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Dragon Q Energy

Passive Geothermal Cooling Efficiency Experiment

Experiment Background:

Experiment Date: September 5th – September 10th 2024

Environmental Conditions: Stationary high pressure, very stable air with inversion layer. Extremely hot day time temperature (35 - 43°C) and cool nights. Light wind and clear skies.

Location: Santa Barbara Mountains (Elevation 2250 ft, Lat 34.5N Lon -119.8W)

Conducted By: Daniel Casey

Battery Pack: NiMH (10S16P) 12v 2000 Wh – Weldless tabs cell to chassis.

We conducted a series of experiments testing the effectiveness of passive geothermal cooling by comparing battery temperature regulation in different environmental setups. A battery pack was tested both below ground and above ground to observe how underground placement could stabilize temperatures without active cooling. The below-ground setup involved burying the battery, while an above-ground test exposed it to full sunlight. Additionally, soil temperature data was collected in both shaded and full-sun conditions to assess the impact of ground cover on thermal stability. Together, these experiments aimed to demonstrate how passive cooling methods could help maintain optimal battery temperatures under various conditions.

Data Collection:

Data Logging Thermocouple: EL-USB-TC-LCD with K-type Thermocouple, 5 min sample rate

Battery Pack Data Collection: Thermocouple probe located central to the battery pack lengthwise and in the center of the module of cells. Battery pack was buried vertically with the bottom of the battery pack being 4 ft below grade, and top of pack 1 ft below grade. An above ground test was conducted Sept 6, 2024 with the battery pack exposed to full sun.

Ambient Air Temperature Collection: Thermocouple probe location in 3 ft length of vented 1" PVC tubing. Apparatus was located leaning against an oak tree, forest shade, approximately 100 ft east from battery test location.

Ground Temperature Data collection – full sun: Through the entire period of the heatwave the thermocouple was located in a sealed 1" PVC tube 4ft long. The PVC was buried vertically with the thermocouple probe 3ft below the surface. The soil was bare at the surface and compacted sandy loam soil with no ground cover.

Ground temperature data collection – shade and ground cover: Same installation and burial of thermocouple as above. Except shaded by forest oak and peaty, leafy, topsoil to 4” depth.

Battery Pack Temps and Observations:

Below ground battery test – Sept 5th

On this day, the battery pack was buried with the bottom 4 feet below ground and the top 1 foot below grade. The experiment aimed to evaluate the pack’s ability to dissipate heat during a constant current overcharge. The battery temperature rose to approximately 45°C, which, while elevated, remained much lower than temperatures observed in the above-ground test on the following day.. This indicated that underground placement provided significant cooling benefits, helping the battery maintain a more stable thermal state even under stressful charging conditions.

Above ground battery test – Sept 6th

The above-ground battery test was designed to examine the thermal challenges faced by batteries in exposed environments. On September 6th, the battery pack was placed directly above ground in full sunlight while undergoing a controlled overcharge to simulate extreme use conditions. The pack quickly reached a peak temperature of 58°C, indicating that it was vulnerable to rapid heating due to solar radiation and the lack of heat dispersion provided by the soil. In order to preserve the integrity of the prototype, the decision was made to curtail charging, shade the pack, then discontinue the experiment for the day. The test highlighted the need for active cooling systems in similar above-ground setups, as the battery was unable to dissipate heat effectively without intervention.

Below ground battery test – Sept 7th

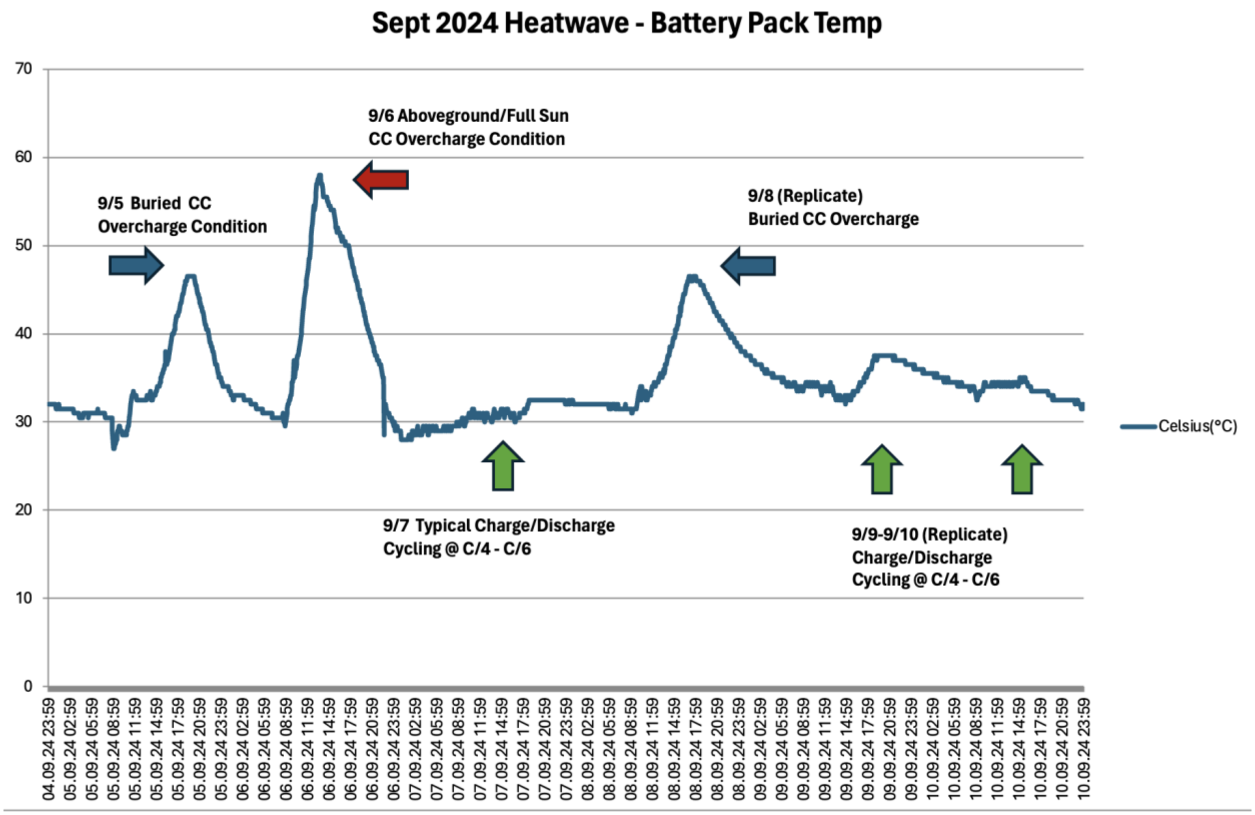
After resetting the battery underground, the experiment simulated regular use by cycling the battery between a 50% and 80% state of charge, with a charging and discharging rate of approximately C/4 to C/6. Throughout the day, the battery temperature remained in a comfortable range around 30°C (+/- 2°C), demonstrating how the soil’s thermal properties helped regulate temperature, preventing extreme fluctuations.

Below ground battery test – Sept 8th

The initial overcharge test from September 5 was repeated, with the battery remaining in its below-ground position. This controlled, consistent current overcharge caused the battery temperature to reach similar levels around 45°C, reinforcing the previous day's findings that the below-ground setup could effectively dissipate heat and stabilize temperature under continuous high-stress charging.

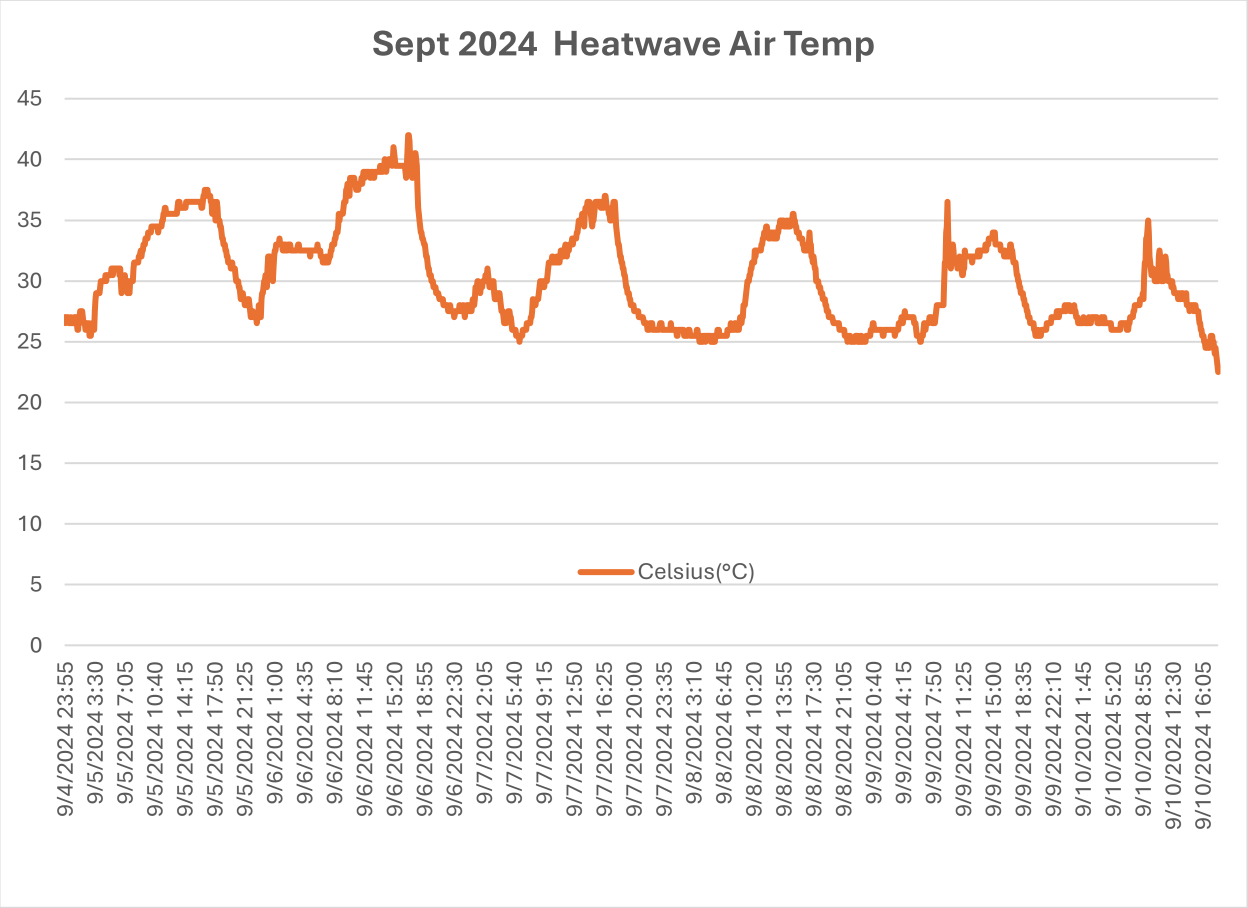
Below ground battery test – Sept 9th & 10th

These final two days replicated the September 7 cycle, simulating typical usage patterns with a 50-80% state of charge range and moderate charging/discharging rates. Battery temperatures remained stable, slightly increasing to just above 30°C, which correlated with a minor increase in the soil temperature over the test period. The experiment confirmed that passive geothermal cooling provided by the soil enabled consistent, manageable temperatures for the battery pack, supporting optimal performance without the need for active cooling systems.



Air Temperature Observations:

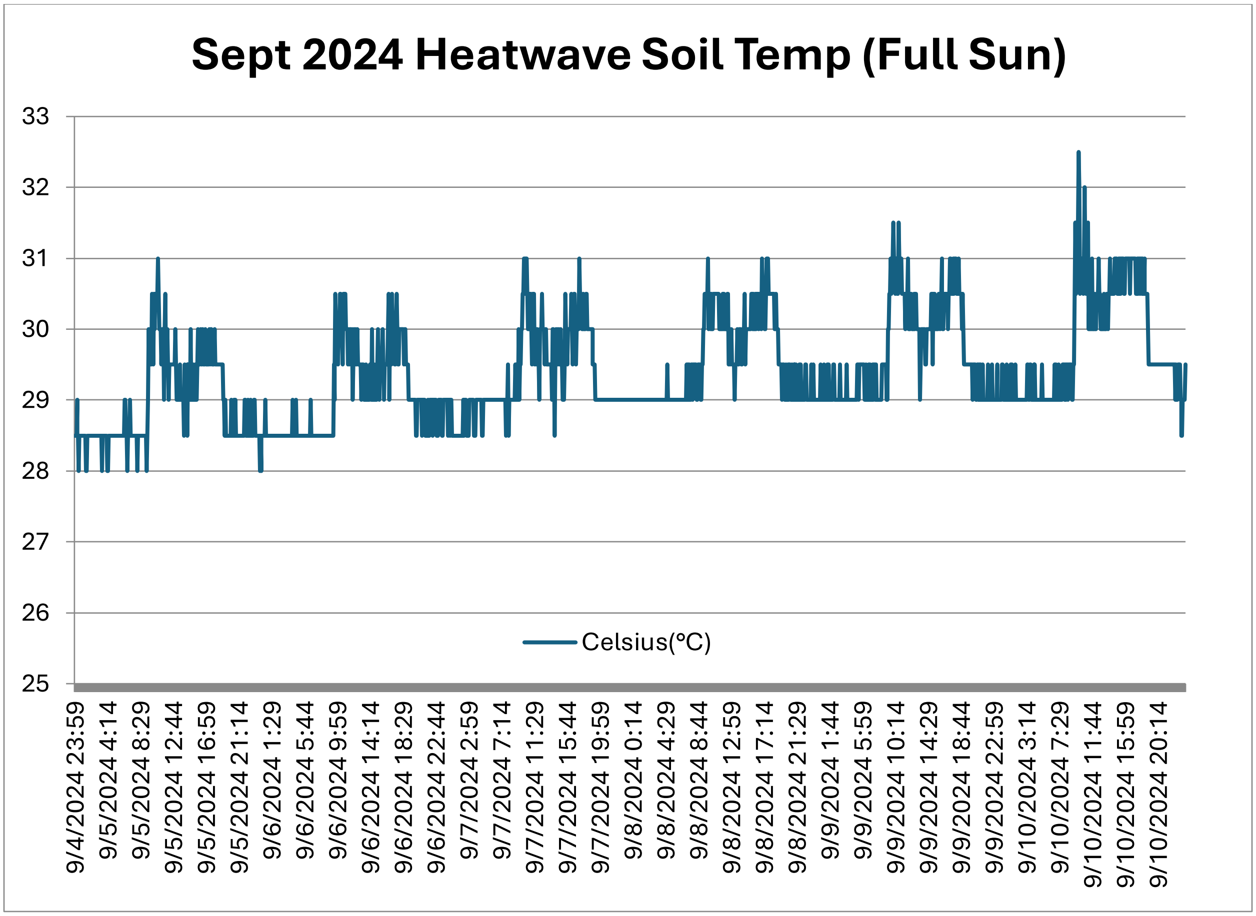
The goal of this experiment was to test how effectively soil could regulate and stabilize temperatures for battery systems in extreme heat conditions. By monitoring both full-sun and shaded areas, we aimed to understand how factors like soil depth, ground cover, and shade impact soil's ability to moderate temperature fluctuations over a 24-hour cycle. Throughout the experiment period, air temperatures consistently ranged between 35°C and 43°C, reaching peak levels in the late afternoon to early evening as a result of prolonged solar heating. The Santa Barbara mountains, typical of Southern California’s climate, experienced substantial overnight cooling in line with Southern California maritime cooling pattern.



Soil Temperature Observations:

Soil Temperature (Full Sun) Observations:

Soil temperature in full-sun conditions was monitored to assess its natural thermal regulation without added shading or ground cover. The thermocouple probe was buried 3 feet deep in compacted sandy loam soil, remaining exposed to direct sunlight throughout the test period. Temperatures ranged between 28°C and 32.5°C, with minor diurnal variations within 2°C daily, providing a consistently cooler environment compared to above-ground air temperatures. During the hottest day, September 6th, the underground soil temperature was notably 15°C cooler than the maximum above-ground air temperature. Over the test period, the average daily soil temperature increased slightly by 1°C, indicating that even under full-sun exposure, the soil effectively maintained stable and lower temperatures than the ambient air, suggesting its potential as a reliable passive cooling buffer.

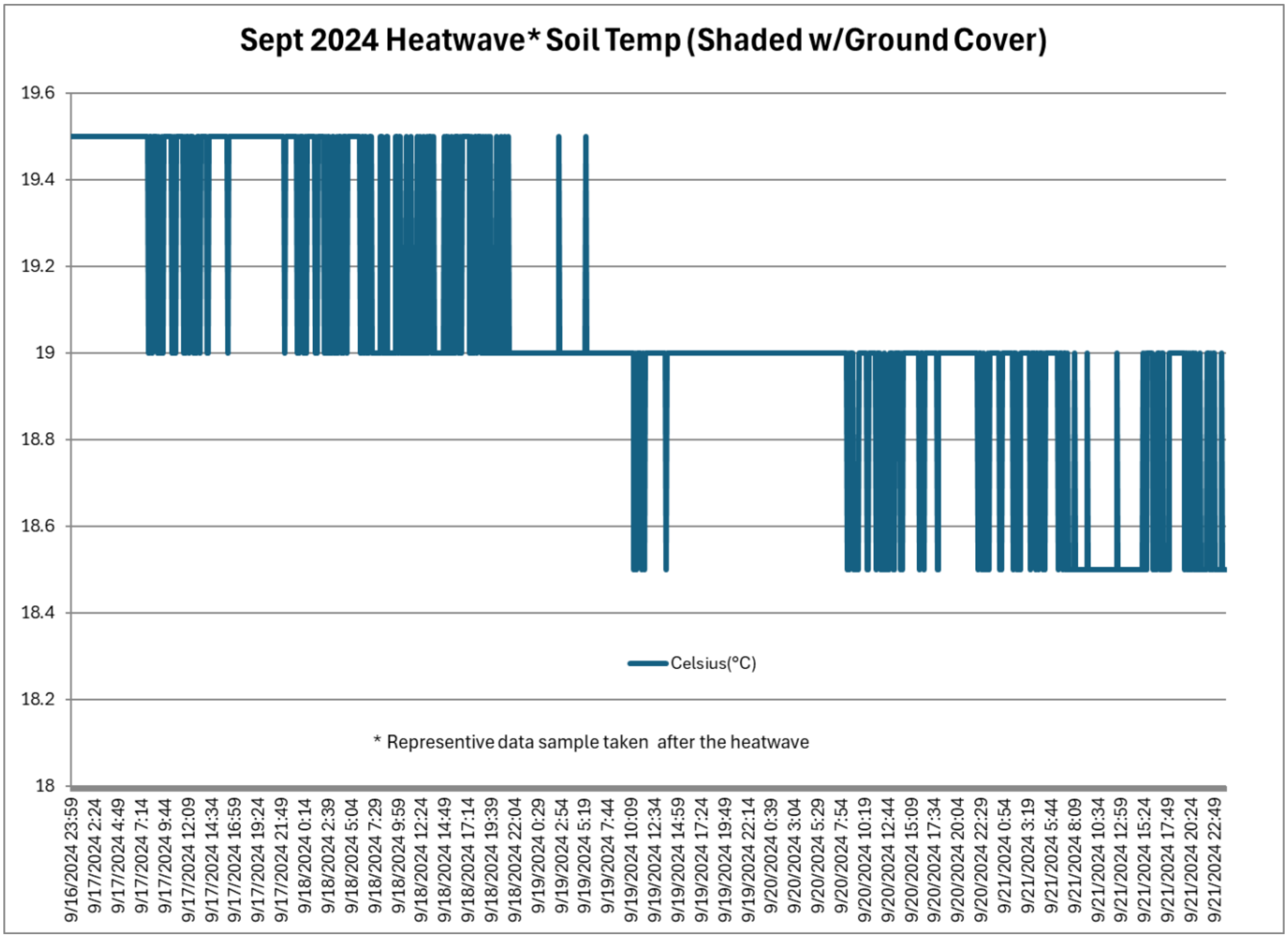


Sept 2024 Heatwave Soil Temp (Full Sun)

Soil Temperature (Shaded Ground Cover) Observations –

(The fidelity of temperature data collection was .5 Celsius)

A parallel soil temperature test was conducted in shaded ground with organic ground cover, which included a 4-inch layer of peaty, leafy topsoil under a forest oak canopy. The thermocouple was buried 3 feet below the surface, similar to the full-sun setup. Soil temperatures in this shaded configuration were remarkably stable, ranging between 18.5°C and 19.5°C throughout the experiment period. The ground cover provided an additional insulating layer, reducing diurnal temperature fluctuations and maintaining cooler temperatures relative to the full-sun test. This section demonstrated the enhanced thermal stability achieved when ground cover and shade are combined, supporting optimal conditions for passive cooling in below-ground battery applications.



DQE Interpretation of Data:

September 5th & 8th– Underground battery

The passively regulated underground battery pack remained significantly cooler than above ground air temperatures and dissipated heat to soil/aggregate overnight. Although the experiment battery pack was buried in soil directly heated by sunlight, it is understood the preferred soil surface preparation would be shaded soil with ground cover to reduce solar heating and retain moisture in the soil. Thermal conductivity and geothermal temperature regulation in an adverse overcharge battery condition was demonstrated.

September 6th – Above ground battery

DQE started the above ground experiment based on the premise that above ground BESS are exposed to heating from ambient air temperatures, solar heating, and internal ohmic resistance and electrical heating. Even though the experiment was curtailed it demonstrated the massive need for active cooling of aboveground systems.

September 7th, 9th & 10th – Soil temperatures This experimental design represented a typical charge and discharge use of the battery pack and power system. Although daily air temperature maximum and averages declined over the test period, the soil temperature exposed to direct solar heating increased over the test period. This validates the observed small increase in average pack temperature between the 9/7 data and 9/9-10 data set. It has been demonstrated that the preferred soil condition and buried pack scenario would include shading and ground cover around the battery pack, the extent of shade and ground cover have not been determined.

The data collected during the experiments provided insights into the thermal behavior of the soil and its effectiveness as a passive cooling medium for battery systems. The results from both full-sun and shaded conditions demonstrate the soil's ability to maintain lower temperatures compared to above-ground air, which is crucial for optimizing battery performance and extending cycle life.Overall, the findings suggest that passive geothermal cooling through buried battery systems could be a viable strategy for improving thermal management in extreme conditions.

Follow on experiments:

It is DQE’s intention to conduct a similar experimental design in the early spring of 2025 at Death Valley National Park. It can be assumed we could find similar temperatures in the 40 Celsius range before things really heat up for the summer in Death Valley. The follow-on experiment will leverage data and lessons learned from the Summer 2024 Santa Barbara Heatwave experiment by using the solar array to provide ground shade and include ground cover to increase shade and retain soil moisture. It is our premise that we can collect data and demonstrate a 10 Celsius cooler soil temperature, with only a .5-1.0 Celsius diurnal variation. We would propose this would translate to an average of 10 Celsius cooler pack temperature resulting in the most optimal pack operating environment to extend cell cycle life.

We would like to test the extreme thermal regulation capability and complete robust nature of our system when the heat ramps past 50 Celsius up later in the summer at Death Valley.

We propose typical BESS would have to throttle back output or completely curtail operation where our passive system operates comfortably within defined limits.

Closing thoughts:

Battery systems are cooled and heated to keep the system in a closely chastised temperature range, this aids in achieving suitable, and sometimes extended cell cycle life. This initial experiment has proven we can passively regulate the temperature of our battery pack, and sets the stage for further efficiency modeling and a techno-economic analysis comparing ocean container BESS with our direct-burial and passive thermal regulation. The delta of power required to operate and run HVAC, chillers and fans compared to our passive thermal regulation will help demonstrate our improved system round-trip efficiency and cycles life and reduced OPEX. Once our total system cost is calculated DQE will show a reduced CAPEX with a simpler system and reduced parts count.