California Energy Commission

STAFF REPORT

Appendix D: Status of Modeling Batteries

FOR THE 2025 BUILDING ENERGY EFFICIENCY STANDARDS

Energy Conservation Manual

October 2025 | CEC-400-2025-006-AP-D

APPENDIX D – STATUS OF MODELING BATTERIES FOR CALIFORNIA SINGLE-FAMILY AND MULTIFAMILY RESIDENTIAL CODE COMPLIANCE

D1 Modeling of Residential Battery/PV Systems for Self-Utilization Compliance Credit

Overview

The California Energy Commission added a self-utilization credit for residential battery systems to its residential building energy efficiency standards for 2019. Under these standards, a residential battery paired with an on-site photovoltaic (PV) system would receive fair credit toward the long-term system cost (LSC) energy. This document defines how the CBECC-Res compliance software will produce the battery credit for single-family residential buildings, and how compliance software will produce the battery calculations within the compliance framework for multifamily residential buildings.

Whereas most energy upgrades reduce energy use in a house or multifamily building, battery systems actually increase electricity consumption in exchange for some shaping of the load. A 14-kWh battery, with a 90% round-trip efficiency, that cycles 13 of those kWh 300 times a year, will consume 4.1 MWh of electricity and discharge 3.7 MWh of electricity per annum. But by charging when there is excess PV production and discharging when PV production is low and electricity is expensive, the battery both saves money for the residence and provides value to the electricity system overall. Thus, the single-family and multifamily self-utilization credit must account not for energy savings, but for savings in value-of-energy.

Distributed electric storage can provide value to the electricity system overall through load shaping and other behaviors. Bolstering demand during low periods helps to leave efficient power plants running full time and reduces ramping requirements. Reducing peak demand helps in a number of ways, including by allowing expensive peaker plants to remain idle more days of the year. In addition, having the batteries on-site can help reduce wear-and-tear on distribution systems.

D2 Long-term System Cost (LSC) and Source Energy

The 2025 Building Energy Efficiency Standards use LSC energy to account for the time value of energy for load and for self-generation credit. LSC is a composite measure of the actual cost of energy (for each of electricity, natural gas, and propane) to the utility, customers, and society at large. It has been crafted for evaluating energy efficiency savings based on when those savings manifest.

The LSC concept allows even-footing comparison of a set of time-series simulations of how different building designs use energy. Accordingly, it is the mechanism by which the CBECC-Res (for single-family residential) and compliance software for multifamily residential converts a residential battery’s load shaping patterns into a self-utilization credit. If a building charges a battery from on-site PV during midday, the simulation foregoes a small LSC credit for power it would have fed to the grid. When the battery discharges in the evening, it can earn a much larger credit for reducing load when LSC is high. That net-LSC reduction counts toward reducing the single-family residential or the multifamily residential building's performance with respect to the compliance margin.

The 2025 Building Energy Efficiency Standards also useSource Energy factors to determine compliance for single-family residential and multifamily residential buildings.

D3 Calculating Compliance

For single-family residential buildings, CBECC-Res calculates compliance for a proposed design based on LSC energy, and Source Energy.

Compliance for a proposed design in CBECC-Res and compliance software for multifamily residential has three requirements:

1. The LSC, ignoring contributions from renewable generation and battery storage (except for the self-utilization credit described below), must be equal or lower than the LSC of the code prescriptive standard design (also ignoring contributions from renewable generation and battery storage). These values are called the Efficiency LSC for the respective proposed and standard designs. The intent of this requirement is to encourage designs that reduce loads in addition to generating energy.
2. The LSC of the final design (including contributions from renewable generation and battery storage) must be equal or lower than the LSC of the code prescriptive standard design (also including contributions from renewable generation and battery storage). These values are called the Total LSC for the respective proposed and standard designs.
3. The Source Energy of the proposed design must be equal or lower than the Source Energy of the standard design.

A minimum of six annual calculations are required to evaluate the compliance of a specific proposed design:

1. Proposed design the Efficiency LSC
2. Proposed design the Total LSC
3. Proposed design Source Energy
4. Standard design the Efficiency LSC
5. Standard design the Total LSC
6. Standard design Source Energy

The specific computations that produce these values are described in the Nonresidential and Multifamily Alternative Compliance Method (ACM) Reference Manual. The standard design is also described in the ACM.

Self-Utilization Credit

Initially implemented in the 2019 energy code, the self-utilization credit for a residential battery system allows proposed designs with PV systems and batteries (5 kWh or larger) to subtract additional LSC from the Efficiency LSC of the proposed design. The self-utilization credit is capped at a fraction of the PV-related LSC of the standard design. The cap varies by climate zone and is between 7% and 14% for a single-family residence and between 2% and 9% for a multi-family building.

The actual credit applied to the Efficiency LSC of the proposed design is the lesser of the battery related LSC in the final proposed design and the cap defined above. Effectively, the self-utilization credit allows the proposed the Efficiency LSC design to also get credit for a portion of the LSC savings that would otherwise be seen only in the final design.

D4 Compliance Software Requirements

Appendix JA12 provides the qualification requirements for energy storage systems.

Compliance software for multifamily buildings must consider usable capacity when determining the effect of energy storage on multifamily building performance. Usable capacity is the energy storage capacity in kWh that a manufacturer allows to be used for charging and discharging. For performance compliance, the usable capacity must be a minimum of 5 kWh.

Compliance software for multifamily buildings must model the time of use strategy and controls for separate energy storage systems as described in Appendix JA12. Software may also model the basic control strategies as described in Appendix JA12.

D5 CBECC-Res, CBECC and California Simulation Engine (CSE) Software Packages

Annual building loads used in the annual LSC calculation for single-family buildings in CBECC-Res and for multifamily buildings in CBECC are simulated using the underlying California Simulation Engine (CSE). CSE models the thermal and electrical interactions within a building. CBECC-Res and CBECC generates CSE input files based on the Title 24 rulesets. Separate CSE inputs files are created to simulate the standard design, and proposed design. For single-family buildings, CBECC-Res then processes the CSE simulation results to determine the Efficiency LSC, the Total LSC, and the Source Energy values as described in the previous section. Similarly for multifamily buildings, CBECC processes the CSE simulation results to determine the Efficiency LSC, the Total LSC, and the Source Energy values described in the previous section.

While the capability of CBECC-Res and CBECC are intentionally constrained by ruleset definitions, CSE has much greater flexibility to simulate a wide range of building components. CSE has the unique capability to define dynamic battery system control strategy using its built-in expression language. CSE predicts the building load and PV generation and operates the battery according to expressions pre-defined by CBECC-Res and CBECC rules.

D6 Battery Representation in CSE

In each simulated timestep, the control strategy sends a charge/discharge request to the battery module. The control strategies themselves are described in the next section. For now, it will suffice to say that the input to the battery module is a charge request (in kW) that can be either positive or negative.

```
charge_request > 0   // charge
charge_request < 0   // discharge
charge_request = 0   // do nothing
```

The battery has maximum charge and discharge rates (kW) with default values set based on the battery's size. CBECC-Res and CBECC define both defaults as the same fixed fraction (kW/kWh) of the battery's user-defined maximum capacity (kWh). The maximum capacity is based on the compliance cycling capacity in the case of single-family buildings, or the usable capacity in the case of multifamily buildings. These default values may be overridden with custom values by the user.

```
max_charge_power = 0.42 * max_capacity
max_discharge_power = 0.42 * max_capacity
```

And both a charge and discharge efficiency (fraction), which are user-defined:

```
η_charge
η_discharge
```

The user has the option to input a round-trip efficiency (fraction) as an alternative to inputting both the charge and discharge efficiencies. In this case, the charge and discharge efficiency would be equal to:

```
η_charge = sqrt(η_rte)
η_discharge = sqrt(η_rte)
```

At each timestep, there are also maximum charge and discharge limits (kW) defined by the state of charge on the battery. Charge and discharge power levels are measured at the battery's edge: before efficiency losses in the case of charging and after efficiency losses in the case of discharging. The battery's state-of-charge is metered between the two efficiency multipliers.

```
max_charge_available = (max_capacity - charge_level) /
                       η_charge * (timestep_minutes / 60)
max_discharge_available = charge_level * η_discharge *
                       (timestep_minutes / 60)
```

Altogether, that enables the module to determine the amount the battery should charge or discharge in the hour:

```
if charge_request > 0:
        charge_power = min(charge_request, max_charge_rate,
        max_charge_available)
else if charge_request < 0:
        charge_power = max(charge_request, max_discharge_rate,
        max_discharge_available)
else:
        charge_power = 0
```

At the conclusion of that timestep, the battery's charge level will have been updated:

```
if charge_power > 0:  // charging
        charge_level = charge_level + charge_power*η_charge
else if charge_power < 0  // discharging
        charge_level = charge_level + charge_power/η_discharge
else:
        charge_level = charge_level
```

D7 Battery Control Strategies in CSE

There are two battery control strategies enabled in CBECC-Res and CBECC: "Basic" and "Time of Use" (TOU). These strategies are responsible for the timestep-by-timestep charge requests that are sent to the CSE battery module.

Basic Strategy

The Basic strategy charges when a) production exceeds demand and b) the battery is not fully charged and discharges when a) demand exceeds production and b) the battery is not fully drained. That is, the battery both charges and discharges as soon as it can.

```
charge_request = -load_seen
```

By charging from any excess production and discharging as soon as it can to serve load, the basic strategy maximizes self-consumption of the on-site PV production. The other strategies account for the time-varying value of electricity (e.g., as measured by LSC) to varying degrees to increase the LSC-savings the battery provides.

If the battery system is standalone (no PV system), then basic control is not an available control option.

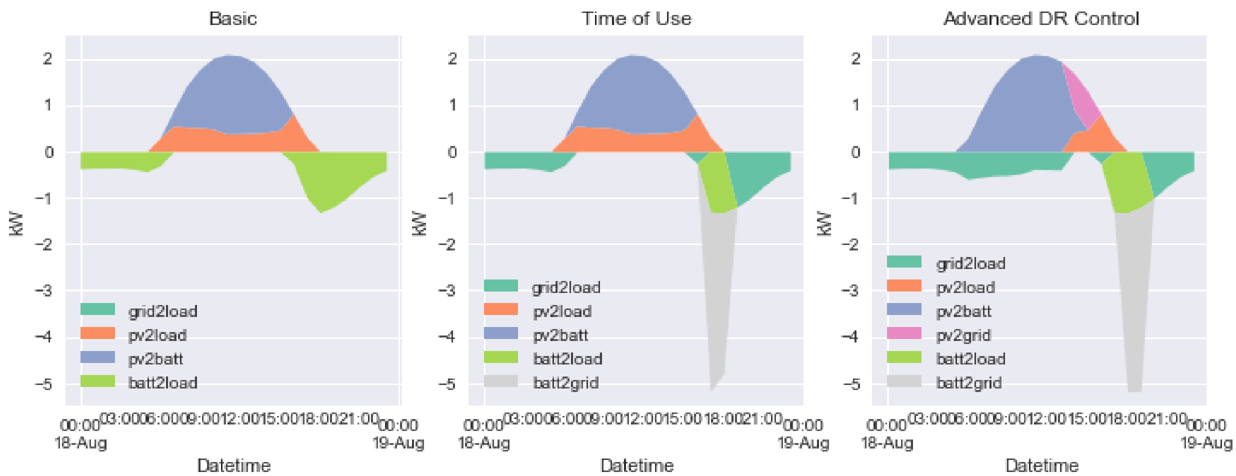

Figure 2: Illustrations of the battery control strategies' different responses to a single day. Note that the TOU and Advanced strategies can discharge directly to the grid. Also notice that Advanced charges the battery from PV while serving loads from the grid.

Time of Use Strategy

The TOU strategy attempts to preferentially discharge during high-value hours during a selected period of months. For a PV-tied system, the default duration for TOU months is July through September. For a standalone battery storage system, the default duration for TOU months is all year. Users can optionally input custom values for the first and last months to apply TOU control.

Charging rules are the same as the basic strategy for battery storage systems paired with a solar PV system. For standalone battery storage systems, the software provides a prescribed input to specify the hour of each day to start charging called "Charge Start Hour". The charging starts at midnight (hour 1) of each day.

Battery discharge follows the same approach for PV-tied and standalone batteries. The discharge period is statically defined (per climate zone) by the first hour of the expected TOU peak, which is a user-input within CBECC-Res and CBECC called "Discharge Start Hour." The default value for "Discharge Start Hour" is 19:00 for Climate Zones 2, 4, 8-15, and 20:00 for all other Climate Zones. The user has the option to change this value within CBECC-Res and CBECC if desired.

Consider a summer day in which the evening peak is defined to start at 20:00 but during which simulation load exceeds PV production during the 19:00 hour. While a simulation utilizing the Basic strategy would discharge to neutralize the net load during the 19:00 hour, a simulation on the TOU strategy would reserve the battery until 20:00 before commencing discharge. Because the LSC at 20:00 is likely to be higher than the LSC at 19:00, this strategy of reserving the battery for higher-value hours results in a lower (better) annual LSC.

A second difference: During the peak window, the battery is permitted to discharge at full power, even exceeding the site's net load. This is in contrast to the Basic strategy, which is limited to the net load.

```
if charge_start_hour <= this_hour < discharge_start_hour:
        charge_request = -min(load_seen, 0)   // only charge
else:
        charge_request = -1000   //  maximum discharge
```

Outside of selected months for the TOU strategy, control reverts to the Basic strategy.

Battery Parameters Included in CBECC-Res/CBECC/CSE

CBECC-Res and CBECC allow the modeler to adjust several battery parameters (Figure 4):

- Compliance cycling capacity/usable capacity(kWh): the CBECC-Res and CBECC software enforce a 5kW minimum size for the battery to qualify for the Self Utilization Credit.
- A checkbox to indicate if a standalone battery (no PV system) is modeled.
- Control strategy, chosen from the three options described in the Battery Control Strategies section of this appendix.
    - Note that "Basic" control is not an available control option for standalone battery systems

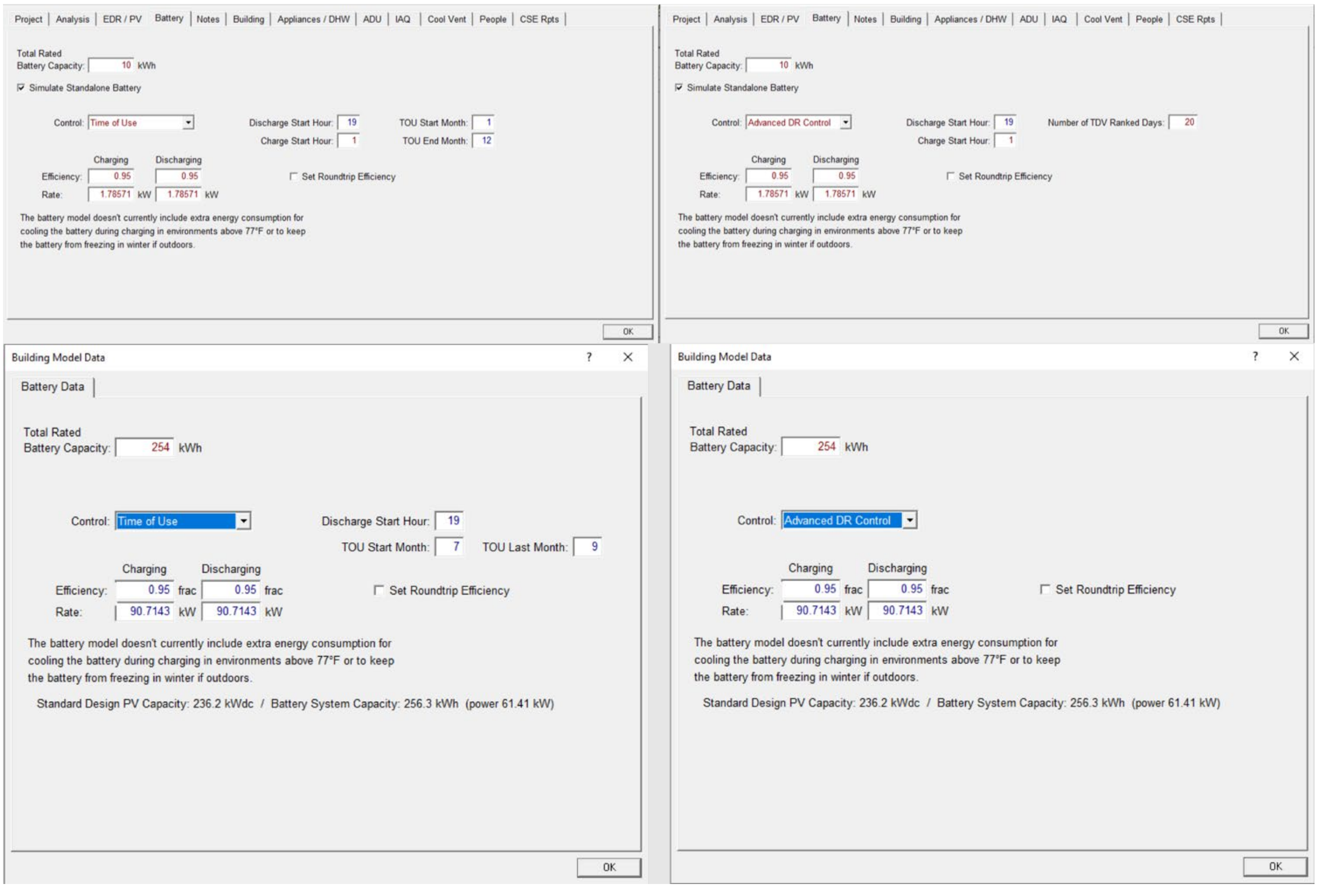

Figure 4: The CBECC-Res (top) and CBECC (bottom) battery dialog box allows the modeler to set battery capacity, control strategy, charge/discharge efficiencies, and other control parameters related to charging and discharging hours and TOU months. Example images are shown for the TOU and Advanced DR Control options.
(Source: screenshot of CBECC-Res and CBECC software user interface.)

- Charging and discharging efficiency (fraction): CSE allows charging and discharging efficiencies to be defined independently. The CBECC-Res and CBECC default is 0.95 for each, resulting in a default round-trip efficiency of 0.9025.
    - A single input for round-trip efficiency may be input by selecting the checkbox "Set Roundtrip Efficiency" (as shown in Figure 4). When checked, the inputs for charge and discharge efficiency are hidden and only the round-trip efficiency input is shown. Round-trip efficiency inputs less than 80% will result in no battery included in the simulation.
- Charge start hour may be input for standalone battery systems. Discharge start hour may be input for standalone and PV-tied battery systems. Allowable inputs are integers between 1 and 24 (inclusive).

- TOU period start and end months may be input. Allowable inputs are integers between 1 and 12 (inclusive).

CBECC-Res and CBECC also makes a set of assumptions to set CSE battery parameters. These are parameters that can be set in the lower-level CSE but that CBECC-Res and CBECC define itself.

- CBECC-Res and CBECC assume that the input battery capacity is the capacity of a brand new system. To account for aging across the battery's life cycle, the software derates the effective battery compliance cycling capacity for single family buildings, or the usable capacity for multifamily buildings to 85% of the input battery capacity. A nominal 10 kWh battery gets 8.5 kWh of usable capacity in the simulation.
- The 85%-of-input-capacity figure interrelates with the fact that battery systems often have different published values for total and usable capacity. The battery management system prevents complete discharges, so the usable capacity is typically single-digit percentages lower than the total capacity (e.g., the Powerwall 2 has 14 kWh total and 13.5 kWh available energy). CBECC-Res and CBECC should clarify whether the input capacity should be total or useful, and the degradation derate figure should be consistent with the input CBECC-Res and CBECC expect.
- CBECC-Res and CBECC derive the CSE parameters Maximum charge rate and Maximum discharge rate (kW/hr) from the battery capacity. They are each defined to be battery capacity * 0.42. That is, the battery is sized to have 2.38 hours of storage at full discharge. (1/0.42 = 2.38). That ratio is likely derived from the 14 kWh capacity and 5 kW discharge power of the Powerwall 2: 14 * 0.85 / 5 = 2.38.
- The battery is assumed to start the simulation fully discharged. It is not required to be fully charged at the conclusion of the simulation.
- Battery-PV installations come in a range of electrical configurations, sometimes with independent inverters for each component (AC-coupled), sometimes sharing an inverter (DC-coupled). CSE assumes an AC-battery-module electrical configuration as shown in Figure 5. The modeling implication of that configuration is that the user-input battery charge and discharge efficiencies should include the losses associated with the battery module's onboard inverter. In CSE, the PV system always has a dedicated PV inverter.

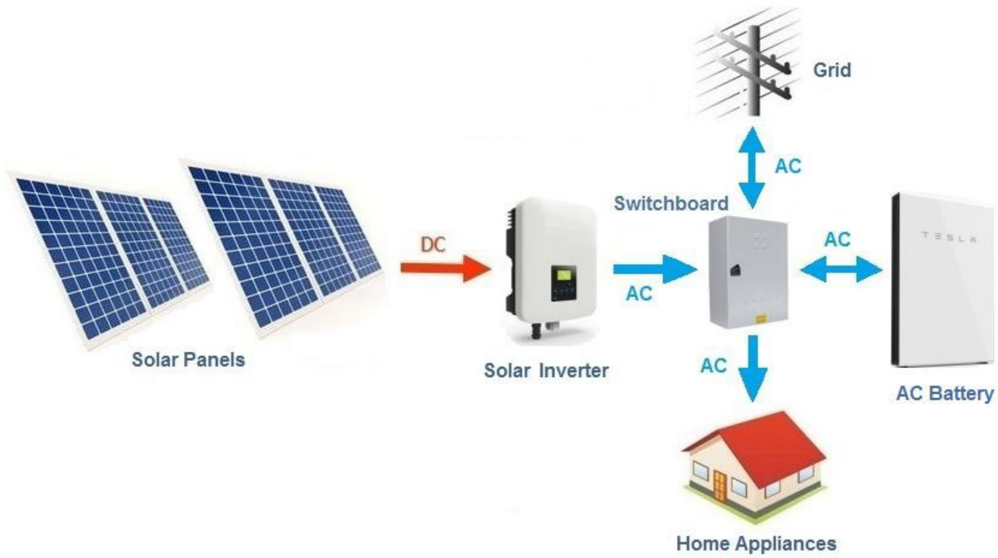

Figure 5: *General diagram of an AC battery module layout of a residential PV-battery system. (Source https://www.cleanenergyreviews.info/blog/ac-coupling-vs-dc-coupling-solar-battery-storage.)*

Simulated battery performance is static in the current CSE implementation. In particular, charge and discharge efficiencies do not vary with either charge rate or temperature. In real-world battery systems, efficiency falls from the benchmark a) with age, b) under rapid charging/discharging, and c) when temperatures are outside an ideal range (e.g., 25 °C/77 °F).

A real-world battery's usable capacity is also subject to age and external conditions. Low temperatures, especially, reduce a battery's in-the-moment usable capacity. CSE neglects those effects as well. The long-term dynamics of how batteries age warrants its own section, below.

The existence of a battery in the CBECC-Res and CBECC models also relaxes size limits on PV systems. Without onsite storage, the PV system is limited by the interconnection rule: solar generation must not exceed the building's electricity consumption over the course of a year. Title 24, Part 6 allows a building with a battery larger than 5 kWh to have a PV system that produces up to 1.6 times the building's annual electricity consumption. The CBECC-Res and CBECC software implement this change.