- To assess the performance and identify the inefficiency of PV system
- To contribute to a lower energy consumption

2. The Monitoring Questions

In accordance with the objectives of this monitoring plan, the monitoring questions are:

- Is the PV system performing efficiently?
- Is the PV system providing the house with the needed electricity?
- How can the system's efficiency be improved?
- Are there any problems or defaults detected in the system?
- Is the PV output sufficient for the required cooling and heating load?

2.1 Literature Review

Literature about Photovoltaics performance is available and extensive, and the efficiency of PV systems has been monitored and evaluated by many researchers with different methodologies. Many researchers have investigated different parameters that affect the system's efficiency.

Several studies have used **simulation method** to investigate the PV efficiency. For example, (Saber et al., 2014) assessed the annual energy yield and daily profile of output power and cell temperature of PV systems in the tropical weather of Singapore. By monitoring solar irradiation, module temperature followed by EnergyPlus simulation, the study found that the energy output varies according to their location, orientation, inclination, and also environmental and shading conditions.

Similarly, in another study in Egypt, (Farghaly and Hassan, 2019) compared the performance of stand-alone BIPV systems and the integrated BIPV systems, (BISOL PremiumBXO 365Wp monocrystalline and BXU 330Wp, polycrystalline) conducting **Building Performance Simulation (BPS)** method. The comparative study found that the BISOL Premium BXO 365 Wp monocrystalline is more effecient and feasible.

(Bellazzi et al., 2018) also carried out a **numerical and experimental analysis** for BIPV modules, by monitoring environmental, thermal and energy variables (weather, air and surface temperature, electricity output)

Moreover, (Ayompe et al., 2011) numerically monitored a 1.72 kW roof mounted PV system in Dublin, Ireland. The performance parameters calculated include: annual energy generated, array yield, final yield, reference yield, PV module, system efficiency, inverter efficiency, performance ratio, capacity factor, array capture losses, system losses and cell temperature losses.

(Oozeki et al., 2003) applied **the sophisticated verification method (SV)** method and estimated the loss factors of PV system that might be caused by temperature, inverter losses, load mismatch, shading, incident angle.

(Aristizábal and Gordillo, 2008) performed a sophisticated monitoring system to evaluate a grid-connected BIPV plant in Colombia. The measured parameters are DC and AC power, inverter and system conversion efficiency, energy generated by the PV array, AC energy produced by the BIPV system.

(Dondariya et al., 2018) performed simulation analysis for a house in India using four different **simulation software**, PV*SOL, PVGIS, SolarGIS and SISIFO. The scholar found that Solar irradiation is the most important input for a professional assessment of energy yield of PV system. Energy generation, performance ratio and solar fraction were the main performance parameters that the study examined.

Some writers (Kulkarni and Kulkarni, 2017) have attempted to **design a monitoring system** structure. Which includes sensors for light, motion and distance, in addition to Raspberry Pi credit card sized PC.

In the same vein, (Xia et al., 2013) designed a monitoring system (hardware and software) for the PV inverter.

However, (Yahya, 2008) used **reference cells** to collect real time data and electronic subsystem for processing.

In all the studies reviewed here, Annual energy output, performance ratio, current and voltage appear to be the most significant parameters examined. Moreover, climatic parameters are principal determining factors of PV performance.

3. Monitoring Plan

Based on the literature review, the section below describes the proposed monitoring plan. Before explaining the monitoring framework, it is important to describe the overall performance of the SOLCER house and the PV panels specifications.

(Coma and Jones, 2015) consider the SOLCER house as a power station house, where energy is generated, stored and used. Electricity generation is mainly from BIPV roof system with a Minimal dependence on the grid.

It is necessary here to clarify exactly what is meant by BIPV technology. (Zhang et al., 2018) refer to BIPV technology as a utilization method for the PV system in which the PV cells integrate into the building envelope as a building material. This integration contributes to a 70% autonomous operation independent of grid supply to the house. (Jones et al., 2017)

Generally, the south facing PV system of this house is a grid connected one. It consists of crystalline silicon cell module glazed 4.3 kWp PV roof array of 34m^2 and a battery storage system 6.9 kWh lithium-ion-phosphate. (Jones et al., 2017)

When SOLCER house was under construction, (Coma and Jones, 2015) evaluated the house energy performance using the BAPS tool, taking the sizing of the PV panels and the Li-ion battery storage into account.

Mainly, solar and wind energy are the main energy supply for the building, this energy can be stored in a Li-ion battery or exported to the grid. Generated energy can be used for lighting and operating other home appliances and devices.

It is obvious from the energy flow path of this building (Figure 1), that the main reason behind the energy efficiency is using the solar and wind energy directly rather than importing or exporting it to the grid. (Coma and Jones, 2015)

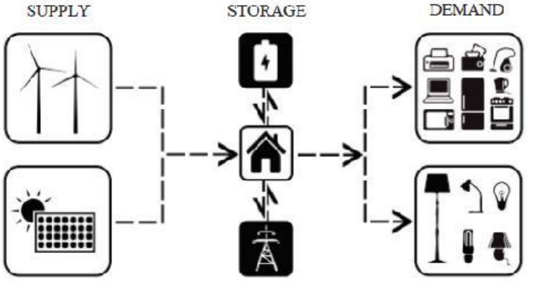

Figure 1 SOLCER house energy flow path. (Coma and Jones,2015)

The researchers found that integrating the PV panels to the house envelope is the best approach, since solar energy is a weather dependent source, and this is the best solution to achieve the balance between energy demand and supply.

Figure 2, shows an analysis of the simulated monthly energy performance which was done by (Jones et al., 2017), and found that the ratio of the grid export to import rate is 1.75:1.0

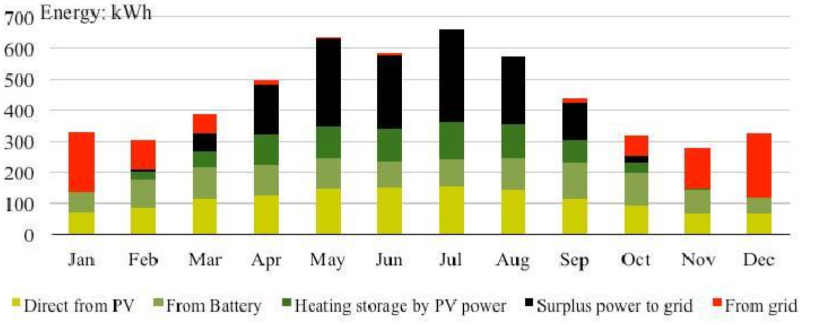

Figure 2: Simulated monthly energy performance of SOLCER house (Jones et al.,2017)

With respect to the performance assessment, Monitoring plan guidelines or framework are established:

- Practicability considerations and feasibility
- Easy to carry out and implement
- Low cost

3.1 Methodology

For the purpose of performing this assessment, the proposed monitoring plan (Figure 3) is based on a quantitative analysis, which consists of two parts, the first part is a real-time monitoring system to collect weather data and system measurements, and the second part is a DesignBuilder simulation tool.

Basically, all monitored data will be collected and compared to the baseline data of the DesignBuilder simulated results. Data comparison and evaluation can help in detecting any energy issues or system defaults.

To meet the objectives of this monitoring plan, some strategies and retrofits will be done based on the monitoring results. After implementing the strategies, another monitoring process should be done to check the improvement of the system.

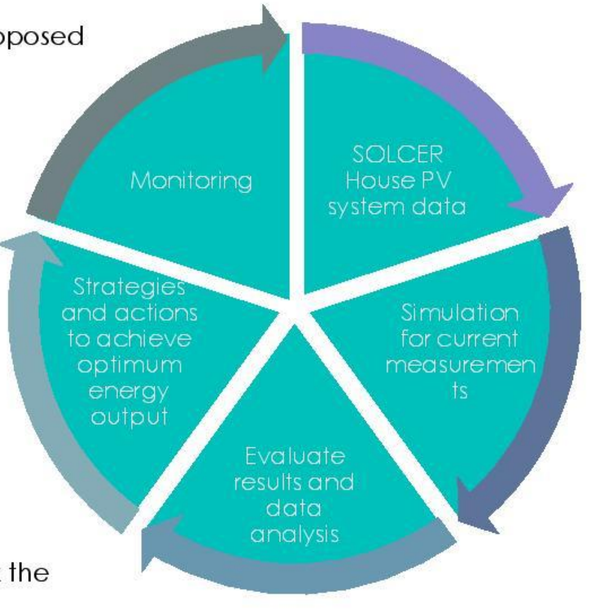

Figure 3 Proposed monitoring plan process

According to the literature review (Xu, P. et al, 2012) cited in (Farghaly and Hassan, 2019), strategies and retrofits to maintain energy consumption reduction are:

- Improving thermal insulation properties.
- Enhancing building cooling/heating efficiency.
- Promoting automatic control system.
- Using renewable energy generation resources and raising awareness of energy conservation.
- And encouraging energy conserving behaviors.

3.2 Proposed Techniques for data acquisition

(Yahya, 2008) states that performance PV system monitoring guidelines require electrical and metrological parameters.

For this monitoring plan, solar radiation and temperature will be the main metrological parameters, while voltage and AC current are assessed for the electrical parameters. The chart below (Figure 4), illustrates the monitored data structure.

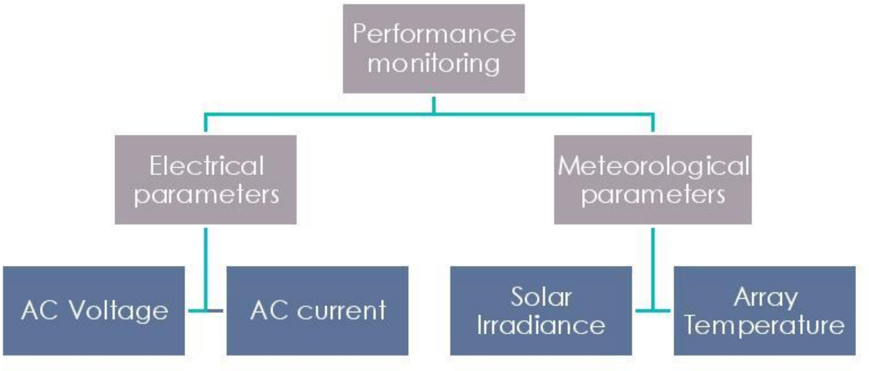

Figure 4 Performance measured parameters

3.2.1. Real-time data monitoring (Part 1)

Metrological Parameters

For measuring total solar radiation and temperature on the PV modules, a sensor will be installed on the PV system.

The solar radiation is one of the factors that disturb the grid. The solar radiation quantity is the reference for planning the monthly power generation and laying the power dispatching plan of the grid departments. (Wu et al., 2015)

Based on literature review (Ayompe et al., 2011), **Sunny SensorBox** is an option (Figure 5). This sensor is installed on the module and connected to the inverter. Data can be displayed on a PC. Table presents the technical specifications of this sensor.

Electrical Parameters

Direct current of the PV array is converted to DC by the inverter, and the performance of the inverter influences the quality of the output electrical power. In order to monitor the Current and voltage of the PV system, I-V curve tracer is proposed. (van Dyk et al., 2005).

I-V500w Curve Tracer (Figure 6) will be used for this step. Table 1, shows the technical specifications for both tools used in the real-time monitoring process.

Figure 5

Sunny SensorBox Source: https://www.mrsolar.com/sma-sunny-sensor-box/

Figure 6

I-V500w Curve Tracer Source: https://www.ht-instruments.com/en/products/photovoltaic-testers/i-v-curve-tracers/i-v500w/

Table 1 Technical specifications of field sensors

Parameters	Field Sensor	Technical Specifications	
Solar irradiance	Sunny SensorBox	• Dimensions (W / H / D) in mm • Weight • Mounting location • Deployment options	• 120 / 50 / 90 • 500 g • Outdoor • Mounting plate, roof bracket
Current-voltage	I-V500w Curve Tracer	• Detection of I-V curve on PV modules and strings • Internal memory capacity 249 I-V Curves • Weight in grams Size (LxWxH) (mm)	• 1500V/10A - 1000V/15A • (batteries included) 1200 • 235x165x75

3.2.2 Software Simulation (Part 2)

DesignBuilder will be used as a simulation tool to find out the expected energy output (kWh) of the PV system of the built model. This helps Compare the evaluated data to the simulated results, and to study the correlation between the expected results with the monitored data.

Figure 7, summarizes the monitoring plan flowchart.

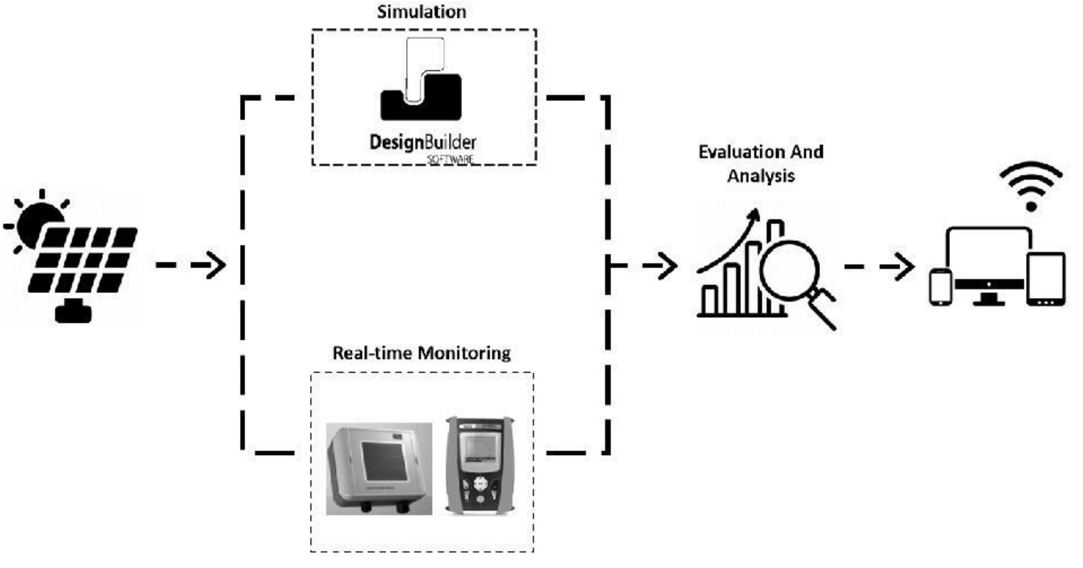

Figure 7 Monitoring plan flowchart

4. Data Analysis

The system should be monitored daily for at least one year, to examine the seasonal and weather variations. Different climate conditions like fog, rain and snow might affect the performance of the solar panels. Solar cells should be monitored three times a day, in the morning, afternoon and at night, to increase the reliability of measures.

The performance indicators are:

- **Performance ratio:** (Pvps, 2000) points out that the Performance Ratio (PR) is the most pivotal indicator of the PV performance. Because this ratio is independent of location and system size and indicates the overall losses on the array's nominal power due to module temperature, incomplete utilization of irradiance and system Component inefficiencies or failures. This ratio can be calculated applying the following formulas:
  - performance ratio

$$(PR) = Y_f / Y_r \text{ where}$$

- Final Yield: defined as the energy generated by the system in a frame of time, divided by the nominal power of the PV generator. (Aristizábal and Gordillo, 2008)

$$(Y_f) = E_{use.PV.d} / P_0 \quad \text{Unit (h/d)}$$

- Reference Yield: defined as the solar irradiance in the inclination plane of the PV generator in a frame of time, divided by the solar irradiance under standard conditions (Sidrach-de-Cardona and Mora López, 1999) cited in (Aristizábal and Gordillo, 2008)

$$(Y_r) = day\ GI\ dt / GSTC \quad \text{Unit(h/d)}$$

- **PV Energy output:** substituting the current and voltage values in the formula below to get the power value.

$$Power = Current\ X\ Voltage$$

The final values obtained, can be compared to the DesignBuilder simulated results, or to a different reference house, that has the same crystalline silicon cell module, located in the same climate as Cardiff city.

5. Results

As explained earlier, the performance indicators are: Performance ratio and Energy output. Therefore, numerical data will be presented in tables to generate average daily, monthly and yearly profile of energy output, in addition to Performance Ratio, in Excel spreadsheets. Table 2 is an example of the data sheet.

Table 2 Data sheet example

Month	Energy Output (kWh)	Irradiance (kWh/m2)	YF	YR	PR (%)
January					
February					
March					
April					
May					
June					
July					
August					
September					
October					
November					
December					
Total					

Since the initial objective of the project is to estimate the PV energy output System which determines the system efficiency. The system output should meet the required load of heating or cooling, this will be based on:

- Internal heat gain
- Occupant heat gain
- Cooling and heating demand for the house
- Heat gain and loss
- How many people live in the house?
- How many appliances

A bar chart (Figure 8) showing the consumed energy in relation to the generated energy is essential.

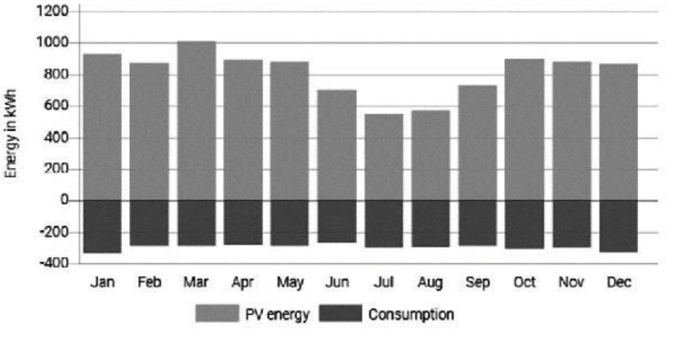

Figure 8 PV energy - Consumption (Dondariya et al., 2018)

Additionally, energy output should be examined with correlation to the solar radiation. Several reports have shown the relationship between solar radiation and output yield. For example, (Wu et al., 2015) found that the monthly output yield increases with a rise of solar radiation quantity. Similarly, (Gupta et al., 2014) examined the monthly PV energy output with the solar radiation and ambient temperature of Cardiff city. (Figure 9 and 10)

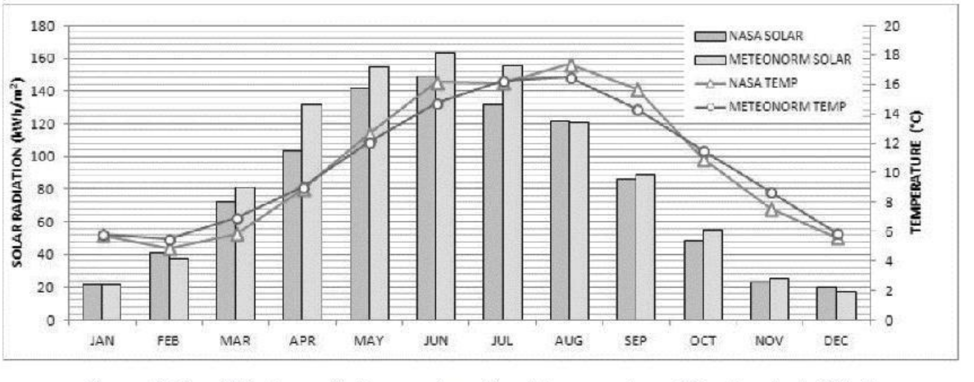

Figure 9 Cardiff Solar radiation and ambient temperature (Gupta et al., 2014)

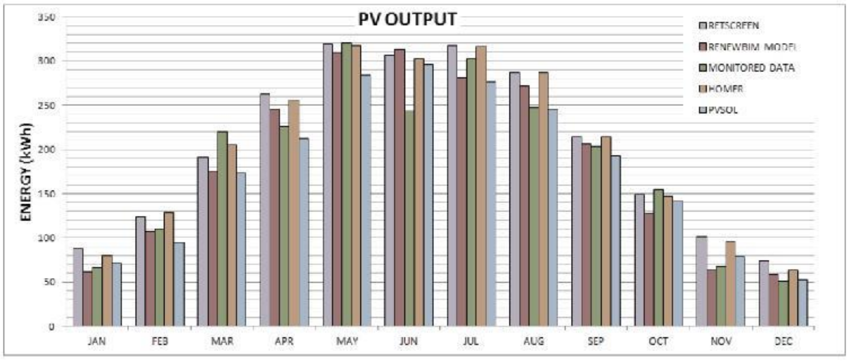

Figure 10 Monthly output of PV simulation tools in Cardiff (Gupta et al., 2014)

Furthermore, finding the correlation coefficient between AC output and solar radiation helps in determining the systems efficiency, (Figure 11) illustrates an example of (Ayompe et al., 2011) study.

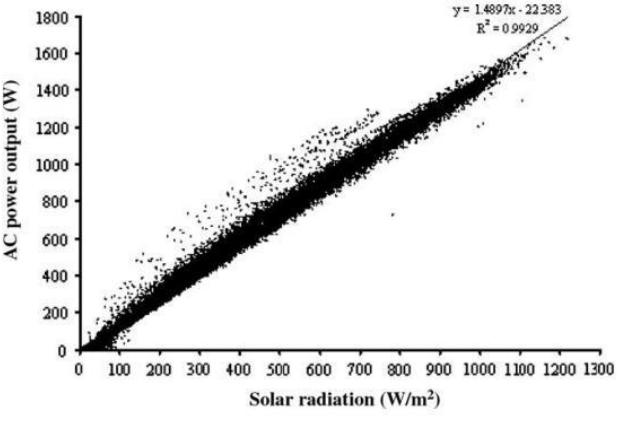

Figure 11 AC output - Solar radiation (Ayompe et al., 2011)

6. Conclusion:

This report proposed a monitoring plan for the PV system of SOLCER house. The report aims at determining the system's efficiency through conducting a real-time monitoring and DesignBuilder simulation. The main performance indicators are the performance ration and the energy output of the solar cells. Based on the literature review, suggested examples of field sensors, data sheet layout, and analysis charts are included.

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