Investigate the PV self-consumption in Solcer House and its self-sufficiency by combining the PV system with Battery Storage

MSc Environmental Design of Buildings, 2 year path, DL. Student Number: C1773063

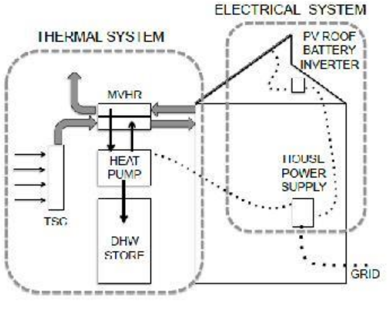
1. Introduction

Buildings account for 36% of carbon emissions in the European Union. As a part of the Climate Change Act 2008, the United Kingdom aims to reduce carbon emissions by 80% of the 1990 baseline by the year 2050 and aims to cut down 50% greenhouse gas emissions specifically in the built environment by the year 2025. Consequently there is a growing requirement of low energy housing and more recently energy positive housing (Jones et.al 2017). Solar PV homes have gained attention all over the world due to their ability to utilize renewable energy and aid in reducing the consumption of fossil fuels. (Xian Li et al 2019). Solcer house, built in Wales in the year 2015, is built on the concept of 'Buildings as Power Stations', where buildings contribute positively in the electric power generation system. This is achieved by reducing the energy demand, integrating renewable energy systems, storing thermal and electrical energy and using a building systems approach. A number of innovative systems such as the PV panel array, battery storage system, transpired solar collector and mechanical ventilation and heat recovery system are used in the house. (Coma and Jones 2015).

2. Description of Electrical System

The electrical system consists of a PV panel array of 4.3 KWp capacity integrated in the south facing roof and a 6.9KWh lithium-ion-phosphate battery for storage. Power generated by the PV cells is used to satisfy the building loads and charge the battery, excess PV power is used to heat the thermal energy storage of domestic hot water, and then the further excess power is exported to the grid. When the consumption demand exceeds the power generated and supplied by the PV and battery storage system, energy is imported from the grid (Jones et.al 2017).

Figure1: Conceptual Image of Electrical and Thermal System



3. Literature review of PV-Battery System

Photovoltaics technology is a promising option considering its economic potential as well as environmental benefit of being a low carbon energy source (Lang et al 2015).
The International Environment Agency has projected that 11% of electricity produced worldwide by the year 2050 will be through photovoltaic panels. The fall in PV prices combined with policy support has resulted in a widespread deployment of distributed PV systems. Due to high grid prices, grid operation costs, transmission charges, distribution charges, taxes, and other cost components, consuming the generated PV power on-site brings greater economic value to the system rather than exporting it to the grid. This is found to be applicable even in countries with minimal regulatory support. (Olive H et al 2019), (Lang et al 2015). This phenomenon is known as PV self consumption and is defined as the amount of power generated by the PV system which is

consumed directly on-site by the PV system producer/owner. Goodrich et al (2013) cited in Luthander et al (2015) states that the conventional definition of self consumption takes only the power consumed instantaneously or within a15 minute window into consideration. The PV system output is not constant as it varies through the hour and through seasons .Also the PV production and PV consumption do not peak at the same time such that their profiles diverge and so storage of electricity generated by the battery present a solution in order to increase the percentage of self consumption. (Vonsein and Madlener 2018). The battery system stores the PV power which is generated during off-peak consumption time and supplies it during on-peak consumption times; this shifting of load from off-peak to on-peak of demand is known as Load leveling. Combining the PV system with energy storage system caters to the issue of variable generation and provides a solution in transforming the renewable energy system into a schedulable high value product with an improved utilization of investment. (Bayod-Rujula et al 2013).

4. Monitoring Question

This aim of this paper is to investigate the PV self consumption in Solcer House and its self sufficiency by combining the PV system (PV) with battery storage (BSS)

5. Monitoring Plan

5.1 Detailed Exploration of Feature

PV self consumption and self sufficiency of Solcer House is directly affected by interaction between energy generated by PV, household energy consumption demand and energy stored in the BSS. On the basis of site visits and literature reviews the modes of operation of the PV-battery system can be described as follows:

Scenario 1: If the household energy demand is lower than the energy generated by the PV, the demand is directly supplied by the PV. Afterwards if the batteries are not charged they will be charged and lastly if there is still a surplus amount of generated energy it will be injected into the grid

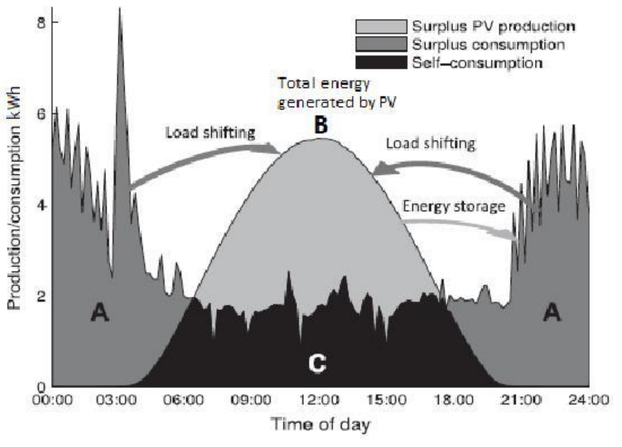
Scenario 2: If the household energy demand is higher than energy generated on site and the energy generated by the PV is not enough to satisfy the demand at that time of the year; and if the batteries have sufficient energy stored in them, the batteries are discharged in the amount of the energy deficit. Further if the energy supplied by the batteries is not sufficient then the remainder of the energy demand is absorbed from the grid.

Scenario 3: If the energy demand is equal to the energy generated in that time interval, the energy required for household consumption is directly supplied by the PV system and the state of charge of the batteries remains unchanged. In case when the battery reaches a minimum state of charge, then the energy is imported from the grid for charging the batteries.

5.2 Quantification of Performance

'A' represents the energy consumed on site which is in excess of the energy generated by the PV and supplied by battery, 'B' represents the total energy generated by PV on site and 'C' represents the amount of energy generated by the PV system which is utilized directly on site.

Figure 2: Conceptual Schematic



<u>*PV Self Consumption (SC):*</u>

In order to understand the self consumption with the battery storage system, the equation is elaborated and described as follows; 'EC' represents the instantaneous energy consumption on site and 'EG' represents the instantaneous energy generation on site, 'S' is the energy supplied to and from the battery storage system, the value of 'S' is negative when the battery is charging and positive when the battery is discharging. 'C' is the energy utilized directly on site taking the overlap of energy generation energy consumption and the energy supplied by the battery into account. Luthander et al (2015) pointed out that in case the limiting factor for self-consumption depends on 'EC', 'EG' and 'S' illustrated in the equation below:

Instantaneous energy consumption on site considering the PV- Battery Storage system:

$$C = \min \{EC, EG + S\} \qquad \ldots (1)$$

PV self consumption can be defined as the energy used directly on site in proportion to the total energy generated on site and is proposed to be calculated as follows :

SC = C *(energy utilized directly on site)* **/ B** *(total energy generated on site)* --- (2)

Self sufficiency can be defined as the degree to which onsite energy generation is sufficient to meet the total energy demands and is proposed to be calculated as follows:

SS= C *(energy utilized directly on site)* **/ A** *(energy imported from the grid)* **+C** --- (3)

6. Monitoring Methodology

6.1 Monitoring Tools and Data Collection

The following measurements are proposed to be collected:

a. PV output energy
b. Household energy consumption
c. Energy supplied by the BSS
d. Energy exported to and imported from the grid

Watthour meters (WM) provide a combined measure of current and voltage integrated over time, which allow measurement of energy with an output in Watt-hours. Thus Wattmeters with integrated data logging are proposed to be installed as measuring tools for monitoring the energy. In order to measure the PV output energy WM1 is proposed to be located between the PV system and the inverter. The household power consumption is proposed to be measured under the heads of Ground Floor sockets, Ground Floor lights (Foyer, Kitchen, Living + Dining Room, Shower Room), First Floor sockets, First Floor lights (Double Bedroom, Single Bedroom1, Single Bedroom2, and Bathroom) and Services and Utility (MVHR, Heat Pump, Utility). This categorization will give the total energy consumption and also give an indication of which spaces/ functions are peaking at what time in the day. Wattmeters WM2-WM6 are proposed for measurement of each category and are proposed to be located between the distribution board and each source category. A bi-directional energy meter (BD1) is proposed to measure the energy supplied to and from the battery system and is proposed to be placed between the PV system, Battery and Inverter. A bi-directional meter (BD2) is also proposed to measure the energy exported and imported from the grid and is proposed to be placed on the gird connection and the inverter.

A number of papers have studied the effects of measurement intervals and their impact on the analysis of on-site power generation. They demonstrate that for single buildings it is beneficial to collect the data on a sub-hourly basis in order to take the high peak power scenario into account (Luthander et al 2015). Thus for the purpose of this paper a time interval of 15 min is proposed for taking the measurements. The monitoring is proposed for one year to take into account the effects of all seasonal variations. It is proposed to install the wattmeters with data logging and a wireless module is proposed which will transfer the measured data to a data acquisition and monitoring platform (example LabView). The platform store the acquired data it in excel files and will plot it in format of graphs for further analysis. It is assumed that the measuring tools are new and calibrated by the manufacturer and recalibration of the tools is recommended after every two years or as specified by the manufacturer

Figure 3: Flow chart of PV-battery system with location of monitoring equipment

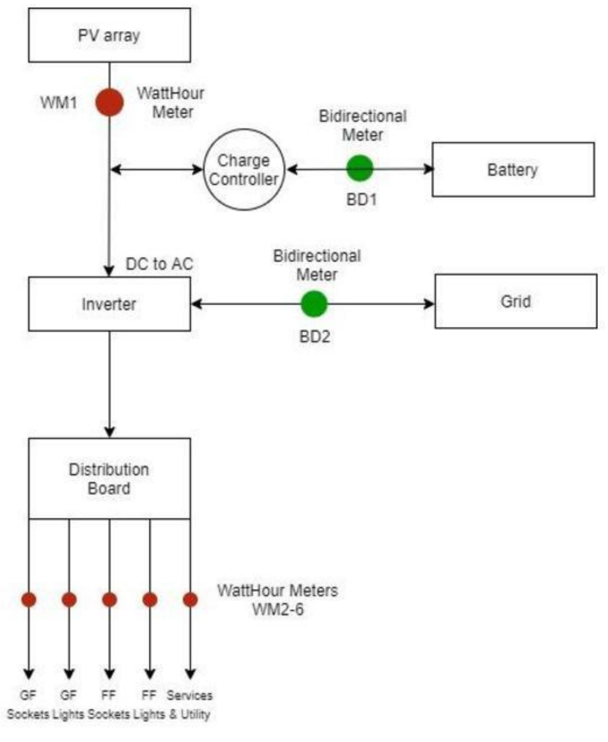


Figure 4: Monitoring equipment

(a) Watthour meter *(b) Bi-directional meter*

6.2 Calculation

Self Consumption: Referring to equation (1) The data collected by WM2 – WM6 will be added to obtain the value of instantaneous energy consumption 'EC' , the data collected by WM1 represents the instantaneous energy generation 'EG' value and the data collected by the bi-directional meter (BD1) represents the energy supplied to and from the battery i.e 'S'

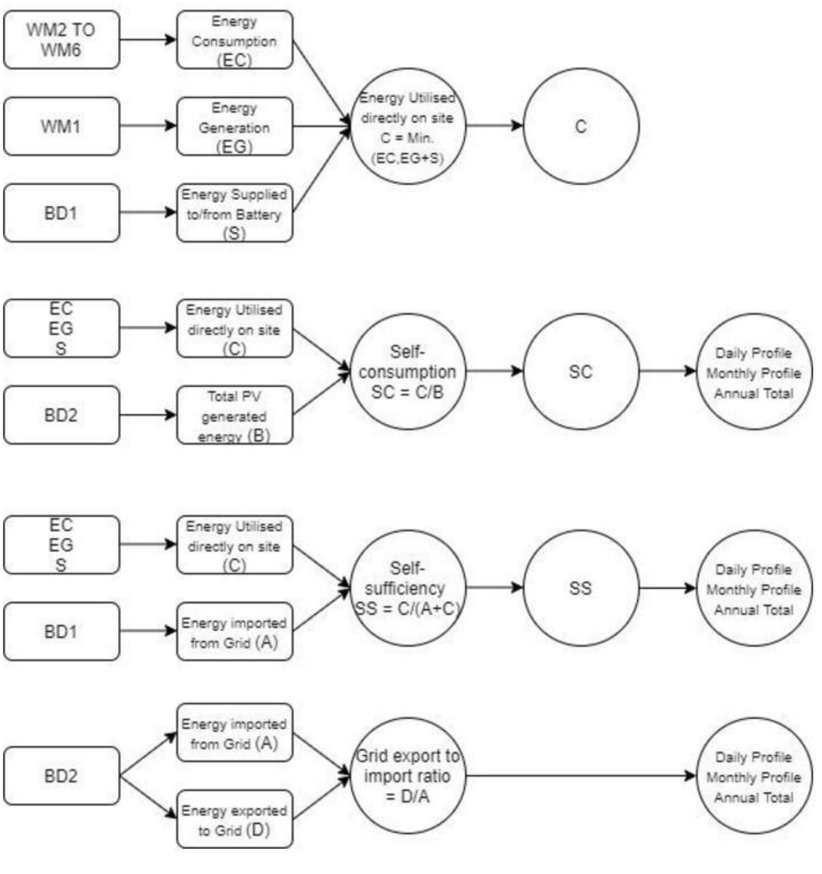
Equation (1) is proposed to calculate the energy utilized directly on site represented by 'C'. The data collected by WM1 of total energy generated on site will be represented by 'B'.

Afterwards obtaining the value of 'C' and 'B' Equation (2) is proposed to be used in order to derive the value of Self Consumption 'SC'

The data collected by BD2 of energy imported from the grid will be represented by (A), thus on obtaining the values of 'A' and 'C' equation (3) is proposed to be used, in order to calculate the self sufficiency value 'SS'

Hourly totals and monthly totals of energy imported from and exported to the grid will be calculated using data collected by BD2

Figure 5: Schematic of monitoring methodology



6.3 Results

Daily self consumption and self sufficiency profiles will be prepared using the 15 min interval values of 'SC' and 'SS' averaged over one hour. Furthermore the values of energy utilized directly on site (C) and total energy generated on site (B) are proposed to be integrated over a period of one month to derive monthly SC totals in order to prepare an monthly self consumption energy profile and likewise they are proposed to be integrated over a period of one year to derive the annual self consumption value. Similarly the values of energy utilized directly on site (C) and energy imported from the grid (A) are proposed to be integrated over a period of one month and one year to derive the monthly self sufficiency energy profile and annual self sufficiency value. Hourly total collected by BD2 are proposed to be used to derive a daily energy import and export profile. Monthly totals collected by BD2 are proposed to be used to derive a monthly energy import and export profile and annual total value. The data acquisition and monitoring platform will be programmed to carry out the calculations mentioned above on the basis of the collected data. The data is proposed to be consolidated in the form of tables/graphs to obtain the following results:

a. Daily *profile:* PV self consumption , Solcer house self sufficiency , Energy imported from and exported to grid
b. *Monthly profile :* PV self consumption , Solcer house self sufficiency , Energy imported from and exported to grid
c. *Annual total value :* PV self consumption , Solcer house self sufficiency , Energy imported from and exported to grid

Figure 6: Sample Daily Profile of PV self-consumption

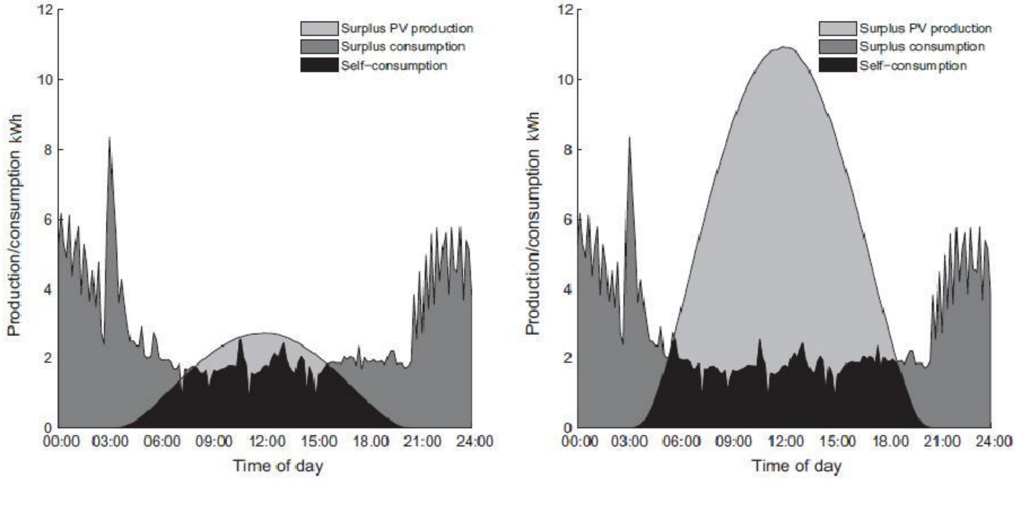


Figure 7: Sample Superimposed Daily Profile of Energy Consumption

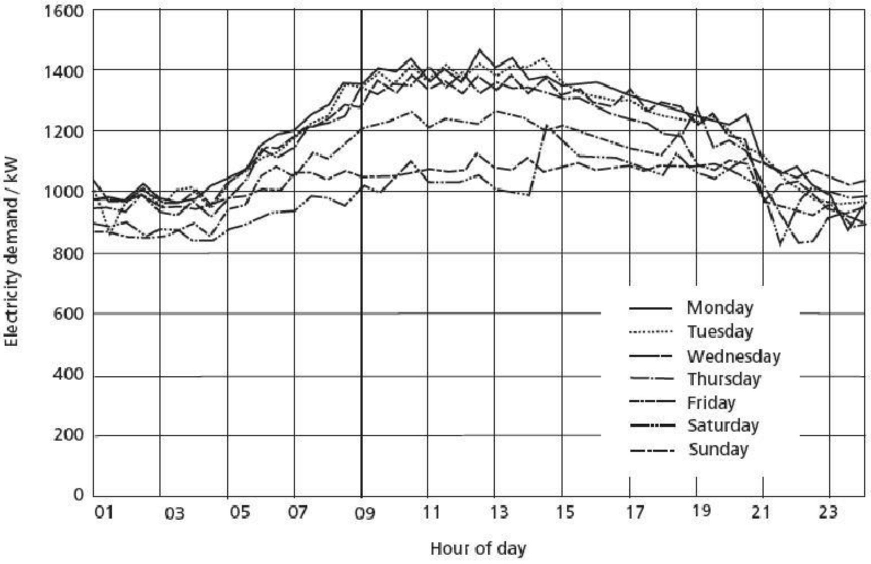


Figure 8: Sample Monthly Profile of Self Consumption, Self Sufficiency, Export and Import to/from grid

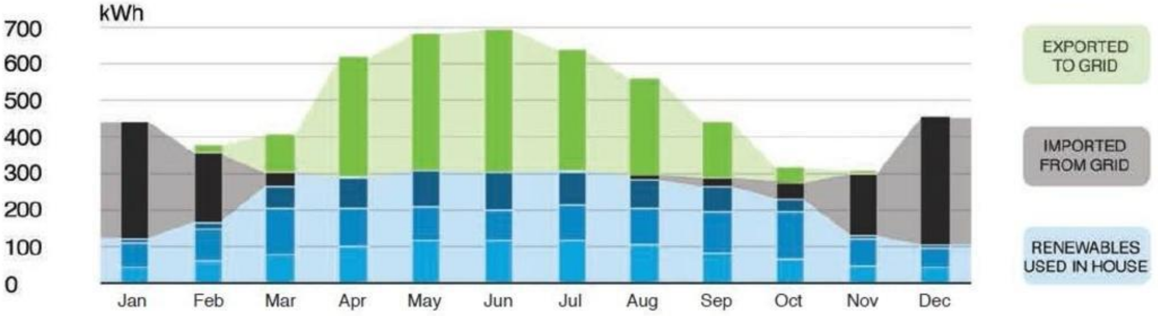
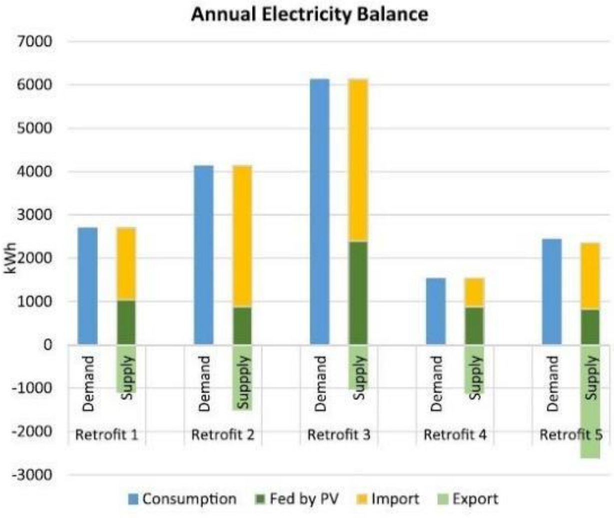


Figure 9: Sample Annual Totals graph of Energy Export and Import



7. Analysis of data and its possible use

The basic self consumption and self sufficiency values obtained through calculation describe the interplay between the energy generation and energy demand on site. These could become a part of a larger set of load matching and grid interaction indicators (Luthander et al 2015).

Analyzing the daily, monthly and annual PV self consumption and self sufficiency values with battery and possible comparing it with a scenario without battery system will demonstrate the role of the battery in increasing the PV self consumption The analysis could prove as a baseline for further research on economic feasibility of PV system and combined PV-battery systems. Lang et. al. (2015) carried out a techno economic analysis on different building types of varying sizes to note that price of electricity along with the achievable self consumption which in turn is dependent on the power generation and power consumption ratio of the specific building play a vital role in driving profitability of the PV system.

The Daily SC profile with battery storage system will highlight the interplay between peak times of PV energy generation and the household energy consumption on a daily basis. Analysis of this collected data could prompt in understanding the energy behaviors in households. Daily profiles could be superimposed to identify changes, trends, similarities and differences. The collected energy consumption and energy export to import data can be used to establish the performance indicator of a building which would allow comparison with historical data and published benchmarks, for example in CIBSE Guide F. (The Chartered Institution of Building Services Engineers 2012)

Load management technique could be combined along with the battery storage system to increase PV self consumption. Luthander et al (2015) point out that study of behavioral responses to PV should be complemented by actual collected consumption data. This data could inform decisions of demand side management, for example some energy demands of loads such as dishwashers, washing machine can be planned to be shifted from periods of surplus power consumption to periods of surplus PV production.

The PV output energy is variable; being null at night and low in winter while reaching peak production at noon and in summers, the monthly self consumption profile, combined with a self sufficiency profile will indicate in which periods is the production low to suffice the consumption. This information can lead to an exploration of possibly overcoming the deficit by combining it with other complementing renewable energy systems. (Bayod-Rujula et al 2013).

8. Conclusion and Further Research

This paper investigated PV self consumption of the PV-battery system in Solcer House and combining this data with the export and import of power from the grid to derive a relationship between the self consumption and self sufficiency. If monitoring is continued over a period of years, trends of increasing/decreasing PV self consumption and self sufficiency of Solcer house and their possible drivers could be studied. Due to increased interest in this self consumption, number of studies highlighting the potential of increasing PV self consumption are being published; however they have a varied range of results. (Luthander et al 2015). This indicates a necessity to make more monitored data available which is comparable for various buildings and end users. Monitoring the PV self consumption and self sufficiency of Solcer house could feed into such a database, which could result in benchmarking of standard, good and best practices for planning an energy positive house. This could inform the design decisions of the PV-Battery system of other households.

9. References

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9. List of Figures and Tables