How efficient is a solar panel

Team 2

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Introduction

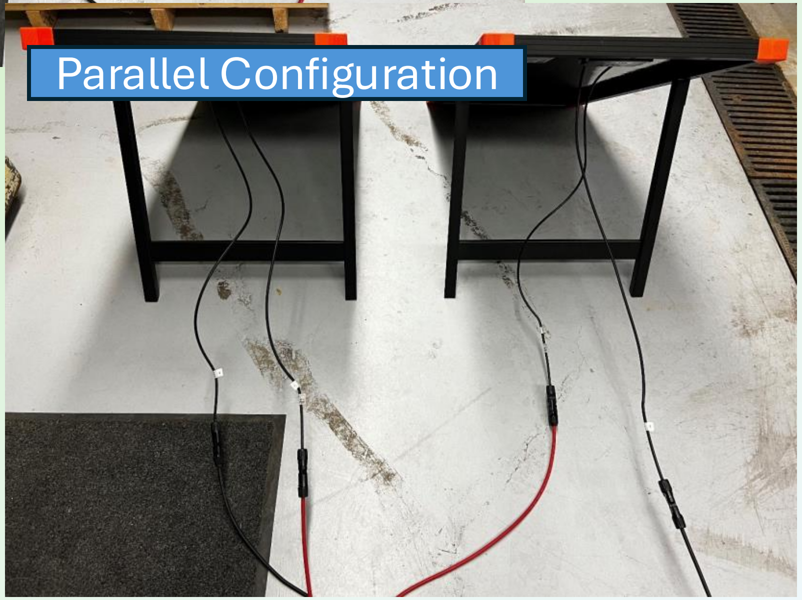
We looked to determine:

1. Test how sunlight and weather affect battery performance
2. Measure how temperature impacts charging efficiency
3. Find out how quickly batteries drain with different devices
4. Create guidelines for optimal system use based on test results

Deciding our Experiments

- Experiment #1: Charging the battery
  - Series or parallel configuration?
  - Where and when?
  - What do we collect?
  - How long?

- Experiment #2: Draining the battery
  - Lamp or another appliance?
  - What do we collect?
  - How long?



Setting up the Experiments

- Experiment #1: Charging the battery
  - Decided on a series configuration
    - More efficient in low light
    - Higher voltage output (LithiumHub, n.d.)
  - Location: the plaza at 1:00 pm on Thurs and 2:00 pm on Fri
  - Collected: voltage, wattage, current and temperature
  - Duration: 1-2 hours

Setting up the Experiments

- Experiment #2: Draining the battery
  - Portable heater
    - Wanted to try something else
  - Collected: voltage and wattage
  - Duration: 1 hour
  - Rated wattage: 1200 W

Charging Experiment Days

- Session #1:
  - October 24th
  - Ambient temperature: 61
- Session #2:
  - November 1st
  - Ambient temperature: 58
- Session #3:
  - November 8th
  - Ambient temperature: 54

Solar Panel Wattage and Battery Voltage

Why wattage and battery voltage matter?

- Predict energy yield over time
- System optimization

Energy Calculations:

$$E = \int_{t_1}^{t_2} P(t)\, dt$$

$$E = \int_{t_1}^{t_2} (m \cdot b + t)\, dt$$

$$E = \frac{m}{2}(t_2^2 - t_1^2) + b(t_2 - t_1)$$

$$t_1 = 0 \; t_2 = 150$$

Energy Yield Estimation for each session

$$P_1\,(t) = -0.44t + 152.68$$

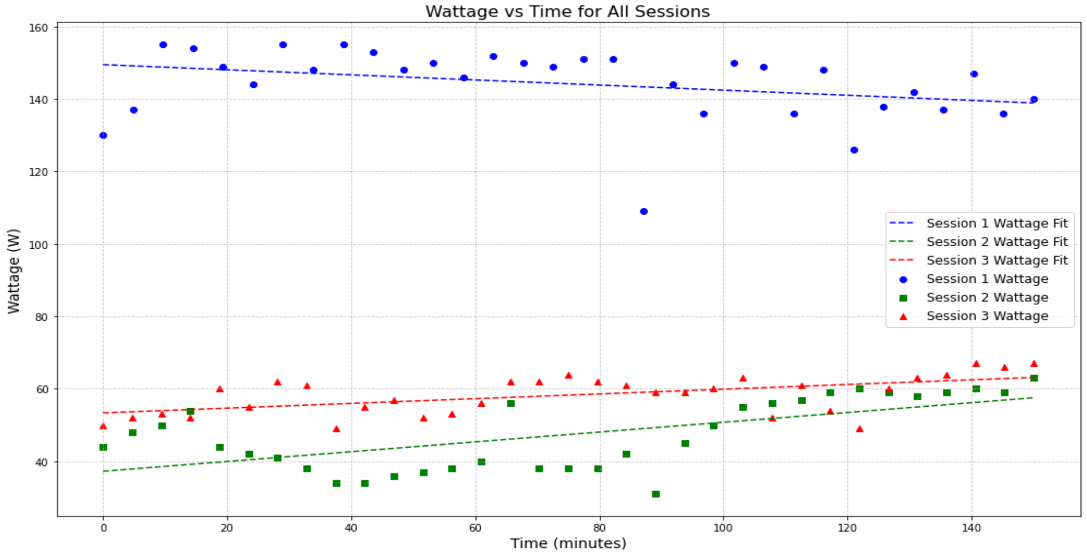
$$P_2\,(t) = -0.29t + 50.33$$

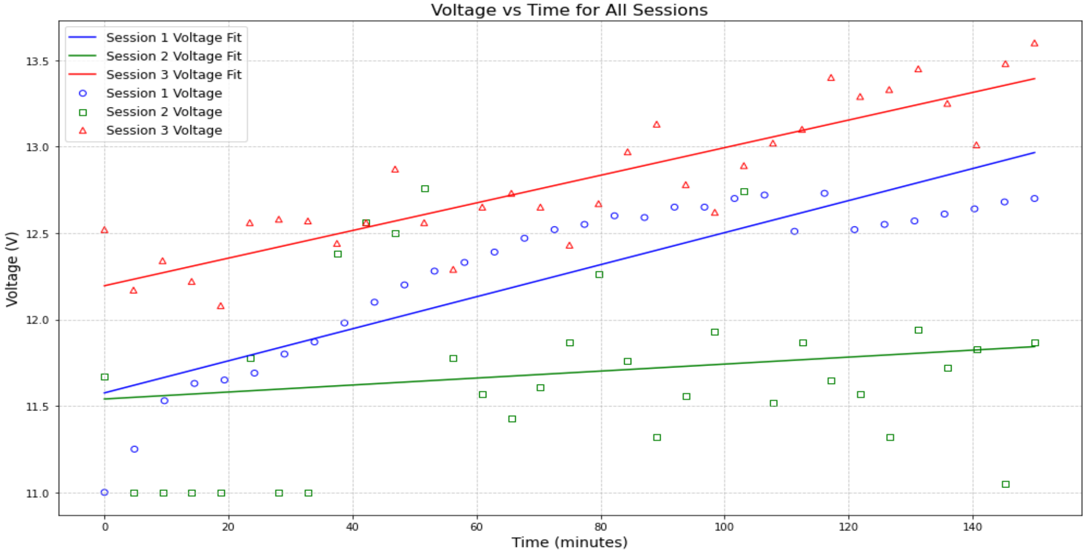
$$P_3(t) = -0.25t + 57.27$$

$$E_1 = 299.2Wh$$

$$E_2 = 71.45Wh$$

$$E_3 = 96.3Wh$$





Significance

Session 1:
R^2= 0.9801
p-value = 1.234e-06

Session 2:
R^2 = 0.8832
p-value = 0.0000234

Session 3:
R^2 = 0.9020
p-value = 2.345e-05

Battery Discharge Data

$LiFePO_4$ Discharge Curve Model Parameters:

Nominal Voltage (V_nominal): 12.1581 V
Initial Voltage Drop Coefficient (k): -0.0578
Linear Decay Coefficient (c): 0.0320

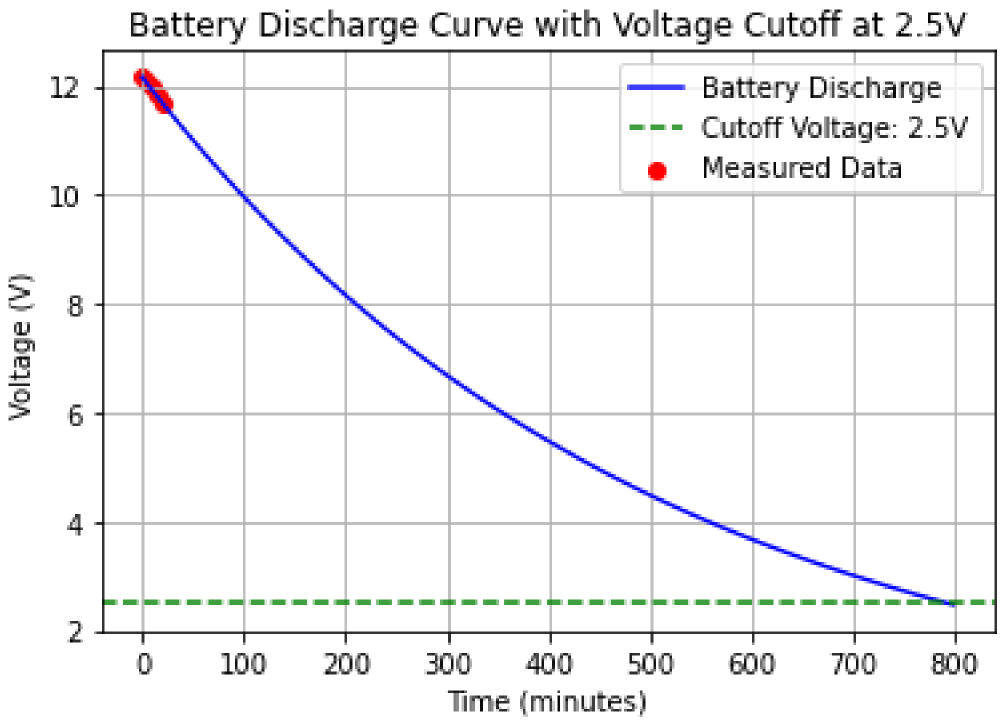
Linear Regression Equation:

$$\ln v(t) = \ln(v_0) - \lambda t$$

Where,
$v(t)$: is the battery voltage at time t
v_0: the initial battery voltage (at t=0)
λ: is the decay constant (rate of discharge)
t: time

Time to reach 2.5V: 793.06 hours when supplying to a small load like a lamp.

2.5 V is the manufacturer recommended cutoff voltage.



Summary Statistics:

- Slope (k): 0.0020
- Intercept: 2.5009
- R^2: 0.9757
- P-value: 0.0016
- Standard Error: 0.0002

System Efficiency

Why is Efficiency Important?

Efficiency determines how much usable power a solar panel can provide from the available sunlight. A higher efficiency means more energy is produced from the same amount of sunlight, which is essential for meeting the energy needs of a load.

General Efficiency Equation

$$\eta = \frac{P}{A \cdot G_T}$$

Efficiency Equation Adjusted for Temperature

$$\eta_a = \eta\left(1 - \gamma \cdot (T - 25)\right)$$

Where,

η : Ideal efficiency

η_a : Adjusted efficiency

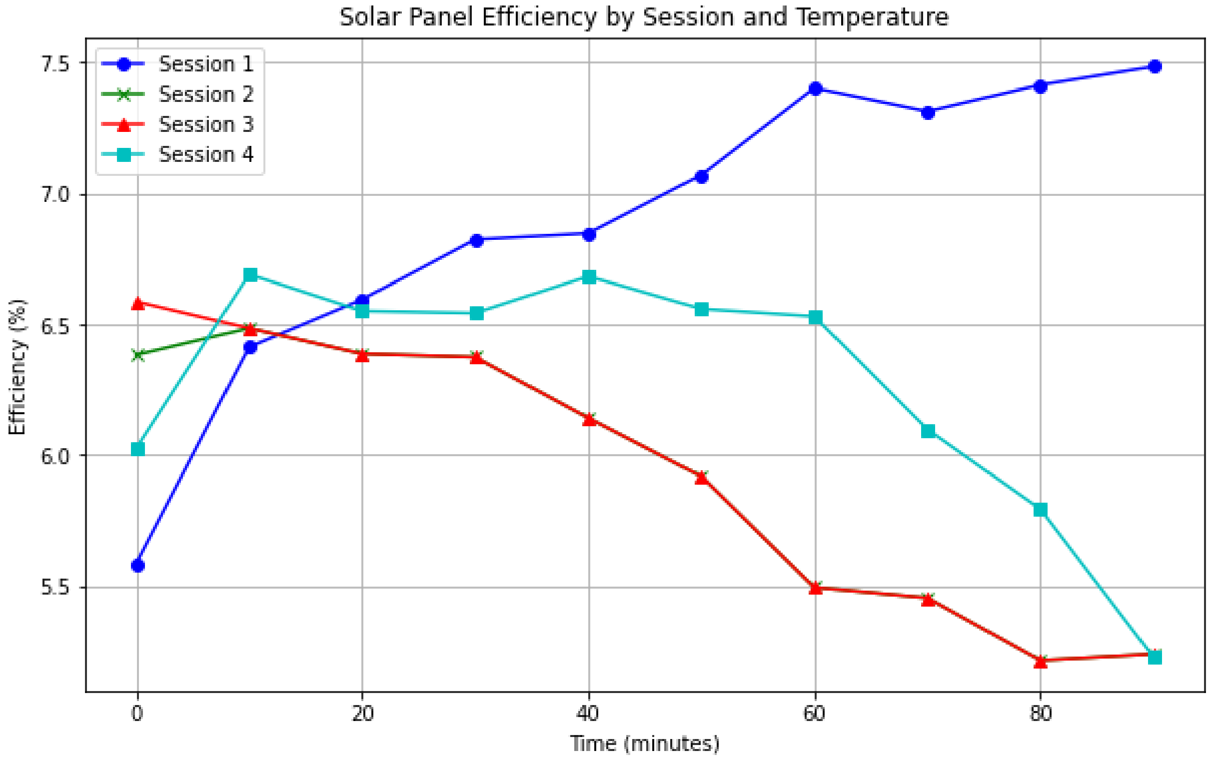
P : Power output (in watts)

A : Area of the solar panel (in square meters)

G_T : Solar irradiance (in watts per square meter, W/m^2)

γ : Temperature coefficient (°C^{-1})

T : Panel temperature (°C)



Standard Test Condition (STC) Assumptions:

- No conversion losses
- ideal efficiency of the panel was assumed to be around 15%
- incoming solar irradiance of 1000 W/m^2

System Performance with Different Loads

Using data from the Energy Projections calculated using the Wattage and Battery Voltage Projection Models:

Total Daily Energy = 369.16×2.58= 1,179Wh

Available Energy = 1,179×(1−0.15)=1,002.15Wh

Assuming an ideal efficiency of 15%

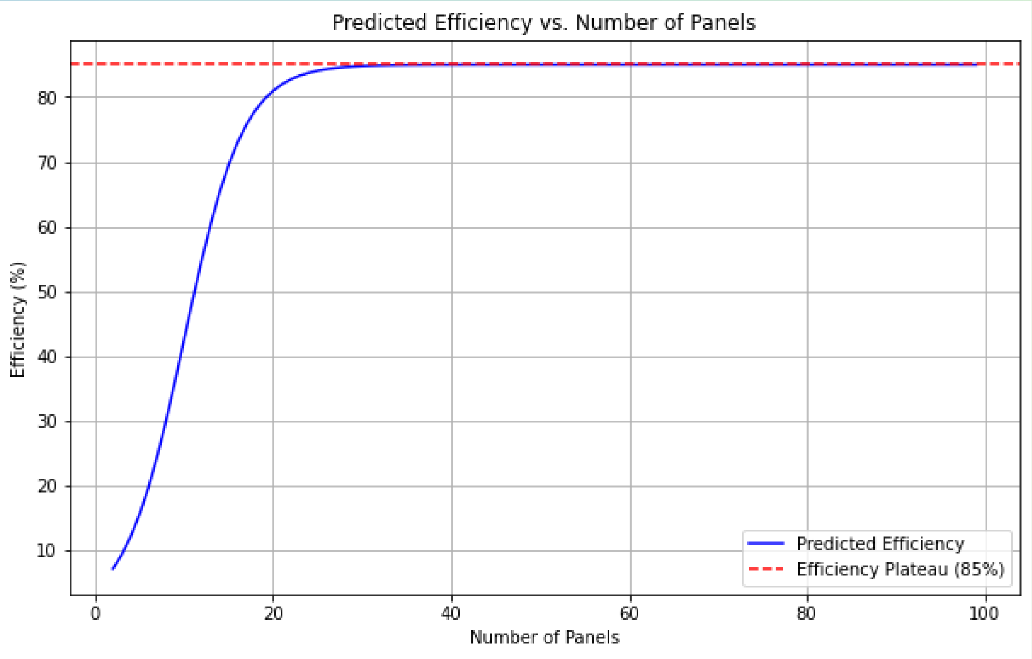
Appliance	Power Consumption (W)	Runtime (Hours)	Energy Consumption (Wh)
LED Bulb	10W	6 hours	60 Wh
Phone Charger (2 devices)	10W	4 hours	40 Wh
Refrigerator (Efficient)	150W	8 hours (cyclical)	600 Wh
Laptop	50W	5 hours	250 Wh
Ceiling Fan	50W	4 hours	200 Wh

Optimal System Implementation

Issue: 2 panel system demonstrates issues with energy efficiency and output.

Solution: Large-Scale Solar Array

- Efficiency increases with large-scale systems due to reduced per-panel shading, more uniform panel temperatures and better system integration.
- Farms achieve cost parity with fossil fuels when scaled to **1 MW** or more, with costs dropping below $0.05/kWh.
- Large-scale arrays can be better integrated with existing grid infrastructure, which allows for advanced grid management techniques, like load balancing and centralized storage integration.
- Subsidies from the state/federal government along with loose zoning policy would further lower cost of installation and make large-scale solar projects more appealing.



Conclusion

- Small-scale solar arrays suffer low energy efficiency and are hit harder by environmental losses like temperature.
- Large-scale solar arrays can dilute low single panel efficiencies and environmental losses through scale.
- Solar can be best integrated into a grid as a supplement during the day to decrease the use of fossil fuel plants, or the excess solar power can be sold during times of peak load.