MINI PROJECT

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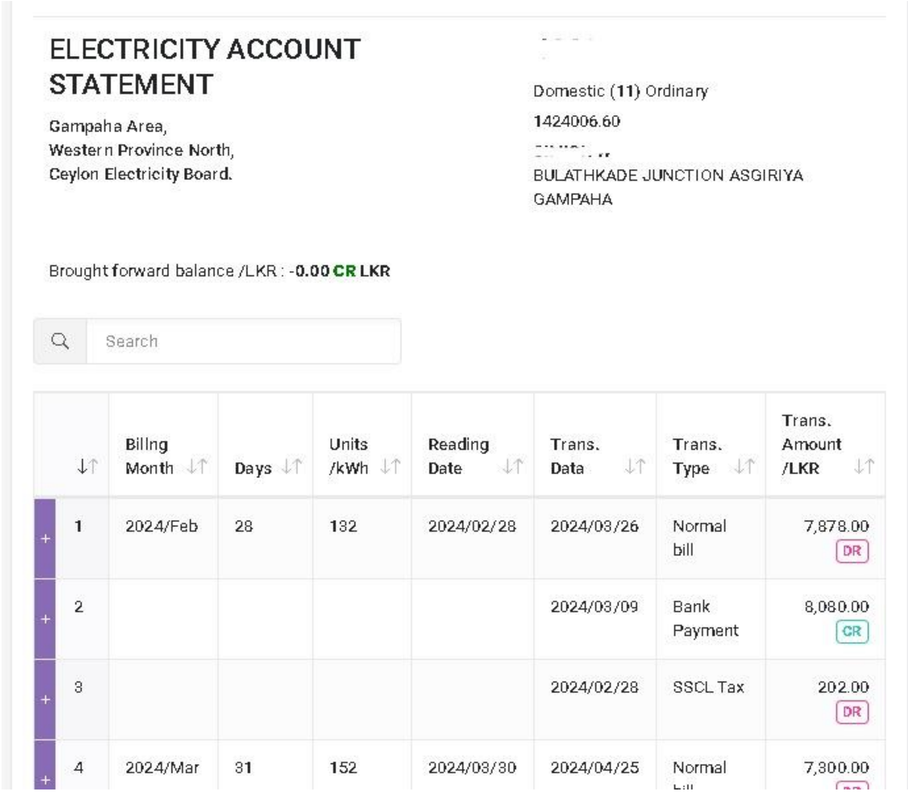
1. Gather Electricity Consumption Data

1. Average daily power consumption

Electricity bills for 10 months were collected for the calculations. Data was collected from the CEB site under the billing information section.



ELECTRICITY ACCOUNT STATEMENT

Gampaha Area,
Western Province North,
Ceylon Electricity Board.

Domestic (11) Ordinary
1424006.60
BULATHKADE JUNCTION ASGIRIYA
GAMPAHA

Brought forward balance /LKR : -0.00 CR LKR

Search

	Billing Month	Days	Units /kWh	Reading Date	Trans. Data	Trans. Type	Trans. Amount /LKR
1	2024/Feb	28	132	2024/02/28	2024/03/26	Normal bill	7,878.00 DR
2					2024/03/09	Bank Payment	8,080.00 CR
3					2024/02/28	SSCL Tax	202.00 DR
4	2024/Mar	31	152	2024/03/30	2024/04/25	Normal	7,300.00

The data collected for 10 months are listed below,

Month	Units (kWh)	Days	Daily average
2/1/2024	132	29	4.551724138
3/1/2024	152	31	4.903225806
4/1/2024	125	30	4.166666667
5/1/2024	114	31	3.677419355
6/1/2024	112	30	3.733333333
7/1/2024	113	31	3.64516129
8/1/2024	112	31	3.612903226
9/1/2024	98	30	3.266666667

10/1/2024	120	31	3.870967742
11/1/2024	112	30	3.733333333
12/1/2024	133	31	4.290322581
Average			**3.950157**

It shows the power consumption each month in kilowatt-hours (kWh). Average daily power consumption in each month and the Overall Average daily power consumption are calculated using the following equations,

$$Average\ daily\ power\ consumption\ on\ each\ month\ = \frac{Monthly\ consumption}{No\ of\ days\ in\ month}$$

$$Average\ daily\ power\ consumption\ = \frac{\Sigma Avg.daily\ power\ consumption\ on\ month}{No\ of\ considered\ months}$$

$$= 3.950157kWh$$

2. **Peak Load analyze**

WATTHOUR METER that we took measurement was a **Time of Use meter (TOU).** It has the capability of providing the total power consumption in each time period

However, it shows the total power consumption in each time period from the installation date. The following table shows the obtained data by ourselves according to the observations.

Time period	Symbol on meter	Hours encountered	Readings
Day	T1	0530 - 1830 hrs	611.1
Peak	T2	1830 - 2230 hrs	**212.9**
Off Peak	T3	2230 - 0530 hrs	128.1
Total	-	0000 - 2400 hrs	**952.2**

Figure 1 : Readings for each time

According to the above data table,

$$Power\ usage\ percentage\ based\ on\ total\ consumption = \frac{consumption\ in\ peak\ hours}{total\ consumption} \times 100\%$$

$$= \frac{212.9}{952.2} \times 100\%$$

$$= 22.3587\%$$

$$Daily\ Consumption\ during\ peak\ hours = 3.950157kWh \times 22.3587\%$$

$$= 0.8832kWh$$

According to the CEB data, the peak period lasts 4 hours from 1830 to 2230 hrs. Therefore, Average peak demand can be calculated as follows,

$$Average\ peak\ demand = \frac{0.8832kWh}{4h}$$
$$= 0.2208kW$$

However, the requirement is to determine the peak load which is not equal to the average peak load. As there will be fluctuation during those 4 hrs., the peak load will be definitely higher than the average. Therefore, the following approach uses the Sri Lankan daily consumption graph with respect to time.

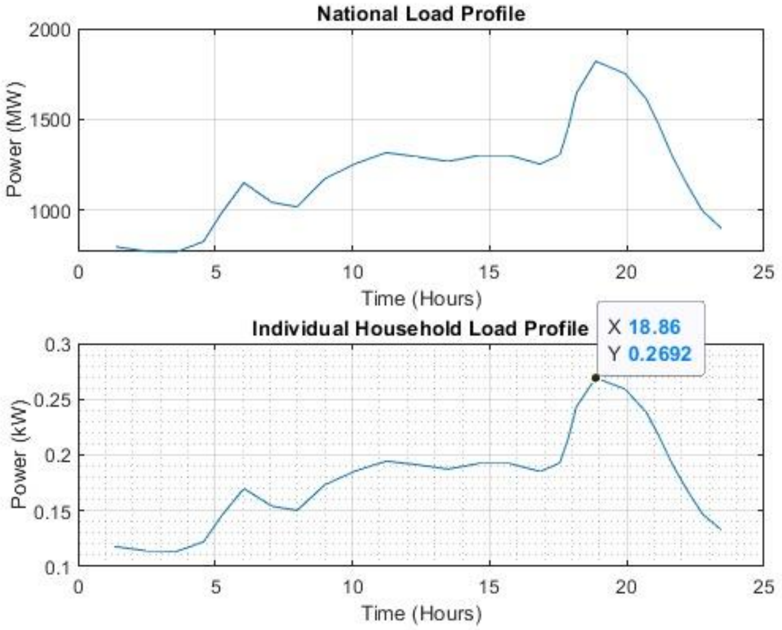
In this case, we assumed the daily national load profile is proportional to the individual house usage pattern. With a few simple down scaling calculations, the peak demand power has been obtained. According to that the peak demand is 0.2692kW.

```
hour=[…data…];
power=[…data…];

figure
subplot(2,1,1);
plot(hour,power)
grid on
xlabel('Time (Hours)');
ylabel('Power (MW)');
title('National Load Profile');


total_energy = trapz(hour, power)
energy_household = 3.95;
scaling_factor = energy_household / (total_energy*1000);
power_household = power*1000 * scaling_factor;

subplot(2,1,2);
plot(hour, power_household);
xlabel('Time (Hours)');
ylabel('Power (kW)');
title('Individual Household Load Profile');
grid on
grid minor
peak_demand_house = max(power_household)
```



As the calculated new peak demand is greater than the average. New peak demand can be taken as the correct value approximately. Therefore, the **peak demand value is 0.2692kW**.

3. Regular appliance usage

Regular appliance usage was calculated using its wattage figure and the number of hours the appliance is in use per day.

$$Regular\ appliance\ usage\ = Wattage\ figure\ \times\ No\ of\ usage\ hours\ per\ day$$

Appliance	Wattage figure	No of hours	Regular usage	Percentage
Refrigerator	100W	20hrs	2000Wh	50.63%
Rice cooker	1200W	40min	800Wh	20.25%
Iron	1000W	30min	500Wh	12.66%
TV, Wi-Fi router, computer.	50W+ 5W+ 30W	1hrs + 15hrs + 7hrs	335Wh	8.48%
Blender and other kitchen appliances	600W	10min	100Wh	2.53%
Water pump	750W	10min	125Wh	3.17%

Other	-	-	90Wh	2.28%
Total			3950Wh	100%

2. Identification of Essential Components

1. Required components for the off-grid solar PV system.

- solar panels
- charge controller
- battery bank
- Inverter
- Circuit protection
- Wiring
- Connectors
- representative load for household appliances.

3. Calculate Required Parameters

Following solar panel data from a reputed company was used for calculations.
(https://www.hayleyssolar.com/service/solar-panels-sri-lanka/)

DESCRIPTION	MONO PERC N-TYPE
WATTAGE	595Wp
TECHNOLOGY	Monocrystalline PERC N-Type
SIZE	2333 x 1134 x 30mm
WARRANTY	12 years 1st year 1% and 0.4% annually to 87.4% in 30 years
EFFICIENCY	22.50%
TEMPERATURE COEFFICIENT	-0.30%/C

And the solar irradiation data was used from “global solar atlas” see appendix for full report. According to that data, July month has the minimum direct normal irradiation. Hence its data was used for calculations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6				4	7	2	1		1	2		
6 - 7	67	72	79	150	97	74	59	64	95	124	119	92
7 - 8	304	336	343	319	179	157	141	146	201	250	264	286
8 - 9	447	486	479	414	227	221	204	206	249	325	366	393
9 - 10	533	566	525	485	312	304	286	331	328	371	420	454
10 - 11	563	594	530	507	352	351	333	387	373	394	427	473
11 - 12	537	572	521	481	374	354	343	361	392	405	407	446
12 - 13	506	541	563	502	377	337	341	365	424	423	372	404
13 - 14	468	529	612	496	330	293	295	327	381	369	321	359
14 - 15	411	484	514	397	270	227	222	247	273	251	233	306
15 - 16	328	382	358	261	184	164	159	168	177	144	138	219
16 - 17	203	254	205	131	105	107	96	100	84	56	51	105
17 - 18	17	43	31	14	13	19	18	14	3			
18 - 19												
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4,384	4,858	4,761	4,162	2,828	2,609	2,496	2,717	2,982	3,114	3,118	3,537

1. The number and wattage of solar panels required

$$E_{pannel} = \sum_{h=1}^{24} (DNI \times Area_{pannel} \times \eta_{pannel})$$

Where;

DNI = hourly direct normal irradiation (W h m^{-2})

A_{panel} = panel area

η_panel = panel efficiency

$$N_{panel} = \frac{E_{daily,house}}{E_{daily,panel}}$$

2. Battery capacity and inverter size

$$C_{battery} = \frac{E_{daily,house}}{DOD}$$

Where;

C = required battery capacity (Wh)

DOD = depth of discharge (assumed 90% for li-ion)

$$P_{inverter} = P_{peak} \times S_{factor}$$

S_{factor} = safety margin (assumed 1.2)

```
% Given Data
panel_wattage = 595; % Wp (Watt-peak)
panel_efficiency = 22.50 / 100; % Convert to decimal
panel_size_m2 = (2.333 * 1.134); % Convert to area in m^2
house_daily_energy = 3.95 * 1000; % Convert kWh to Wh
DOD = 0.9; % Depth of Discharge (Assumption)
safety_factor = 1.2; % Inverter safety factor

% Hourly DNI data (Jul)
DNI_hourly = [1 59 141 204 286 333 343 341 295 222 159 96 18]; % Wh/m2
for 5 AM - 6 PM
hours = length(DNI_hourly); % Count hours

% Compute total daily DNI
DNI_daily = sum(DNI_hourly); % Wh/m2 per day

% Energy output per panel per day
E_panel_daily = DNI_daily * panel_size_m2 * panel_efficiency; % Wh/day

% Number of panels required
N_panels = ceil(house_daily_energy / E_panel_daily);

% Battery capacity needed (in Wh)
battery_capacity = house_daily_energy / DOD;

% Inverter sizing
house_peak_power = 0.2692 * 1000; % Convert kW to W
inverter_size = house_peak_power * safety_factor;
```

```
% Display results
fprintf('Total daily energy per panel: %.2f Wh\n', E_panel_daily);
fprintf('Number of panels required: %d\n', N_panels);
fprintf('Battery capacity required: %.2f Wh (%.2f kWh)\n',
battery_capacity, battery_capacity / 1000);
fprintf('Inverter size required: %.2f W (%.2f kW)\n', inverter_size,
inverter_size / 1000);
```

Results -

Total daily energy per panel: 1486.97 Wh

Number of panels required: 3

Battery capacity required: 4388.89 Wh (4.39 kWh)

Inverter size required: 323.04 W (0.32 kW)

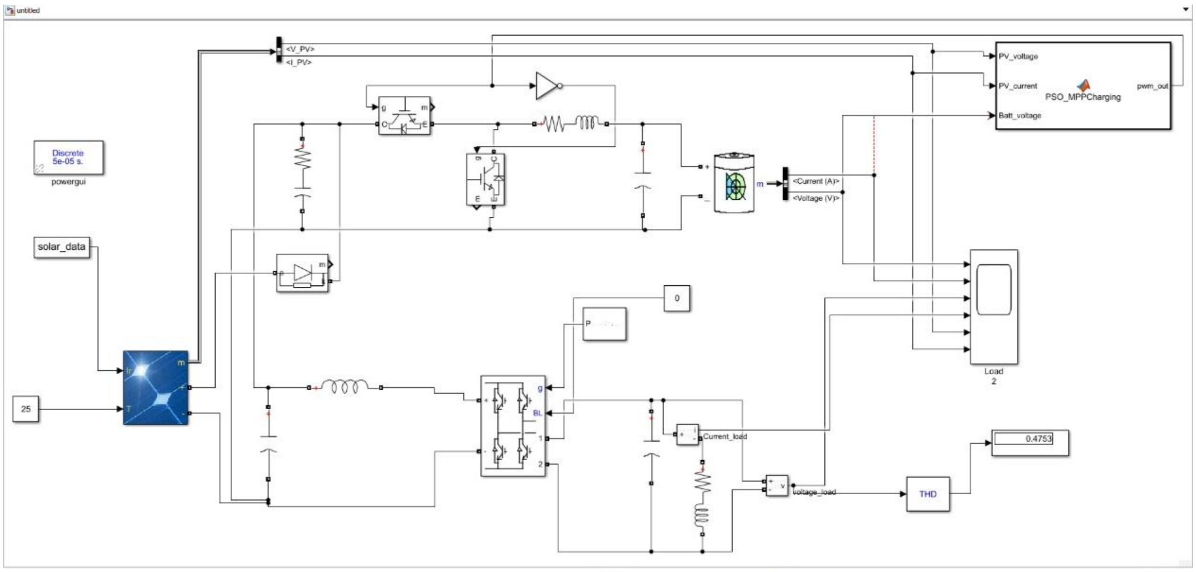
4. Specify Circuit Elements, Controls, and Algorithms

Component	Specifications
Solar Panels	
Total daily energy	1486.97 Wh per panel
Number of panels	3
Total energy generated	4460.91 Wh (4.46 kWh)
Wattage per panel	300W
Voltage (Vmp)	30-35V
Current (Imp)	10A
Total voltage (series)	90V (3 panels × 30V)
Total current (parallel)	30A (3 panels × 10A)
Battery Bank	
Total capacity required	4388.89 Wh (4.39 kWh)
Battery voltage	24V
Capacity in Ah	182.87 Ah (4388.89 Wh / 24V)

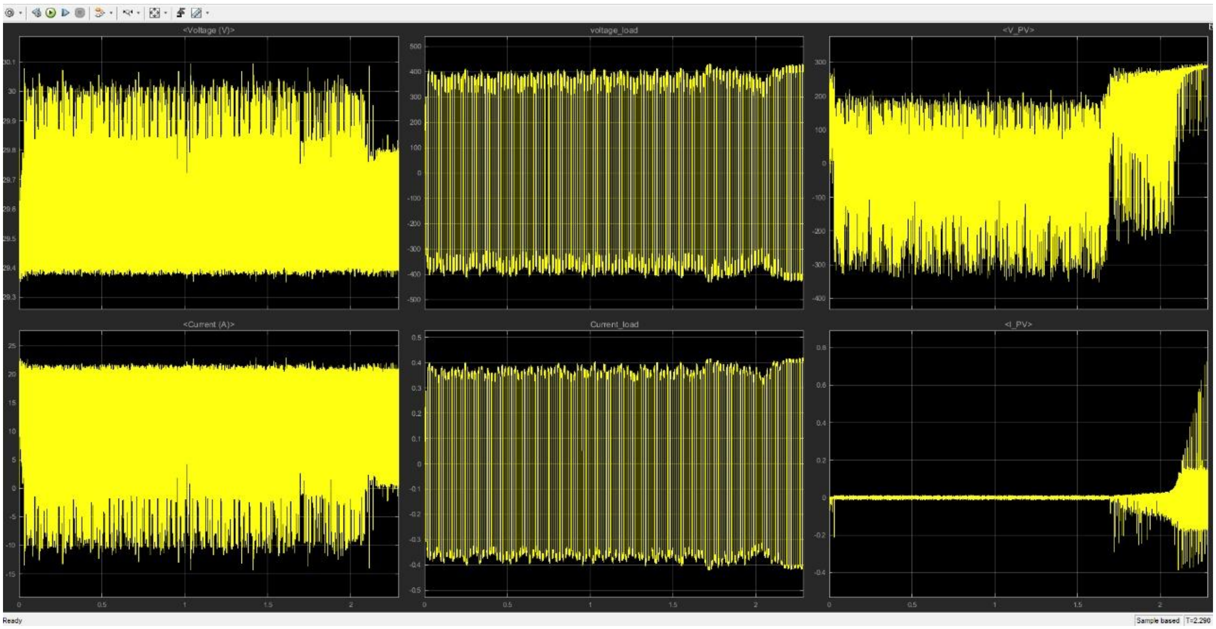
Type	Lithium-ion
Depth of Discharge (DoD)	90% (for lead-acid)
Number of batteries	2 (12V batteries in series) or 1 (24V battery)
Inverter	
Power rating	500W (slightly higher than peak load demand of 323.04 W)
Input voltage	24V (matches battery bank)
Output voltage	230V AC
Type	Pure sine wave inverter
Charge Controller	
Type	MPPT (Maximum Power Point Tracking)
Input voltage	90V (matches solar panel array voltage)
Output voltage	24V (matches battery bank)
Current rating	30A (matches total current from solar panels)
Circuit Protection	
Fuses/Circuit breakers	30A (for charge controller and inverter)
Surge protectors	To protect against voltage spikes
Wiring and Connectors	
Wire gauge	10 AWG (for solar panels), 6 AWG (for battery bank and inverter connections)
Connectors	MC4 connectors (for solar panels)
Controls	
Charge Controller Logic	Bulk Charging (28.8V), Absorption Charging (27.6V), Float Charging (26.4V)
Inverter Control	Automatic switching between battery and solar power, overload protection
Load Management	Prioritize essential loads, shed non-essential loads during low battery conditions
Algorithms	
MPPT Algorithm	Perturb and Observe (P&O) method to maximize solar panel efficiency
Battery Management	Monitor SoC and voltage, prevent overcharging (28.8V) and deep discharging (24V)
Energy Flow Optimization	Prioritize solar power for direct use, store excess in battery, use battery as backup

5. MATLAB Simulink Modeling

1. Simulink Model of off-grid solar PV system



2. Testing system performance



6. Additional Details

1. Shading analysis

The shading analysis is done by evaluating potential obstructions that may block the sunlight from reaching the panel that is going to be installed. This ensures optimum energy generation from the available sunlight for the location. We have use Google Maps, the SunCalc.org Online platform, and the Global Solar Atlas data for the analysis.

Based on the collected data analysis was continued as follows,

Latitudes and the longitudes of the site: 07.11166°, 079.986974

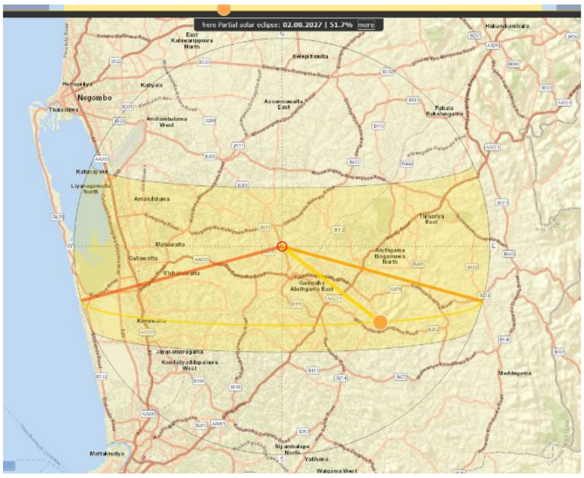


Figure 2: Location where the Solar panels going to be installed.

Sun's Position throughout the day (from 6 am to 6 pm) based on 07 Feb 2025 was taken as follows,

Time	Sun position	Solar altitude	azimuth	Shadow length

6.00		-5.67°	104.76°	N/A
8.00		21.02°	109.39°	2.7
10.00		47.77°	122.10°	0.91
12.00		66.58°	162.36°	0.43
14.00		57.89°	57.89°	0.63
16.00		32.46°	246.95°	1.57
18.00		1.97°	254.53°	29.06

Focusing on the hours between 9 AM and 3 PM when the sun is highest and typically causes significant shading,

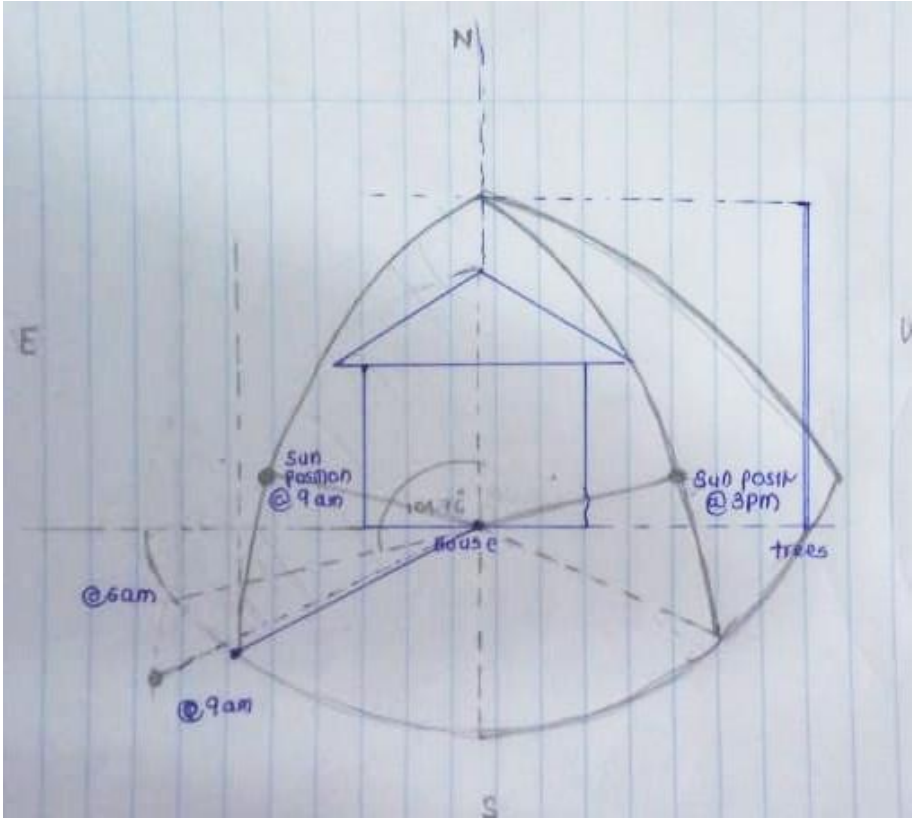


Figure 3: Calculation based on observed data

2. Optimal panel placement