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Enhanced Energy Modeling Methods for Electric Battery

Final Report

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Executive Summary

More residential and small commercial facilities are installing PV and battery energy storage. A recent study showed that while many residential PV systems are adding a single battery, the multi-battery installations in California nearly doubled from 20% to 40% between 2017 and 2020 (Barbose, Elmallah and Gorman). As this market evolves, understanding how electric battery systems operate and can be optimized is essential for end users, electric utilities, and the California energy compliance code. Today, few detailed analyses exist on battery control systems as they affect energy use, costs, and savings, particularly as the energy compliance standards seek to accurately value and represent these systems.

The 2019 California energy code adopted criteria for minimum energy allowances for on-site PV and batteries. This study investigates battery algorithms and methods used to represent battery controls, often called rulesets, and currently used in Title 24 compliance software to assess the accuracy of representation. The study seeks to identify and evaluate the feasible enhancements to these algorithms and rulesets to inform and enhance future Title 24 compliance software.

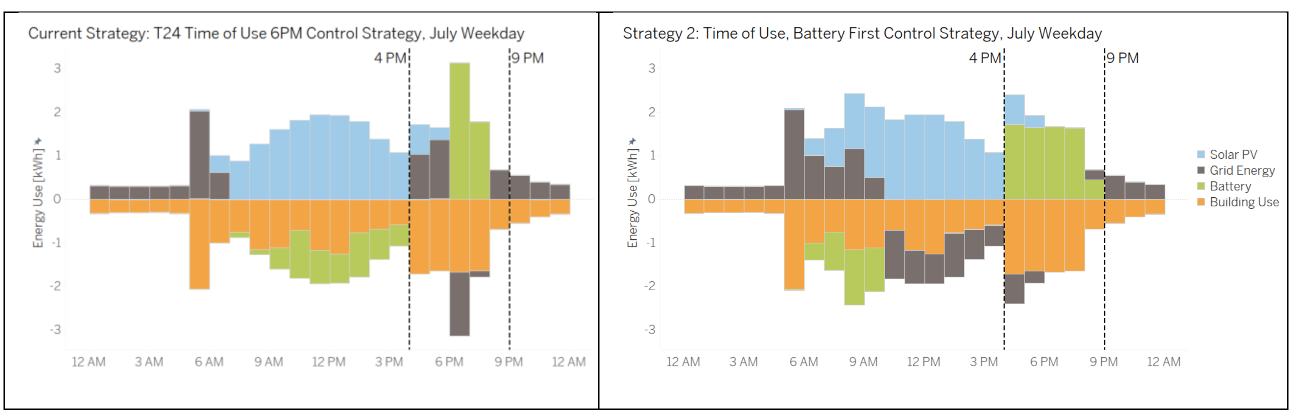
Key Findings

The study performed investigations and analyses to understand the impact of different battery control strategies on annual energy use and, to understand the benefits and impact of 15-minute and 1-hour timesteps on onsite solar PV and the batteries.

Key observations from the analysis of control strategies were:

1. The current battery control strategies used by the Title 24 compliance software for time of use control do not represent how actual battery systems are able to be configured and operated in today's battery market.
2. Some battery systems can control how solar PV is utilized to either charge the battery first or serve building loads in real time. Charging the battery first allows the system the greatest energy shift during a Time of Use period. Based on observations, charging the battery first was the default option for batteries with time of use controls.

The current time of use control in the Title 24 software has two distinct differences from the real time of use controls operating battery systems. For example purposes, the 24-hour profiles of a typical building load, solar-PV, and battery charging and discharging are shown in two graphs: the figure on the left represents the current Title 24 time of use control, and the figure on the right represents the observed control strategy in operation (referred to in this report as Strategy 2). Examples of both findings 1 and 2 are discussed below.



For battery control strategies, one of the key differences between T24 compliance software and actual battery operations centers on when to charge the battery from on site solar-PV and if it should be charged before the building's electrical loads are met or after. In the T24 software, the assumption is to charge the battery as the second priority after charging the building. The second difference is the magnitude of power discharge from the battery to the electrical grid. In the T24 software, the battery discharge rate is only limited by the battery itself and power is allowed to exceed the building's load for a given hour and push power back to the grid. In the observed battery system, the building's active energy consumption limited the battery's output, allowing the battery to be used for a longer period of time and making the building neutral to the grid.

Both strategies were investigated in this report for their individual contributions to energy use, cost, and carbon differences.

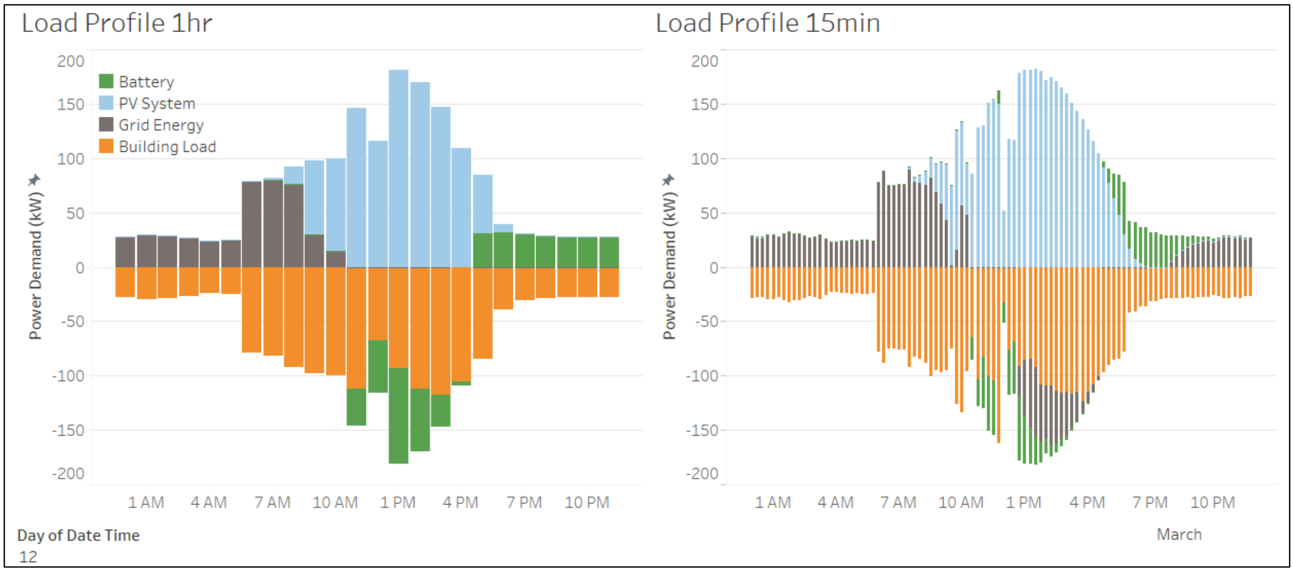
The report also carried out a secondary analysis by using a simulated single family energy model and battery controls iterations to evaluate the potential changes in operational costs between the net energy metering 2.0 (NEM 2.0) current rates and the proposed revised NEM 3.0 rate structure for future homes, as proposed by electric utilities.

The analysis of hourly costs using different import and export energy costs to determine the cost effectiveness of using battery control strategies beyond self-consumption found it dependent on the size and ratio of battery system to solar PV system; findings show that larger batteries to solar systems (3 kWh battery / 1 kW solar) achieve the lowest cost with control Strategy 3, though smaller systems (1.5 kWh battery / 1 kW solar) self-consumption results in the lowest cost. In all strategies evaluated, NEM 3.0 energy costs and the monthly solar inter-connection fee will reduce the simulated house cost savings from 88% per year to 41% per year from the largest solar and battery system evaluated.

Key observations and findings from the timestep analysis were:

3. The increased resolution of the energy analysis to 15-minute timesteps from the traditional model of 1-hour intervals can lead to better predictions of potential spikes in peak power demand and quantify the benefits and solutions that electric batteries can provide.
4. With a 15-minute interval analysis, a building with solar PV and battery may still need to import or export power at critical times throughout the day, which would not be visible with only 1-hour analysis. The analysis above 15-minute intervals can lead to under-representing grid requirements for buildings with battery systems and provide inaccurate data to building designers as they size systems to reduce peak load at critical times of the day and year.

The figure below shows an example 24-hour day of data analyzed at 1-hour timesteps and 15-minutes on a typical March day.



From the analysis, the building peak demand is higher, passing 150 kW at 12pm in the 15-minute data compared with the 110 kW in 1-hour data. Using smaller timesteps, even at 15-minutes, can allow the energy models to quantify peak demand savings as well as identify when during the day and year a building + battery system relies on grid interactivity.

Recommendations

Based on these findings, the research team recommends:

1. Revise compliance software for any time of use control, not allowing back feeding to the energy grid beyond the current building power load predicted by the energy model and making the default time of use strategy reflect Strategy 1 in this report.
2. Include a new time of use control strategy so the user can specify prioritizing their building or battery for solar PV charging.
3. Create an ability to select multiple control strategies by the month and within the year. The current time of use control strategy only deploys during summer months, defined as July through September, and does not give the design team and software user this functionality. Functionalities are likely to only increase operational energy costs based on the analysis studied in this report though provide increased functionality to reduce carbon or be used by building research teams working with the software. For compliance verification, this study recommends either making this functionality available in a non-compliant run or always maintaining a set TOU control for the standard which would always minimize energy costs.
4. Add a lower limit at which point the battery can be deployed and depleted. Based on a literature review of leading product manufacturers, most products include a lower limit for reserve or backup power of 10% to 20% in some instances and do not fully discharge.
5. Change the timesteps, from 1-hour to 15-minutes, to accurately account for battery controls and solar PV energy use. Current energy modeling software runs at sub-hourly intervals when determining building loads, and this evaluation should be aligned to increase resolution and accuracy.

Introduction

Battery energy storage for residential and commercial buildings is a growing market with significant future potential (Barbose, Elmallah, Gorman, 2021). As this market evolves, understanding how actual electric battery systems operate and can be optimized is essential for end users, electric utilities, and for the California energy compliance code, referred to in this paper as Title 24. Recently, the 2019 energy code adopted criteria for minimum energy allowances for on-site PV and batteries. Today, few, if any, detailed analyses exist on battery control systems as they affect energy use, costs, and savings and particularly as the energy compliance standards seek to accurately value and represent these systems.

Background

The general understanding of the building energy code is to reduce energy use. The California Energy Commission (CEC), which develops building energy codes, was begun from the larger goal driven by the Warren Alquist Act of 1974, charged with the responsibility for energy resources, energy supply and demand, and regulating electrical generation and transmission facilities. The CEC is responsible for guiding the state toward a 100% renewable energy future, decreasing energy costs and environmental impacts while providing a safe, resilient, and dependable energy supply.

The energy standard utilizes a long-term cost of energy, forecast for electricity and gas, to reflect the anticipated hourly costs for utilities, both for the next 30 years in residential buildings and 15 years in commercial buildings. The commercial rates are shown below for a sample region in California (CZ3), in an energy ratio of kTDV/kBtu over a 24-hour period for each quarter of the year.

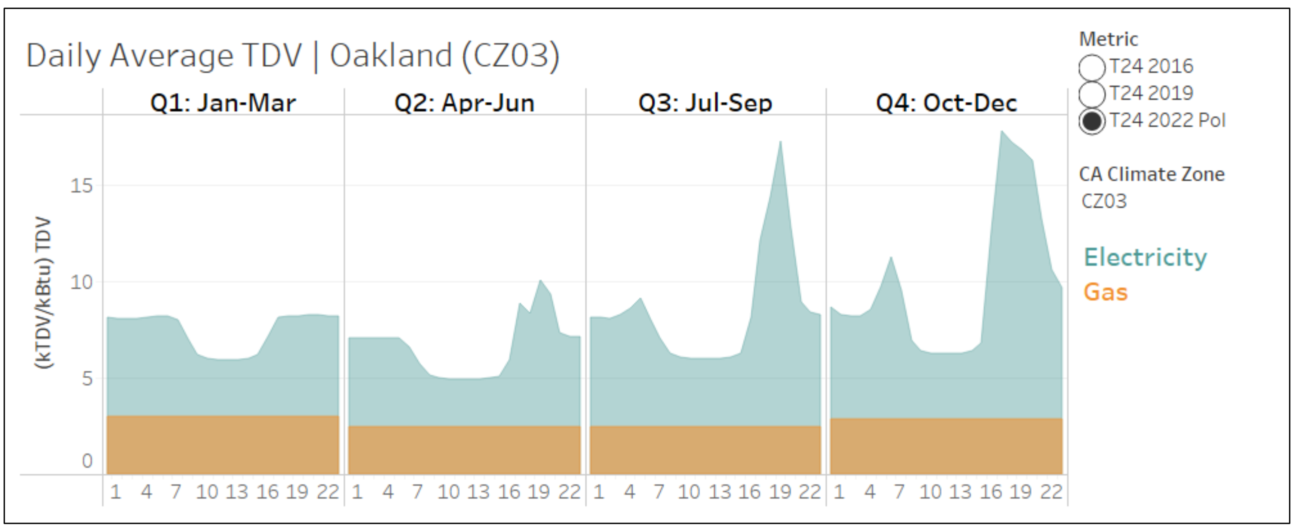


Figure 1: Average Hourly Long Term Cost Metric for Energy Code Compliance, TDV from Title 24 2022 for Non-Residential Buildings

In commercial and residential buildings, these long term costs show the same shape of cost intensity, with afternoon electrical costs dramatically increasing, specifically in the summer season (Q3). The morning electricity costs increase when compared to the middle of the day, although not with the same intensity as the afternoon.

In addition to monitoring energy costs, the state of California has set ambitious climate change goals to reduce greenhouse gas, using buildings as one of the primary focus points. Accordingly, the energy standard now includes a second set of metrics for source energy (the energy consumed by the powerplants, as they provide the energy) and the carbon emissions of the energy on an hourly basis. These metrics are now utilized in the residential energy code to set a secondary criterion by which buildings must also reduce source energy and be cost-effective against the energy cost metric to drive long-term carbon reductions in buildings. The same daily graph of carbon intensity by fuel type is shown below for reference.

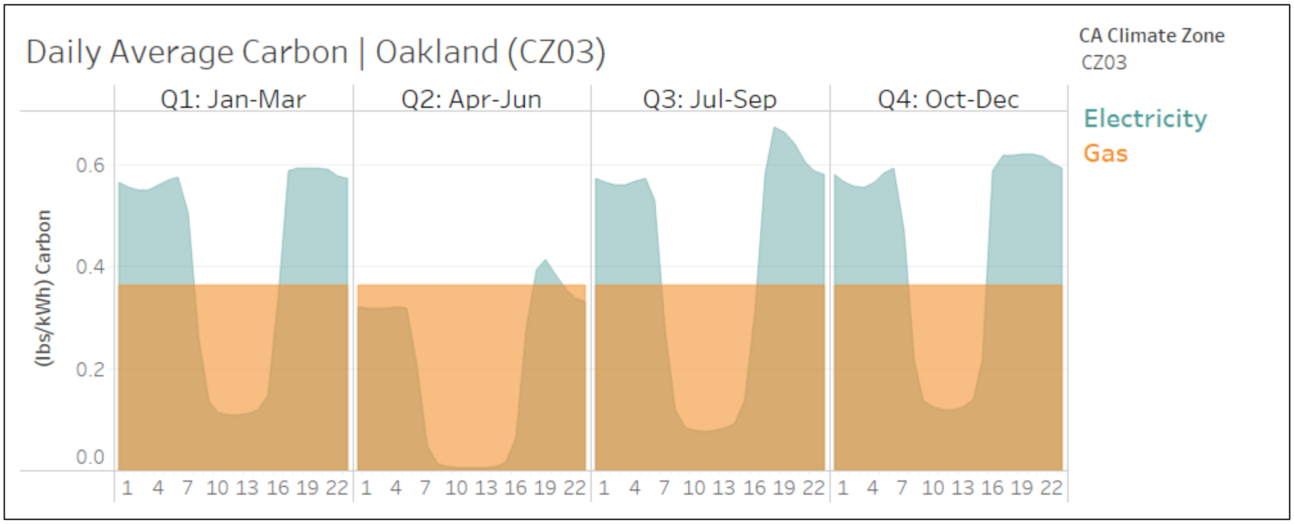


Figure 2: Average Hourly Carbon Emissions factors for Energy Code Compliance, TDV from Title 24 2022

While the focus is on afternoon peak intensity today for reducing operational costs, long-term challenges in building operations will have to consider what strategies can be deployed to address the morning power consumption of electricity. Electric batteries are one solution that could be utilized.

Title 24 Compliance Software Capabilities

The California Building Energy Code compliance software (to be referred to as Title 24 or Title 24 software) allows users to input the specifications of an electric battery based on the capacity (in energy, kWh), the charging and discharging efficiency and rate (with default assumptions available) based on datasheets provided by manufacturers. The user can then select a control strategy from a short list of options to represent when the battery is discharged. The user interface and input fields are shown below:

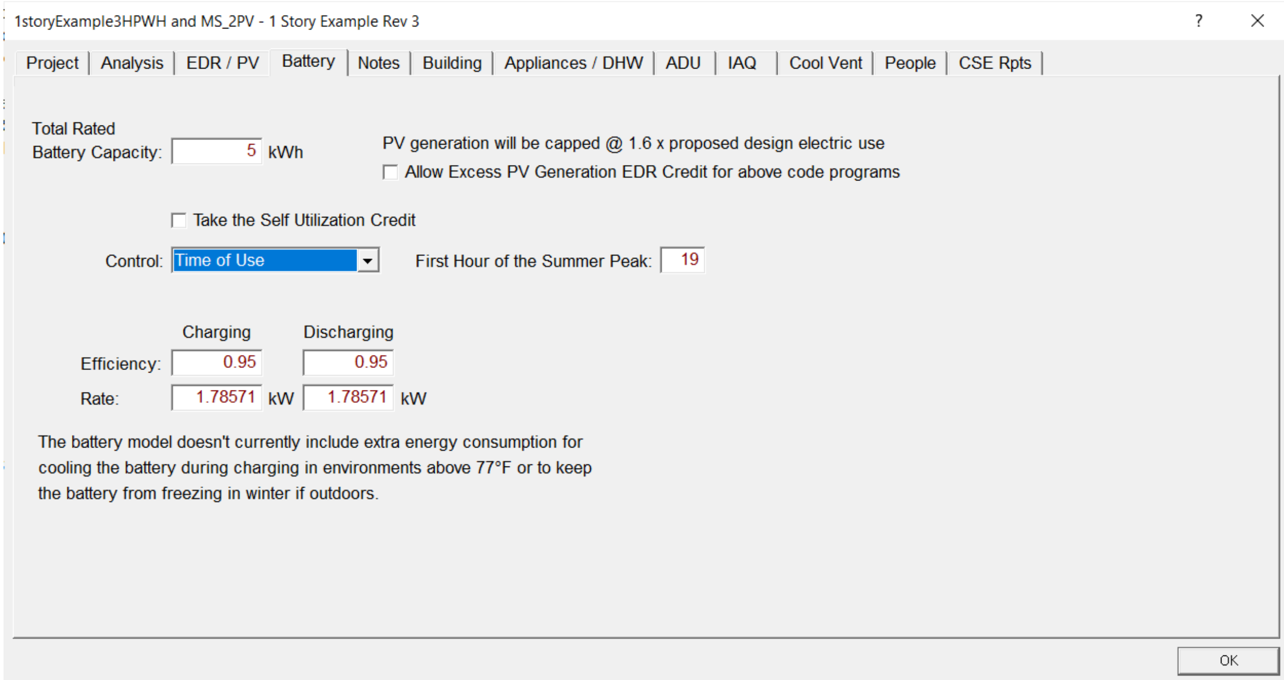


Figure 3: Title 24 Compliance Software Input Screen, CBECC-Res 2019

The Title 24 software provides three battery control strategies for buildings with on-site photovoltaic (PV) generation, which control when the battery can discharge and provide energy. The options are as follows:

1. Self-Consumption
2. Time of Use (TOU)
3. Advanced Demand Response Control

The details of strategies 1 and 2, self-consumption and time of use (referred to as Title 24 Time of Use) are separated for comparison with the actual battery control strategies utilized today.

The current Title 24 compliance software calculates battery power based on battery charge and discharge rate, round trip efficiency and size of PV and battery. It does not consider factors like peak load shifting, outdoor air temperature and depth of discharge that may change battery performance. Battery calculations are also only evaluated at 1-hour intervals that fail to capture solar PV fluctuations. The aggregation of PV data to 1-hour may also be misleading about the benefits batteries can provide in managing the net load on the larger electrical grid.

Literature Review

Most residential energy storage installations were paired with solar, according to Lawrence Berkeley National Laboratory market research study (Barbose et al., LBNL 2021). And most residential systems use a single battery, although multi-battery installations have nearly doubled from around 20% to 40% between 2017 and 2020 (Barbose et al., LBNL 2021). This same study found that California accounted for the vast majority of all Behind the Meter (BTM) solar+storage systems built to date, owing to its sheer size. These findings show the importance of understanding battery control capabilities as more residential systems come online.

Field observations and studies have focused on the battery control variables that effect energy savings. According to a recent study, incorporating battery controllers and calibrating battery algorithms in systems can increase energy savings (Frontier Energy, 2021). In addition, this study investigated how aligning battery controllers with Time of Use (TOU) rates resulted in energy savings in some parts of California, compared to other parts of the state that did not (Frontier Energy, 2021).

Most analyses to determine the value of residential PV-battery storage systems are conducted in 30-minute to 1-hour intervals. In a 2017 case study, Australian researchers examined a set of data to understand the benefits of using lower timesteps when calculating battery algorithms (Abdulla, et al., 2017). The study findings showed that using smaller timesteps, such as 15 minutes to one minute, can impact cost saving potential and influence how we value storage systems. The authors recommended future studies use coarser resolution data to assess different storage technologies and to determine the value of optimizing battery storage (Abdulla, et al., 2017).

A literature search for studies specific to battery performance degradation in stationary batteries for buildings found few sources. For the select articles investigating this topic, the primary driver for performance degradation over a product's life was related to extreme temperature and operational controls pertaining to frequency of charge state and depth of charge (PV-Magazine) (Intercel). For temperature, lower average temperatures were shown to increase the life of batteries, while higher temperatures were seen to reduce the battery lifetime. While manufacturers do not quantify this in terms of battery life expectancy, they make operating temperature recommendations, such as LG recommending operating temperatures between 59F-86F and Tesla Powerwall recommending the operating temperature between 32F – 86F.

A study carried out (Smith) to predict the lifecycle of a battery used the number of cycles to create comparisons for battery capacity degradation. Observing a specific control strategy, researchers found a battery capacity loss of six percent after 3000 cycles at 23C. These topics warrant further detailed research into finding the range of battery degradation over time, with contributing factors like outside temperature and capacity degradation. However, beyond the energy code cost metrics, energy code compliance does not consider products life cycle degradation currently outside of defining components of the building as either system components which utilize a 15-year energy cost metric or envelope components which utilize a 30-year energy cost metric.

Purpose

The purpose of this study is to investigate battery algorithms and rulesets currently used in Title 24 compliance software and assess the accuracy of representation in demand side batteries. The study seeks to identify and evaluate the feasible enhancements to these algorithms and rulesets to inform future enhancements to the Title 24 compliance software.

Objectives

To accomplish this purpose, the study established 4 goals for the research:

1. To identify typical packaged battery control algorithms available in small battery systems and compare them to Title 24 compliance software algorithms.
2. To identify the changes to operational energy costs and savings, and energy code compliance by using different battery control algorithms.
3. To determine the benefits of simulating electric battery systems in annual energy models with smaller timesteps than one hour.
4. To determine the benefits of enhancing energy modeling rules or rulesets for the future.

Methodology

To study the impact of battery controls on energy use and energy savings, the team employed a combination of technical research and analysis, including:

1. A technical review of available battery products and control sequences.
2. An evaluation of residential battery systems, their operations and available configurations.
3. A scenario analysis of annual energy impact potential for different battery controls using an annual energy model.
4. A data analysis using a data set from an operational net zero energy office building to evaluate the changes in values by using timestep calculations either every hour or every 15-minutes.

Technical Review

The team reviewed the Tesla, LG, and Enphase battery specification literature to understand the capabilities and operational controls available. Subsequently, expert interviews with battery analysts (working in the small-scale market of packaged batteries for end users) were conducted to learn about their experience with building and battery interactions and gain insight into the different types of products forecast.

Evaluation of Operational Residential Battery

The PV and home battery system, installed adjacent to the Red Car Analytics office, was evaluated for its control strategies by looking at the operational data of those strategies over time, including a self-consumption setting and a time of use functionality.

Scenario Analysis of Battery Controls

Based on the research in this report, new different battery control strategies were devised with the purpose of benefitting building owners and the larger electric utility grid.

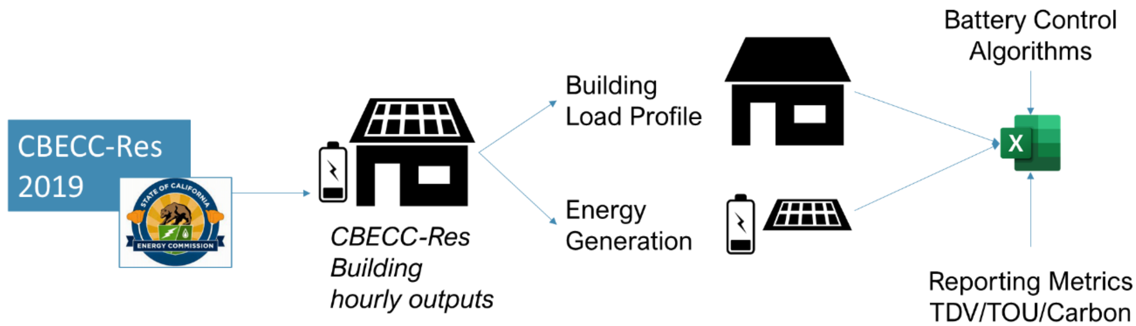
Assessment and Observation

Battery Charge and Discharge Control Strategies

Approach

The research team investigated battery controls from both the Title 24 software, the manufacturer's literature and available documentation from Enphase and Tesla. For a closer study of an operational PV and battery system, the research team used the Enphase system operating at the Red Car Analytics office. An excel worksheet was compiled using the Title 24 software control scenarios and a spreadsheet tool developed by Southern California Edison (SCE) to replicate the same basic logic of Self Consumption and Time of Use and aligned with the algorithms in CBECC-Res., to assess similarities and differences between current control strategies.

An energy model of a single-family residential house was created to evaluate control strategies and understand how the current Title 24 battery strategies and proposed enhancements would impact net energy use and savings annually. The base building load and solar generation profiles were obtained from a typical residential house energy model using the CBECC-Res 2019 software. An excel based calculator was built to simulate different control scenarios to allow for multiple sizes of battery and solar systems.



Analysis was done in the long-term energy cost metric used by the energy standard, Time Dependent Value (TDV) for 30 years' time in residential, as well as the short-term cost metric of energy rates for the Southern California Edison (SCE) region serving residential homes. While the Energy Design Rating (EDR) is a secondary metric used for residential energy compliance, this metric was not evaluated in this study, although the EDR could be enhanced further by using findings from this research.

Observations

The two strategies analyzed in this report, utilized by the current Title 24 compliance software for battery controls, are a self-consumption control and a time of use control (referred to as Title 24 Time of Use). Using these strategies, the battery is only allowed to be charged from on-site solar PV generation, which aligns with current net energy metering (NEM) rules.

The most basic control is self-consumption, by which the battery is charged from on-site PV when the energy generation exceeds the building energy use for that hour. Next, the battery is utilized immediately as the building requires, and into the evening as the on-site PV stops producing energy. An example diagram is shown below for each of these:

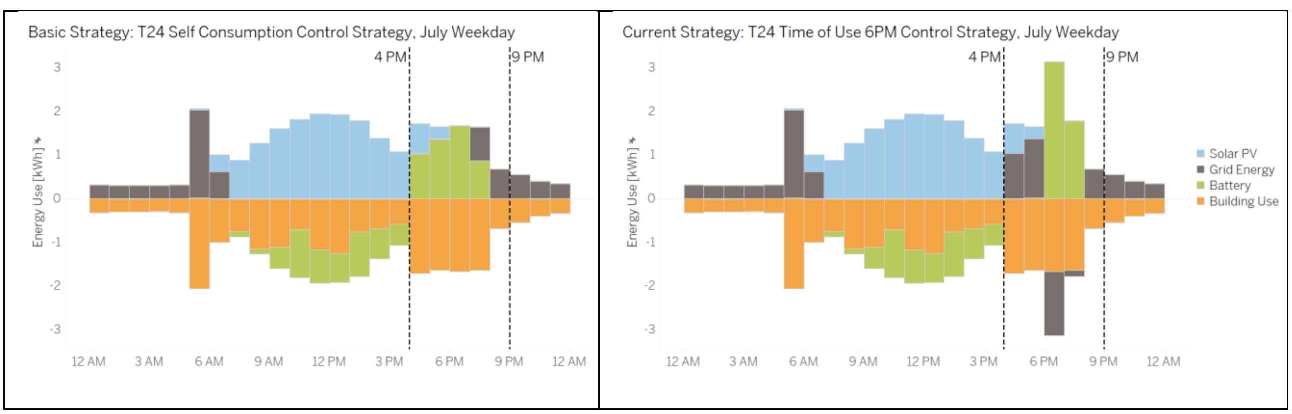


Figure 4: Title 24 Battery Control Diagrams for Self-Consumption and Time of Use Controls

From the figure, the Basic Strategy for self-consumption can be observed to charge the battery in the daytime when solar energy is available and immediately start to discharge the battery at 4pm when the building load increases. The Time of Use Title 24 strategy charges the battery and holds it until the specified starting hour, which is configured to be 6pm and discharges the battery. While 9pm is shown on these charts, there is no ending period in the current compliance software and the battery controls effectively end each day at midnight. Technically, the software Time of Use Title 24 strategy is only enabled during summer months, July to September, and reverts to a basic strategy of self-consumption for all other months.

Based on observations of how an operational battery system performs when configured to a time of use control, the battery system did two distinctly different things:

1. The battery charging was prioritized first before the building utilized solar energy.
2. The battery discharge was limited to the building load and not allowed to exceed this limit.

The control strategy is shown in the figure below for the same sample day in July.

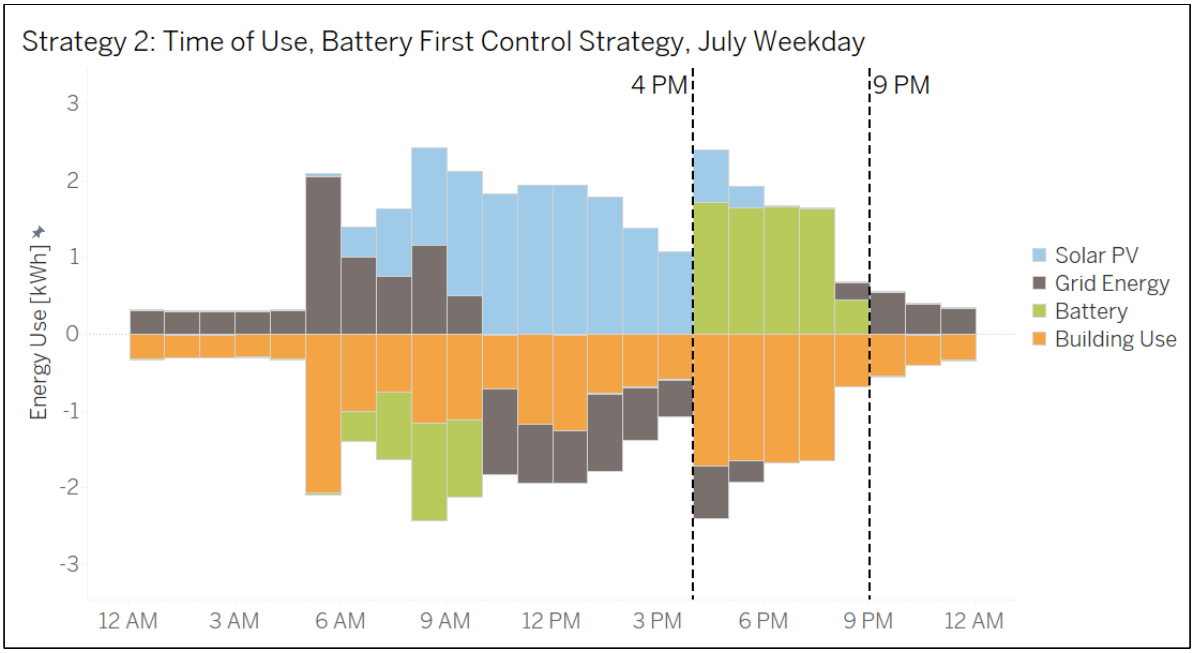


Figure 5: Time of Use Control Strategy 2 for observed battery system, prioritizing battery charging, example of operational behavior

In the course of the study, the differences between the control Strategy 2 and the Time of Use Title 24 strategy prompted the research team to develop two additional control strategies:

1. Strategy 1 - Time of Use, Building Priority
2. Strategy 3 – Time of Use, Battery to Grid

The two strategies are shown in the figure below.

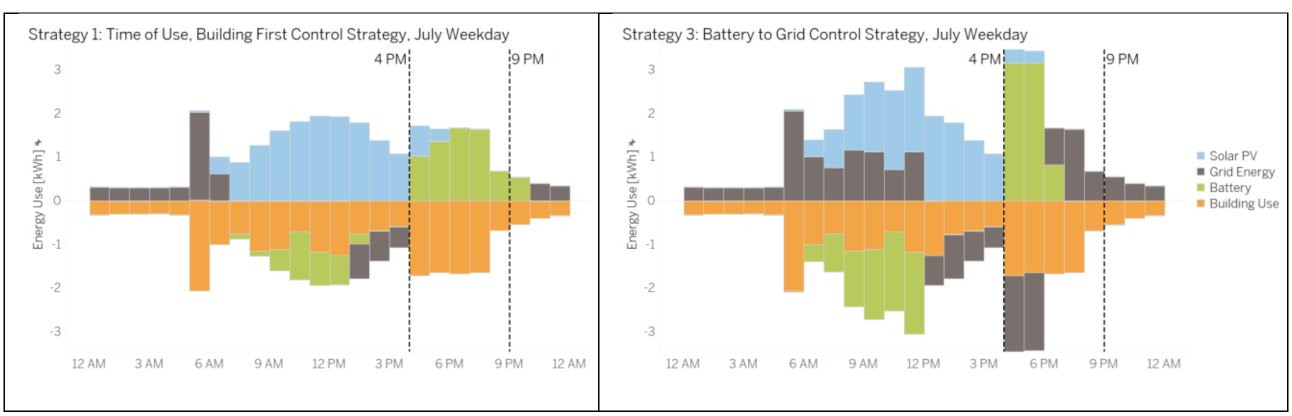


Figure 6: Time of Use Control Strategies 1 and 3 example diagrams of charging and discharging behavior

Strategy 1, Time of Use, Building Priority: utilizes solar PV energy for building loads first and, once those are met, allows the battery to charge. This strategy then discharges the battery based on the hour indicated by the user; however, the discharge is limited to the building's consumption on that hour and nothing higher.

Strategy 3, Time of Use, Battery to Grid: utilized solar PV energy to the battery first and once fully charged, directly serves the building energy needs. This strategy reflects the observed behavior of the real time of use system in Strategy 2 combined with the observed programming of the Time of Use Title 24 scenario. The battery is allowed to discharge energy based on the hour indicated by the user, and it is allowed to export energy at the maximum rate, determined by the size of the battery and an assumption of power at 42% of the rated capacity. In this example, the battery is 7.5 kWh so 3.15 kW of power can be exported each hour. Strategy 3 does not exist, based on the literature review conducted by the research team, although it could be developed to represent a potential grid deployment strategy.

The attributes of these five strategies are summarized on the table below:

Table 1: Battery control strategies and attributes

	Battery Export Limit	Battery Charging Priority	Annual Availability	Time of Use Structure
Basic Strategy: Title 24 Self Consumption	Building Load Limit	Building Load first	Annual Available	None
Current Strategy: Title 24 Time of Use 6PM	No Battery Discharge Limit	Building Load first	Summer Only	Fixed Times, 6pm
Title 24 Demand Response (current) *(not evaluated)*	No Battery Discharge Limit	Building Load first	Annual Available	Dynamic Responsive Time (top 3 hours)
Current Strategy: Title 24 Time of Use	No Battery Discharge Limit	Building Load first	Annual Available	Fixed Times, 4pm
Strategy 1: Time of Use	Building Load Limit	Building Load first	Annual Available	Fixed Times, 4pm
Strategy 2: Battery Charging Priority	Building Load Limit	Battery first	Annual Available	Fixed Times, 4pm
Strategy 3: No Discharge Limit with Battery Charging Priority	No Battery Discharge Limit	Battery first	Annual Available	Fixed Times, 4pm

Annual Energy Cost and Compliance Impact

Approach

To weigh the potential energy cost savings and impacts on the energy standard from the control configurations identified, an energy model for a small single-family house was utilized, evaluating the annual energy use with multiple sizes of solar PV and electric battery storage. The energy model was first simulated using code compliance software for residential buildings using CBECC-Res 2019. Hourly outputs for the design, standard, and reference building were merged with an hourly calculation for solar and storage systems. This calculation was developed in Microsoft (MS) Excel with the battery deployment controls constructed to match those used by CBECC-Res for the existing three control scenarios. Additional control configuration rules were added based on simplified criteria for each.

Five control strategies were evaluated in a single-family residential energy model, combining CBECC-Res with a parametric battery and PV modeling tool for each strategy. The evaluation was based on three climate zones. It used a single-family residential model with two versions of the house, one with all-electric heating sources and one with mixed fuel with space heating and water heating provided by gas. The table below outlines the basic energy model, with more details included in the appendix.

Table 2: Annual energy model key input parameters

Type	Parameter	Inputs
Building Parameters	Building Size	Building A Mixed Fuel: 2100 sf Building B All Electric: 2100 sf
	Building Occupancy Type	Building A: Residential House-1 Floor Building B: Residential House-1 Floor
	Climate Zone	CZ09
	PV Size	2.5 kW, 5kW
	HVAC Type	Building A: Gas Furnace Building B: Heat Pumps
	Battery Sizes	0 kWh, 7.5 kWh, 15 kWh

The PV size and battery size were evaluated based on the size of the house, using the minimum requirements for the home per the energy code, and the maximum system size based on component sizes of solar plus storage not to exceed annual energy generation by more than 3x the usage.

The model was evaluated using the following metrics:

- Time Dependent Value, 30 year (TDV 2022) for Residential.
- Time of Use Rates, based on a set of rate schedules for Climate Zone 9 from SCE.

Metrics not evaluated: EDR

Observations

As control strategies change to be more dynamic, energy costs can be reduced, with cost savings primarily from optimizing sequences to avoid summer peak cooling demand and price increases reflected in the long-term cost metric, TDV.

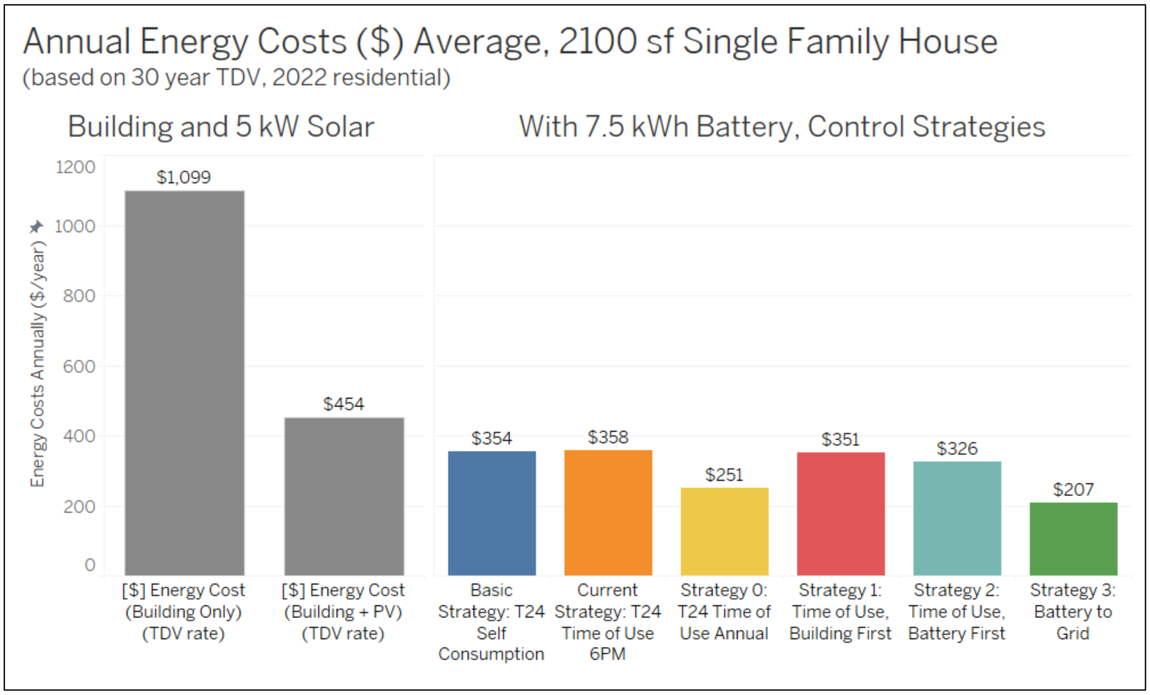


Figure 7: Annual energy modeling results for single family house with different battery control strategies

Changing the strategy of the three proposed strategies (1, 2, and 3) to instead discharge the building annually from 4-11 pm results in lower grid import during the high TDV evening hours, resulting in higher annual savings. Applying a grid export limit in Strategy 1 and Strategy 2 helps to reserve the battery use by 2 to 3 additional hours during peak pricing periods, ultimately resulting in a lower annual energy cost.

While using these strategies certainly will reduce costs, the next focus of controls shifts to primarily summer afternoon and cooling in general. This type of control is reflected in the current TOU Title 24 control and in all TOU controls that focus on reserving battery usage for evening hours. While this has the potential to maximize cost savings, the net impact of a solar PV and battery system over the year results in more significant swings in power import and power export throughout the day and year. Each strategy's net grid demand is shown below, over 24-hours, with all the data for a full year of operations, with the average net grid demand highlighted for each hour.

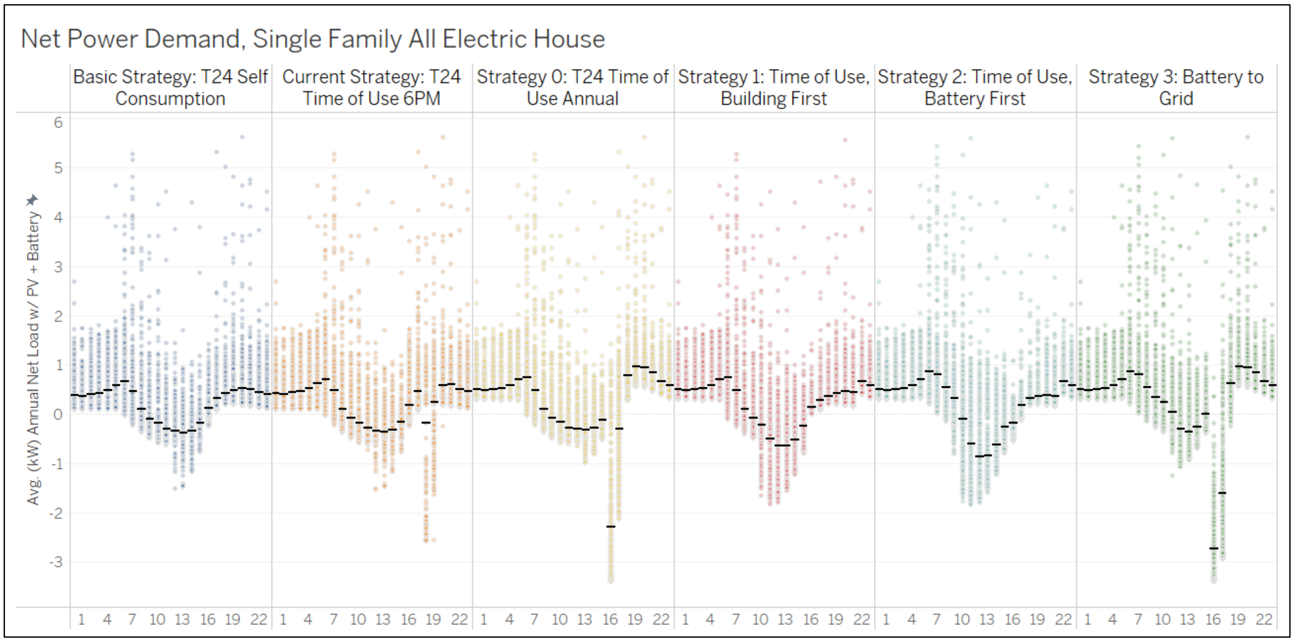


Figure 8: Annual energy modeling results of net electric load for each control strategy

From these net grid demand trends of power (kW), the basic strategy of self-consumption results in the flattest shape of grid demands over the year, with each level of control strategy beyond this increasing the intensity. The Title 24 Time of Use strategy is currently limited to deployment in July through September, so the following graph isolates only those months to make a clear comparison for each strategy in the summer season.

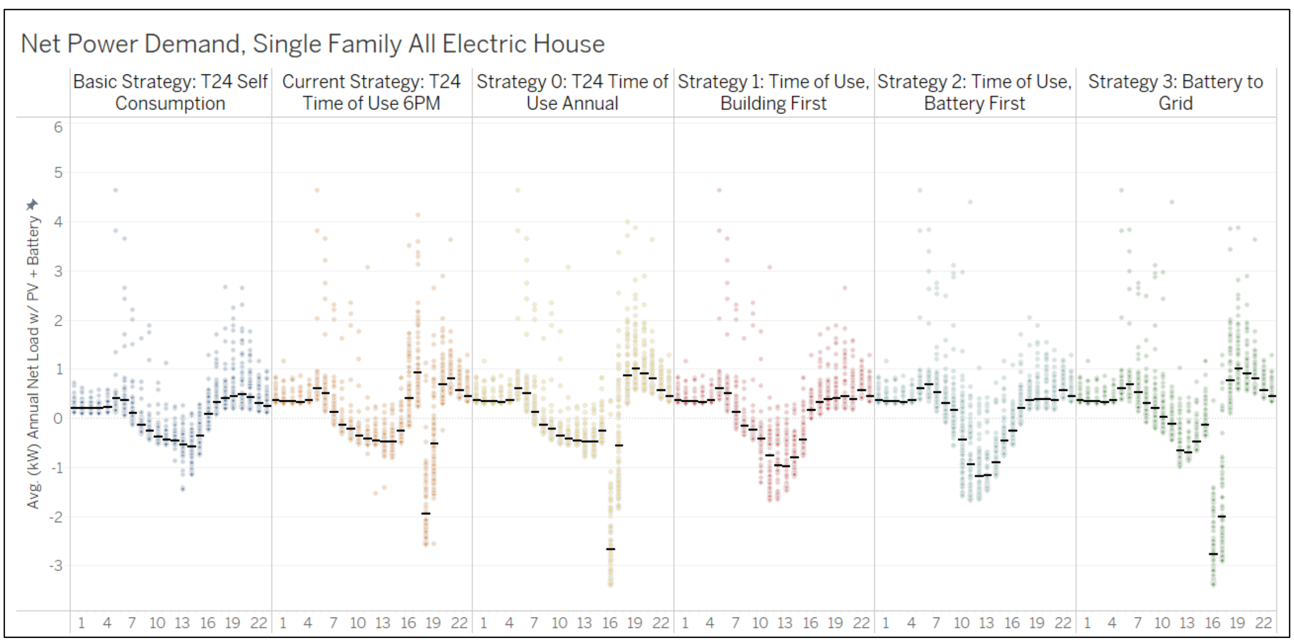


Figure 9: July through September energy modeling results of net electric load for each control strategy

From July through September, the Title 24 Time of Use strategy and Strategy 3 shows the most significant grid export of power in the evening hours, when the battery is allowed to discharge fully. This functionality is part of the compliance software's current algorithms; however, it requires more in-depth research than was allotted to the current research project.

Battery Capacity and Control Strategy Impact

The potential for battery system size and control strategy to increase the benefits of energy use, cost, and carbon emissions was investigated. The results, shown below, are based on the single-family residential house model and the six control sequences simulated, with two size batteries installed for the 5 kW of solar: 7.5 kWh and 15 kWh. These battery sizes were selected based on the nominal size of a component battery of a leading battery manufacturer.

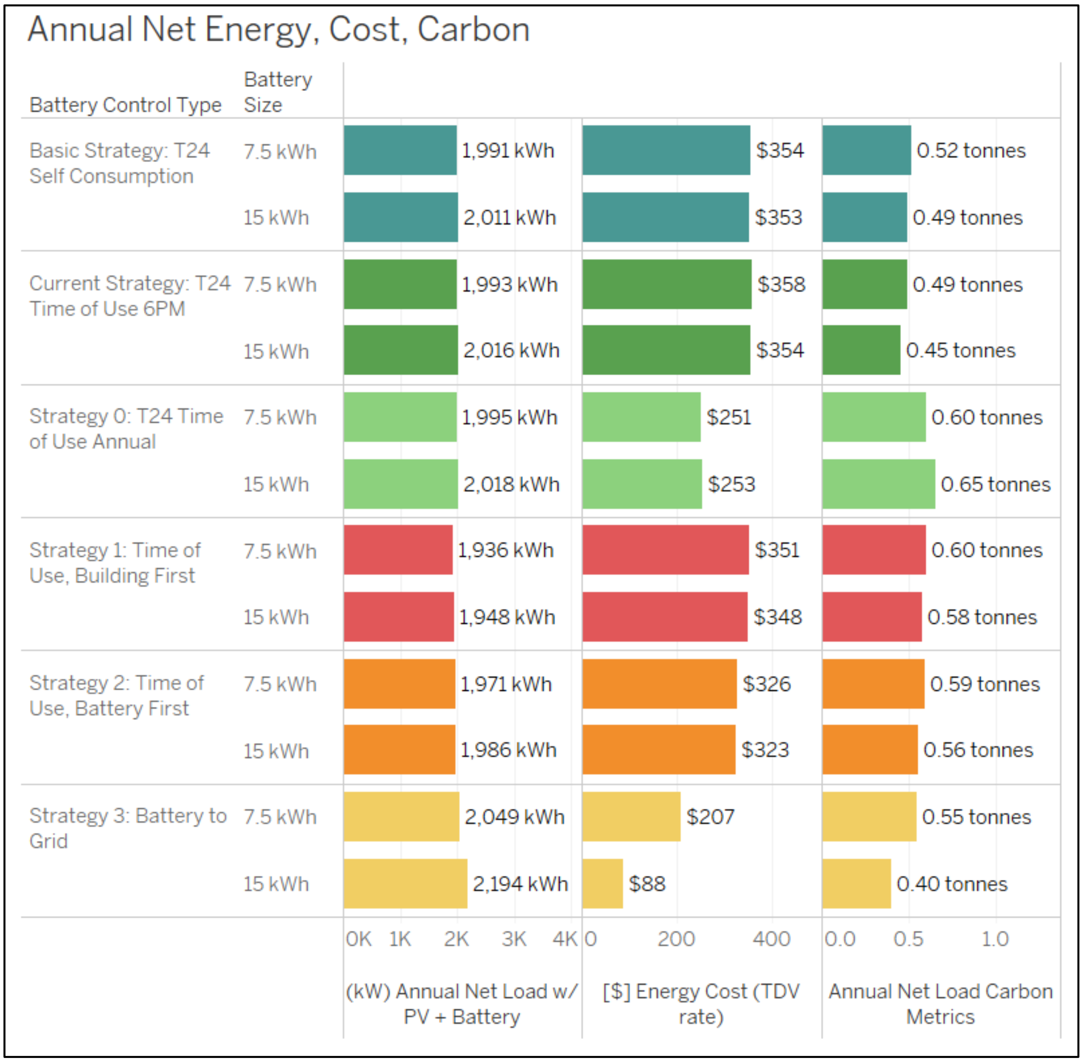


Figure 10: Annual energy use, energy cost, carbon emissions of single-family house with different battery control strategies

From the annual results, the two current strategies, Self-Consumption, and the Title 24 Time of Use, show a minor impact between net energy use, cost, or carbon when doubling the battery capacity. Under the Title 24 Time of Use Annual control, the battery size increases all three metrics. Strategy 3 is the only control that showed potential net energy benefits in operational cost and carbon savings for the house. In this strategy, the battery is charged first from the solar PV, and when it is discharged, it is allowed to discharge at its maximum capacity, effectively providing a grid service of power export. These same results by month are detailed in the appendix.

Hourly Peak Demand Impact on Electric Grid

Observing control strategies at a higher resolution of one month shows substantial differences between the strategies and their potential impact on the electrical grid. Figure 11 shows the three strategies that include an ability to back-feed the electric grid and provide power limited by the battery export limits only and not limited by the building power need.

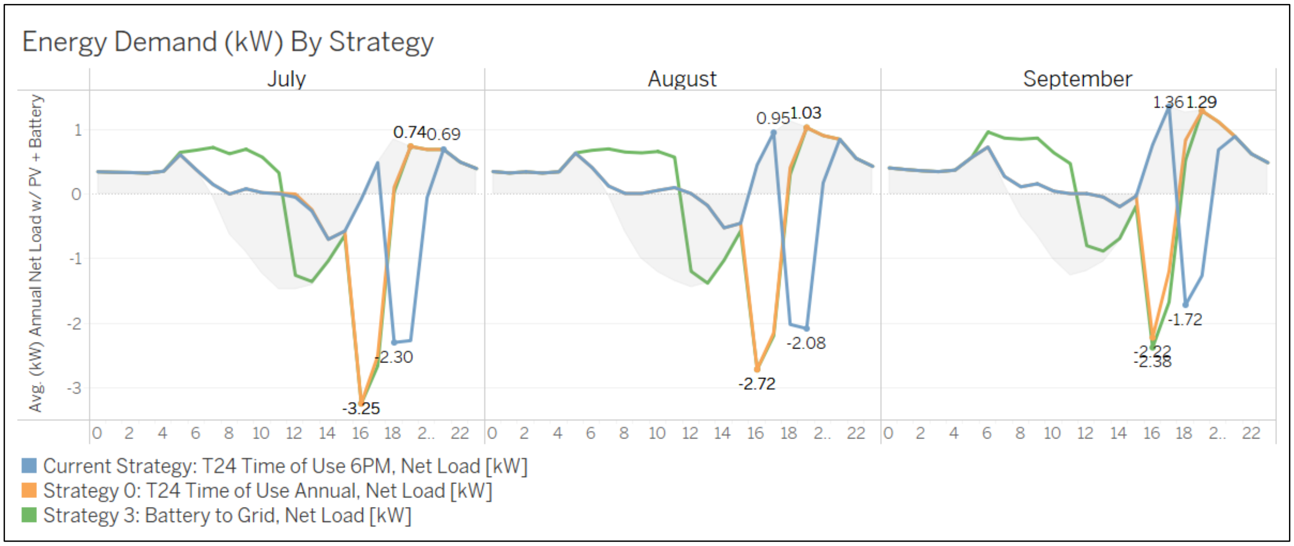


Figure 11: Average summer day electrical load (in kW) shapes of battery control strategies with grid export capabilities

These three scenarios were grouped since these functionalities are currently limited to pilot projects or select electric utilities or may not exist in California, even though they are now part of the compliance control strategy. In each scenario, the significant negative value seen in Figure 11 indicates the power provided to the electric grid. It is important to note the extreme sensitivity in net power export intensity to the start time when the battery is allowed to deploy, with the blue line reserving the battery to 6 pm and other scenarios using the battery at 4 pm. Looking at this same data in energy costs using the TDV metric (shown in Figure 12 below), the building's cost implications and compliance credit show that the battery's sensitivity to the starting time can impact how these strategies back feed the electric grid at full power.

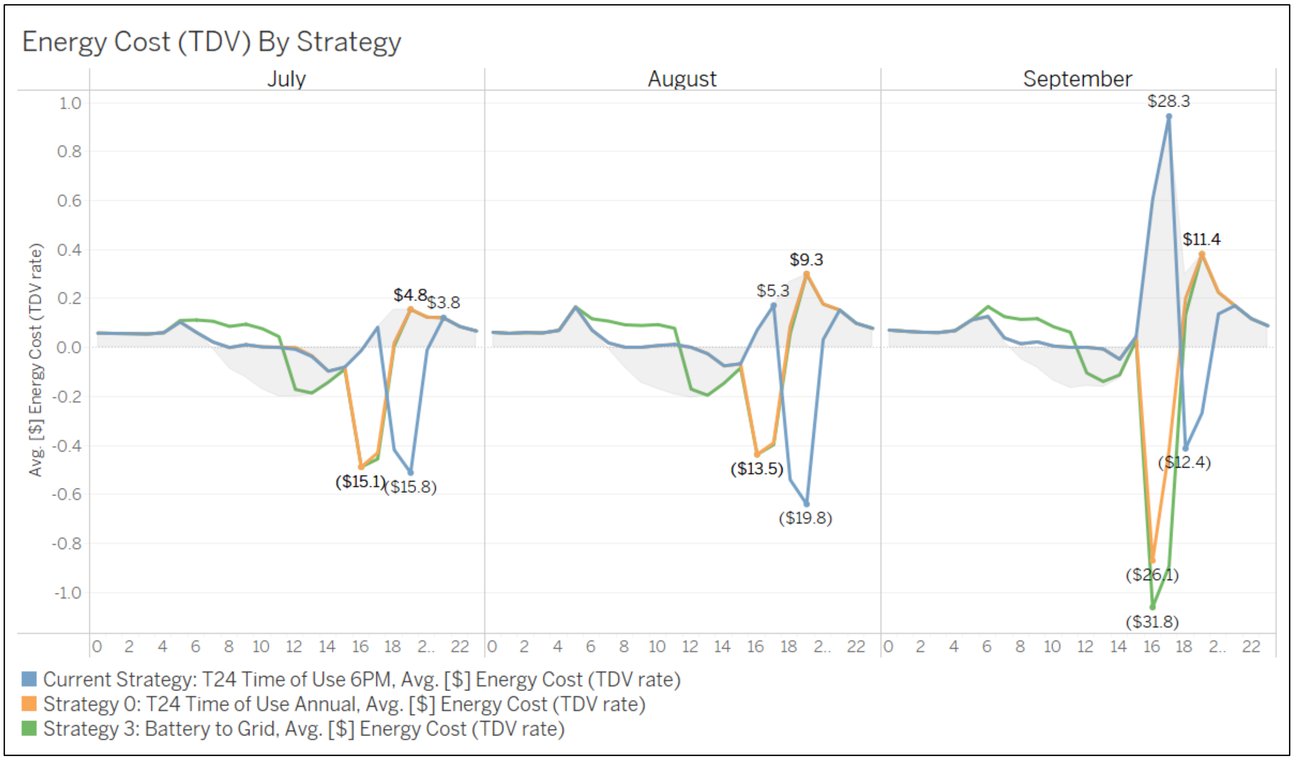


Figure 12: Average summer day electrical energy costs ($) shapes of battery control strategies with grid export capabilities

The three strategies listed in Figure 12 are the basic self-consumption strategy and the two time of use strategies (which do not allow the battery export to exceed the building demand). These look similar in magnitude; however, the research shows that the benefits of charging the battery first before the building, as shown in Strategy 3, have the most significant ability to reduce demand in the afternoon and evening hours.

The Self Consumption Strategy and the two Time of Use Strategies are shown in Figure 13 and Figure 14.

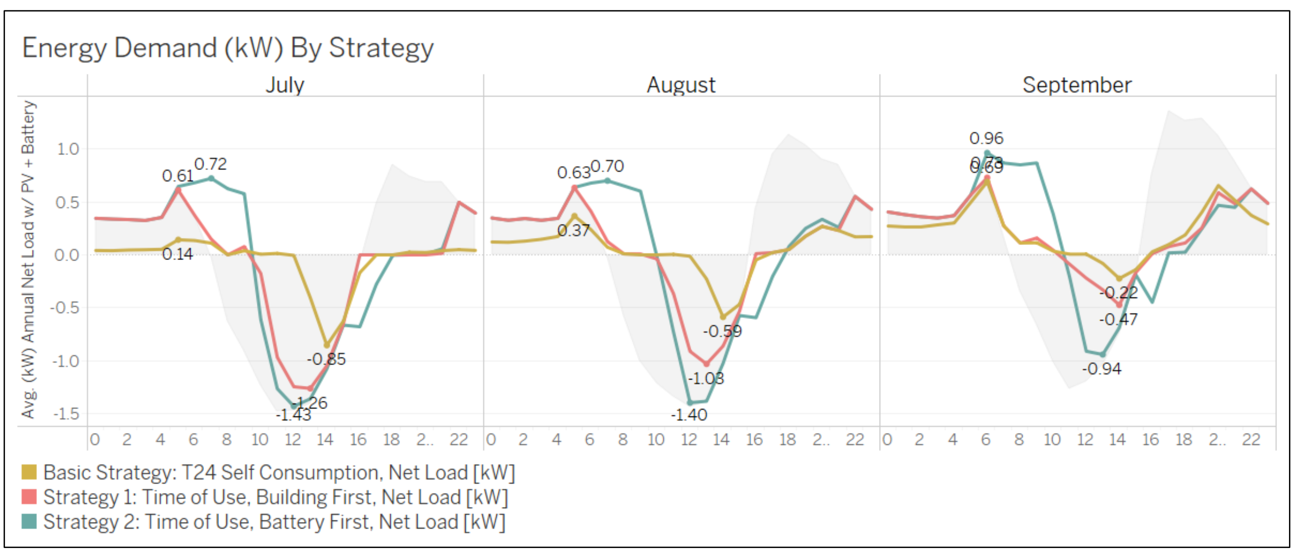


Figure 13: Average summer day electrical load (in kW) shapes of battery control strategies with different Time of Use capabilities.

In Figure 13, Strategy 2, charging the battery first before using the solar PV directly for the building loads stands out, with a higher net load on a typical morning and a higher energy export to the grid. Strategy 2 shows an ability to reduce the afternoon peak in September further than the other two Strategies evaluated.

In terms of energy cost, in Figure 14 below, the same Strategy 2 shows the most considerable cost reduction in the evening, after charging the battery to full capacity earlier in the day and allowing the afternoon solar PV to back feed the electric grid.

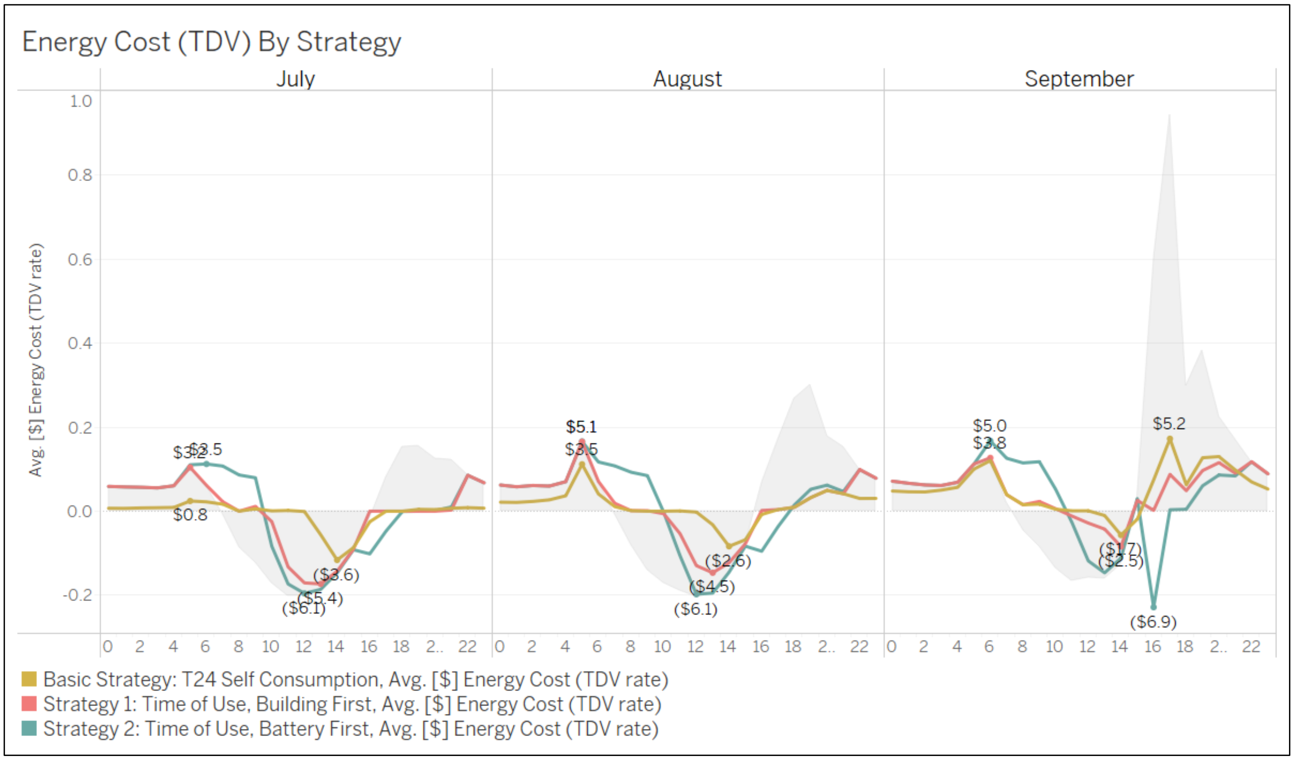


Figure 14: Average summer day electrical energy costs ($) shapes of battery control strategies with different Time of Use capabilities.

Net Energy Metering Feasibility Assessment

Approach

Leveraging a building analysis of the 2,100 single-family all-electric home provided the basis of evaluation for each control strategy. The net metering data for energy imports and exports were evaluated under two different net energy metering (NEM) strategies: one, reflective of the current NEM structure (referred to as NEM 2.0) and the other under the potential future NEM structure, currently proposed to the California Public Utilities Commission (CPUC), referred to as NEM 3.0. The assessment developed the import and export rates based on the hourly cost components of the TDV metric for the residential 30-year period. The NEM 3.0 structure will reduce the hourly costs of energy as valued at the retail rate, impacting the cost effectiveness of building solar PV and battery systems.

Table 3: Net Energy Metering Assessment Rates

NEM RATE	Import Energy Rate	Export Energy Rate
NEM 2.0	TDV 2019, Res, Full Cost *mid-day $0.20 / kWh*	TDV 2019, Res, Full Cost *mid-day $0.20 / kWh*
NEM 3.0	TDV 2019, Res, Full Cost *mid-day $0.20 / kWh*	TDV 2019, Res, - hourly retail rate *mid-day $0.08 / kWh*

The energy rates were developed based on the hourly components of TDV 2019, whereon the retail rate was able to be isolated and removed from the other energy costs. All costs do not include the utility's fixed costs, including the proposed solar interconnection charge per month.

Observations

And energy model of a single-family home located in climate zone 9 used hourly rates under the NEM 2.0 and NEM 3.0 scenarios described above. The following chart summarizes the home's annual energy costs for residents working from home, without solar or battery, and with different configurations of solar and battery.

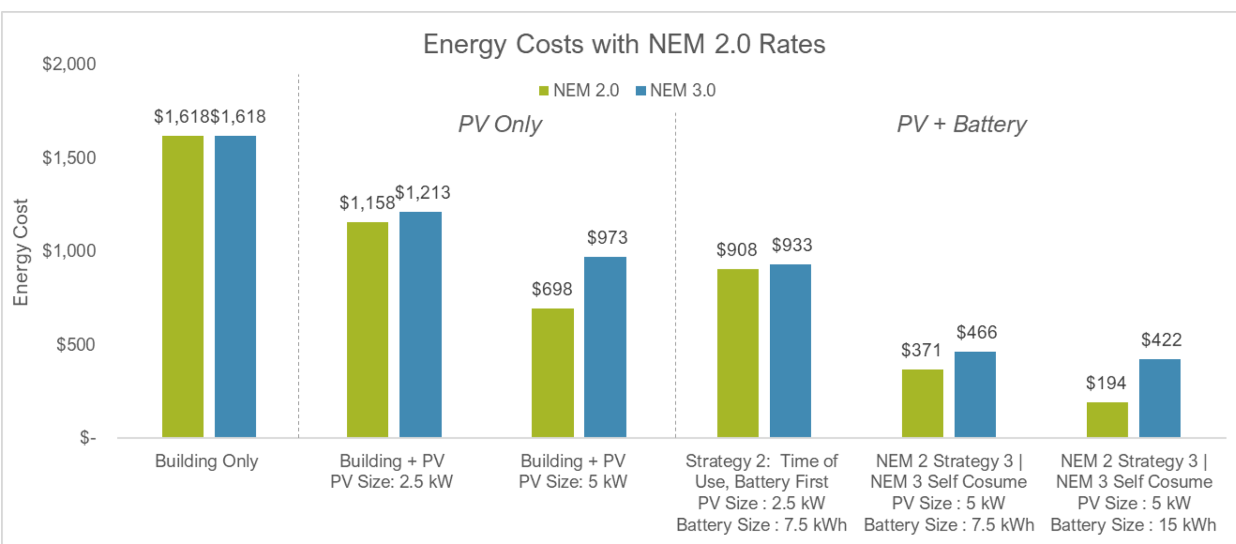


Figure 15: NEM 3.0 Impact Results of Single Family All-Electric Simulated House

From Figure 15, the NEM 2.0 structure sees the greatest reduction in annual energy cost from the additional solar PV, with 2.5 kW of solar reducing cost by 29% and 5.0 kW almost doubling this cost savings at 57%. Under NEM 3.0 the benefits of solar only are reduced, with 5.0 kW reducing costs by 40%.

By adding electric battery storage, the largest benefits for either NEM 2.0 or 3.0 require the building to have enough solar production to fully maximize the benefits of a battery. With 5.0 kW of solar, both NEM cost structures can reduce operational costs further. Under NEM 3.0, the house with 5.0 kW of solar and 7.5 kWh of battery can reduce annual energy costs by 71% to $466 from $1618.

This calculation only accounts for the energy cost reduction and does not take into consideration any increased fixed fees for the solar system on site which is being proposed at $8/kW of solar per month. This would increase this option by $480 for 5.0 kW of solar, effectively reducing the energy cost savings to 41%. This additional charge for solar connection would apply to each option shown for NEM 3.0 based on the solar size.

The final set of analysis in the chart above show the impacts of further increasing the battery size by doubling the system capacity to 15 kWh. Under NEM 2.0, costs would be able to be reduced if the battery was configured in either Strategy 2 or 3, where the battery charges first from the grid and in Strategy 3, where the battery is able to be discharged at full capacity for a cost benefit. Under NEM 3.0, further increasing the battery size with a fixed solar system size (5 kW) shows little increased cost benefits.

Detailed Findings by Control Strategy

The following figures show the analysis results for each control strategy shown for a NEM 2.0 and NEM 3.0 scenario of the single-family home with 5 kW of solar and two battery sizes, with the costs of each control strategy evaluated.

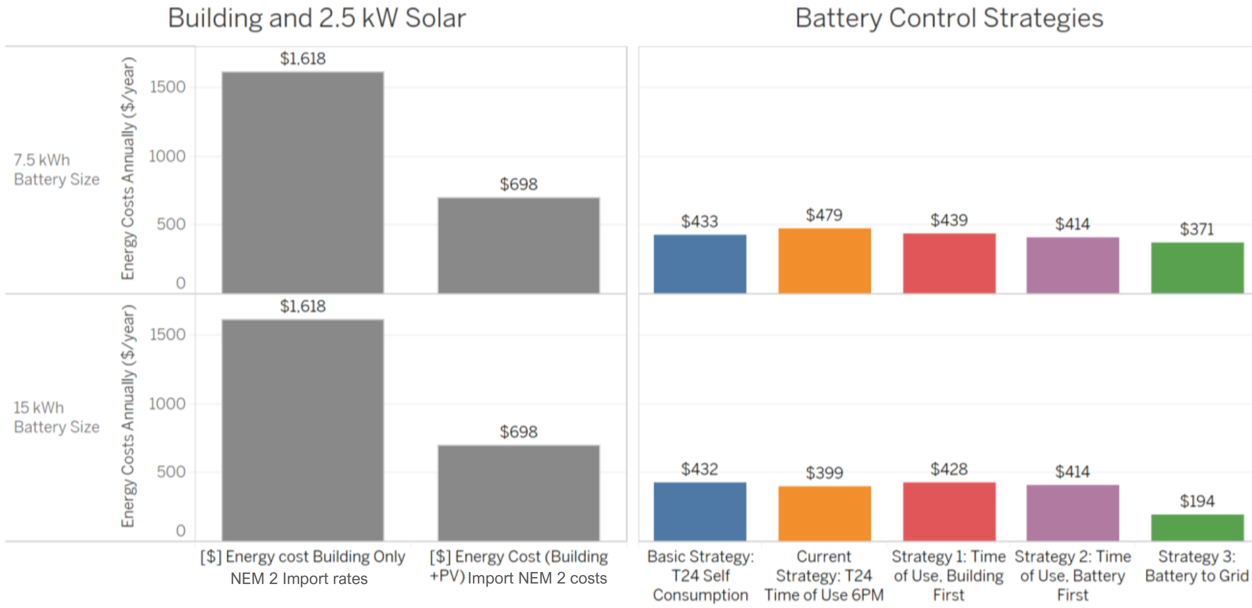


Figure 16: NEM 2.0 Annual Costs of the Simulated Single Family All Electric House Under Multiple Control Scenarios

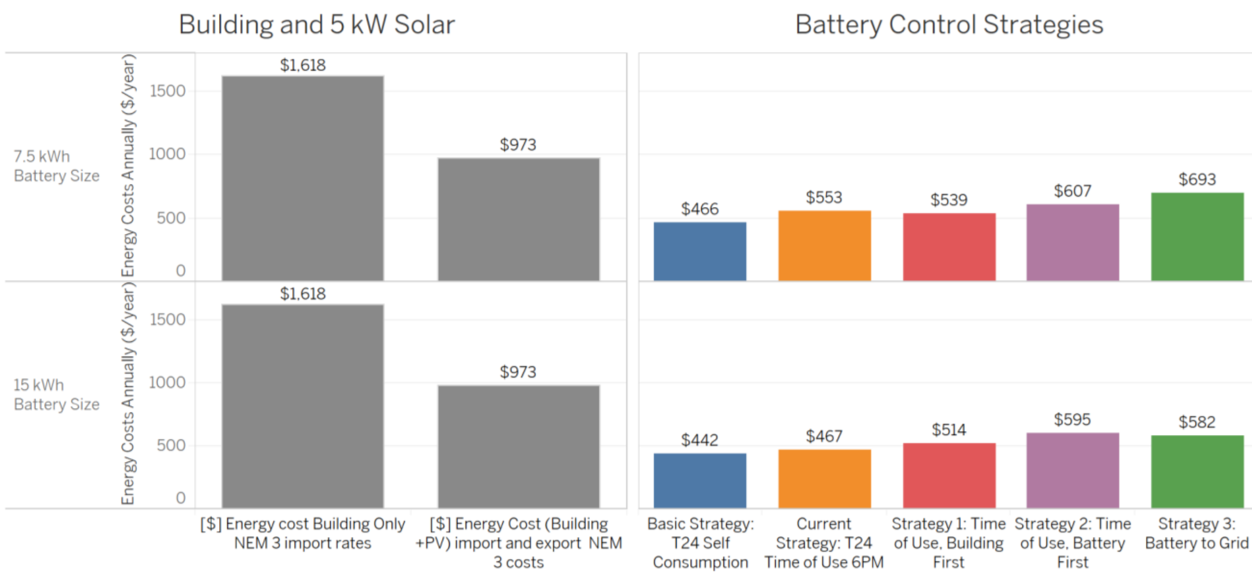


Figure 17: NEM 3.0 Annual Costs of the Simulated Single Family All Electric House Under Multiple Control Scenarios

From Figure 16, solar PV provides the greatest cost savings and battery size, and controls are able to reduce costs further, with strategy 3 and the largest battery reducing costs by 88% potentially. From Figure 17, energy costs can be reduced to $442 with the largest battery size and the self-consumption control strategy, 73%, however these costs do not include the fix solar inter connection fees which would reduce savings to 44% or $902 a year.

Timestep Impact on Battery System Potential

Approach

The purpose of this research was to evaluate the impact of a battery system by using fewer timesteps within an annual energy simulation. The analysis model used a set of 15-minute data from on operational commercial building with solar PV on-site and post-processed the information to include different sizes of an electric battery. The battery was set to a self-consumption strategy for simplicity with a focus on the timestep impacts. The data was refined to create an hourly data set by averaging the 15-minute data measured and comparing this data set to the 15-minute data set for trends that might demonstrate any benefits from adding an electric battery. Multiple battery sizes were assumed to be included in the building, and the resulting impact on the electric grid, operational cost, carbon, were evaluated to assess the depth of power demands and frequency of occurrence. The parameters used for this analysis are summarized in the following table.

Table 4: Energy assumptions and parameters for timestep analysis

Type	Parameter	Inputs
Building Parameters	Building Size	39,000 sf
	Building Occupancy Type	Commercial Medium Office
	Climate Zone	Sunnyvale, CA, CA CZ04
	Annual Energy Use	420,000 kWh/year
	Annual PV Energy Generation	310,000 kWh/year
	PV Size	206 kW (estimated based on 1,500 kWh/kW)
	Building Load Data	15-minute data measured over 1 year
	HVAC Heating and Cooling Type	DOAS with heat recovery, VRF Heat Pump
Battery Parameters	Battery Size	0kWh, 250kWh, 500kWh
	Battery Control Type	Self-Consumption Mode
Timestep Parameters	Timesteps	1-hour, 15-minute

Observations

Peak Power Demand Reduction Potential

The 15-minute power demand profile demonstrated a higher building need when compared with the same data averaged over 1-hour. The same size battery and on-site PV system can therefore demonstrate higher demand reduction benefits and quantify those reductions. Further evaluation of the sample commercial building data set illustrates an increase in the average peak demand by 12% when evaluating data at 15-minutes compared with averaging the data to 1-hour intervals. Figure 18 demonstrates the same 24-hour day in July with 1-hour data on the left and the same data in 15-minute timesteps on the right.

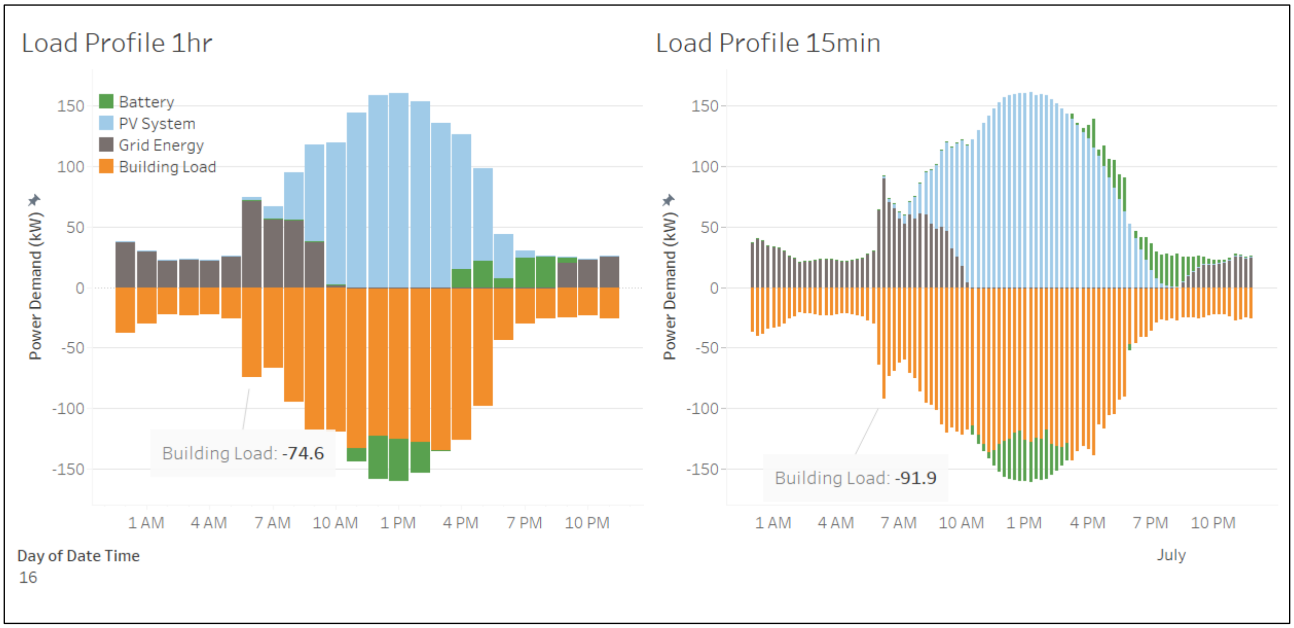


Figure 18: Typical peak demand profile of measured office building evaluated at 1-hour and 15-minute timesteps, July summer day

In the figure, the building load in the morning peaked at 92 kW with 15-minute data compared to 75 kW at 1-hour data.

Grid Export and Import Frequency

Evaluating the 15-minute data set and comparing it with the 1-hour data set shows a more frequent need for the 15-minute data set to export and import energy. From reviewing the analysis, 1-hour timestep evaluations will often average the solar PV generation and building use and depict a building that may never need to export or import power during the middle of the day, while the same data, when evaluated at 15-minutes would require many interactions during the same period. Figure 19 demonstrates the same 24-hour day in January with 1-hour data on the left and the same data in 15-minutes on the right.

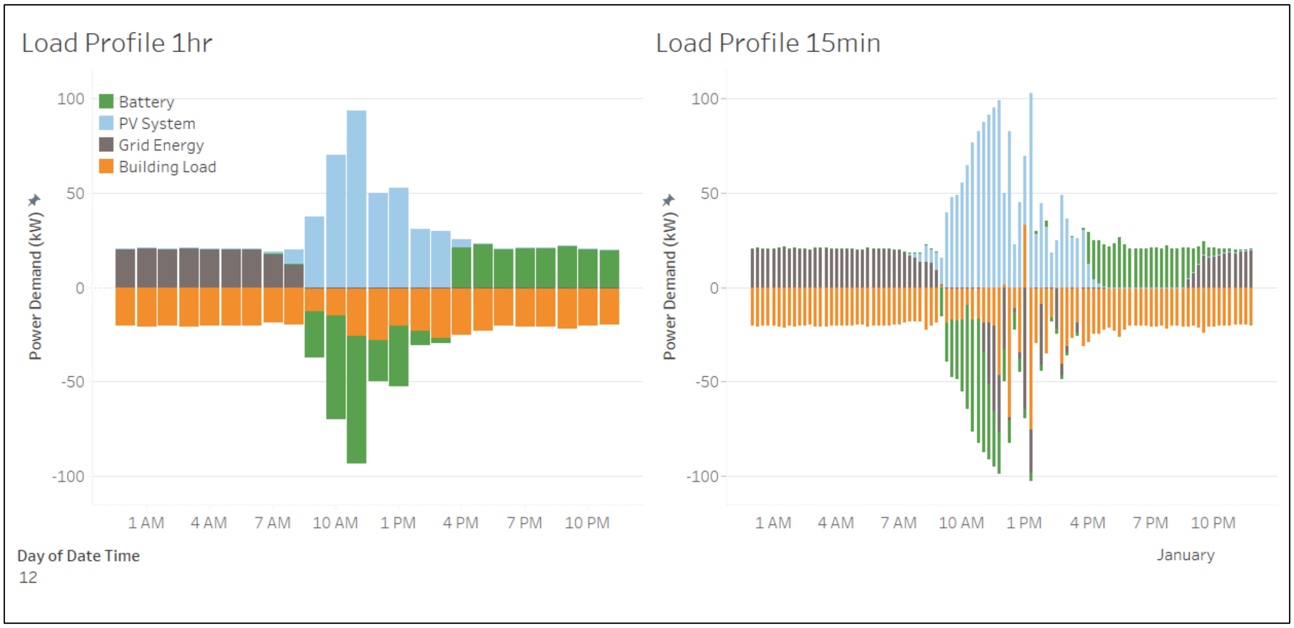


Figure 19: Typical peak demand profile of measured office building evaluated at 1-hour and 15-minute timesteps, January winter day

From the figure, 15-minute data shows mid-day spikes and drops in grid energy interactions which are averaged out when utilizing 1-hour data for the same day. The high fluctuations in building load represent the changes in the building's heating system cycling on and off to maintain temperature on a cold day.

Changes in Building Peak Demand Intensity

The March day shows higher mid-day demand spike of power without solar and a battery. The building also requires exporting power at 1pm with a 15-minute analysis, whereas the 1-hour shows no export.

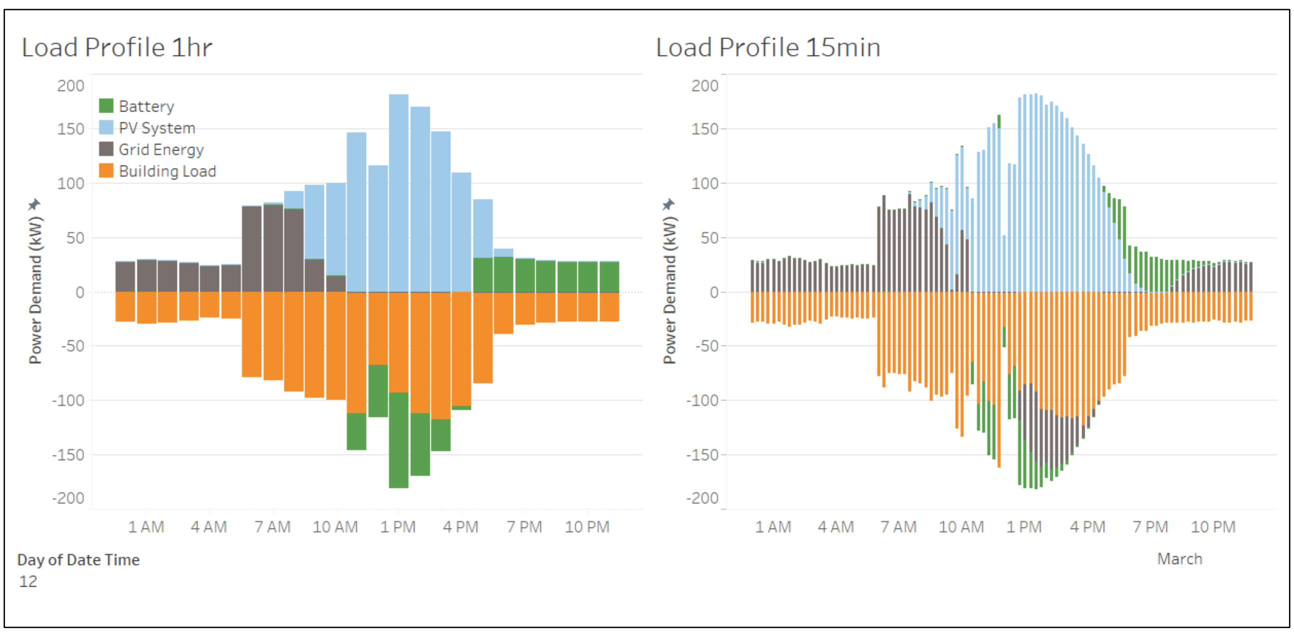


Figure 20: Timestep evaluation of electric batteries showing afternoon spike in building load, 1-hour versus 15-minute, typical March Day

The 15-minute data in March shows an afternoon net export of power after the battery reaches full charge. In the future, net metering rules may be different, and in evaluating a set of building systems in a design-phase, using low resolution battery process results could lead to errors as calculations for annual energy demand are made.

Morning and Afternoon Spikes in Peak Demand Intensity

Using a 15-minute analysis in the month of June shows a higher power intensity in the building load before solar PV and battery are applied. The net grid peak demand in the afternoon is also higher, at 125 kW compared with 100 kW, evaluated with 15-minute data. Likewise, 15-minute timesteps show a higher evening peak right at 6pm, which is not visible in the 1-hour analysis. For utility planning purposes, June and other summer months are the most critical time on the electric grid for power plants.

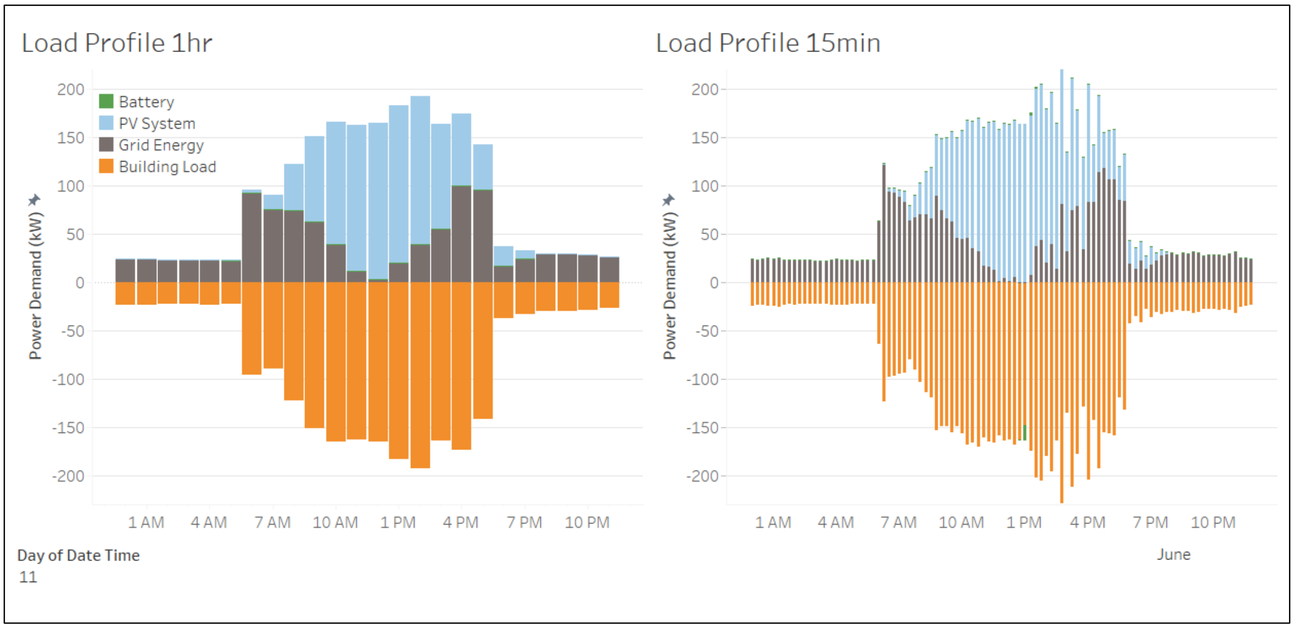


Figure 21: Timestep evaluation of electric batteries showing late afternoon increase demand at 5pm, 1-hour versus 15-minute, typical June day

121 kW spike in the morning with 15-minute data compared to the 92-kW spike with 1-hour data.

Size Of Battery Impact on Timestep Differences

The size of a battery was evaluated with the same 15-minute and 1-hour frequency at three levels of battery size: 0 kWh, 250 kWh, and 500 kWh. Based on reviewing the analysis results, a daily profile for two sample months for winter and summer (February and August) of net power demand were found to be the most interesting finding when looking between the battery sizes. Figure 22 shows the results with no battery (0 kWh).

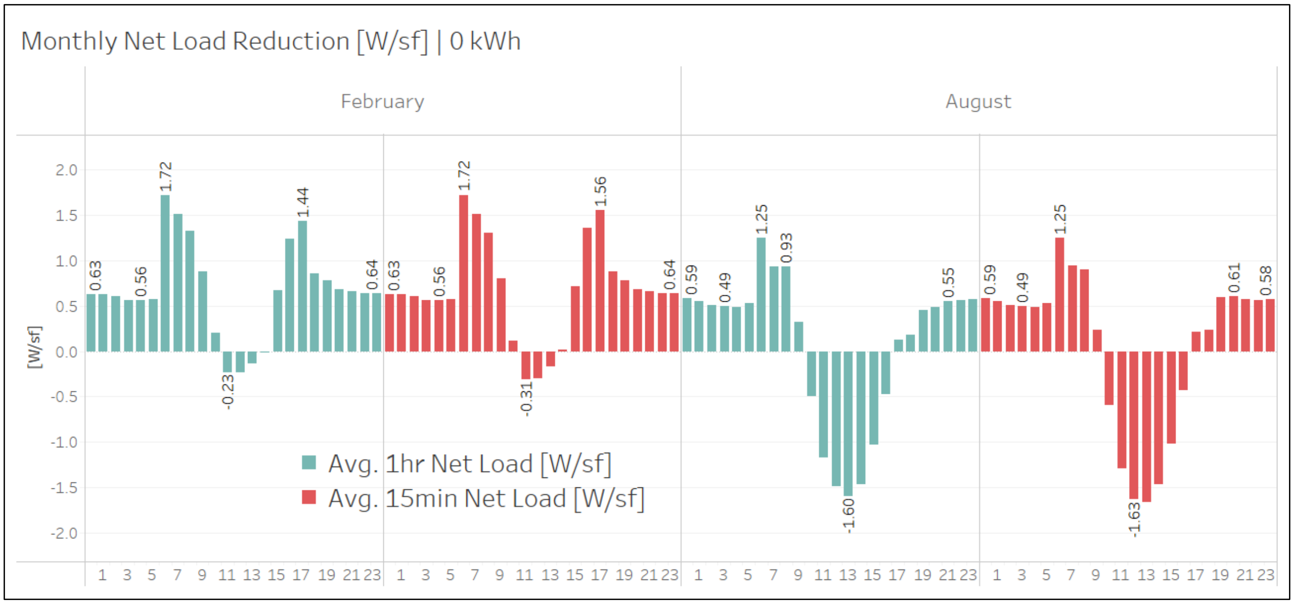


Figure 22: Timestep evaluation of February and August average net load over 24 hours with no battery in a commercial building in W/sf of 1-hour and 15-minute evaluation periods

Without a battery, the difference in 15-minute timesteps versus 1-hour shows similar trends in grid consumption with higher intensities occurring at 5pm when evaluating results with 15-minute data.

Results of the 250-kWh battery are shown in

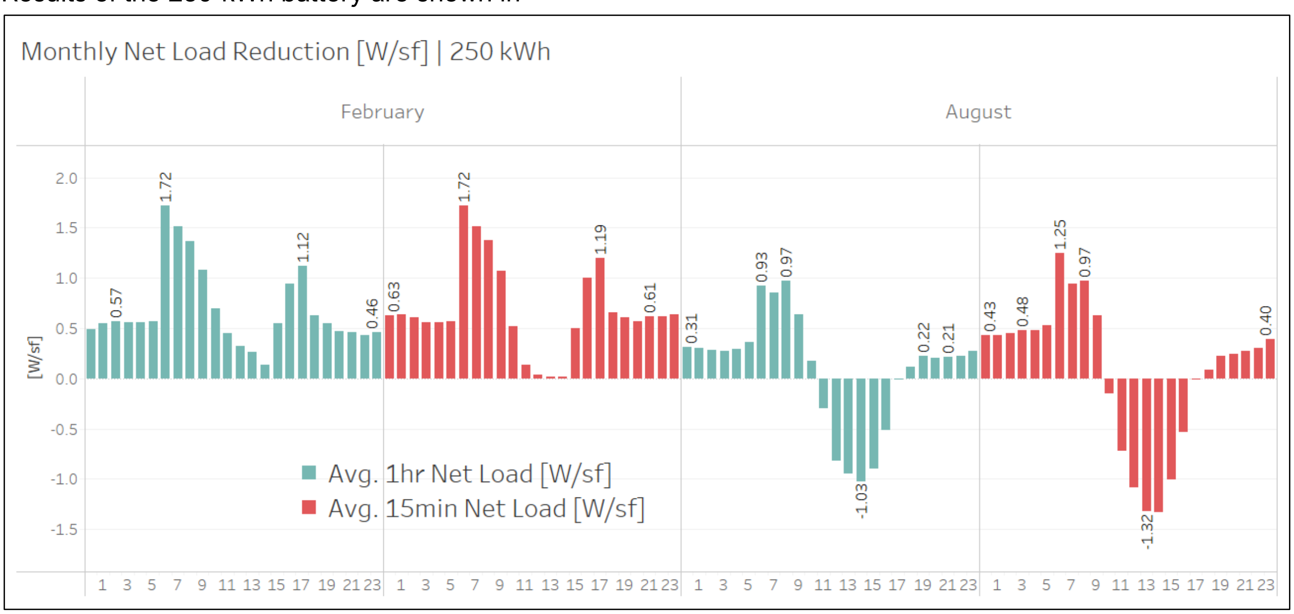


Figure 23 for the same two months, February and August.

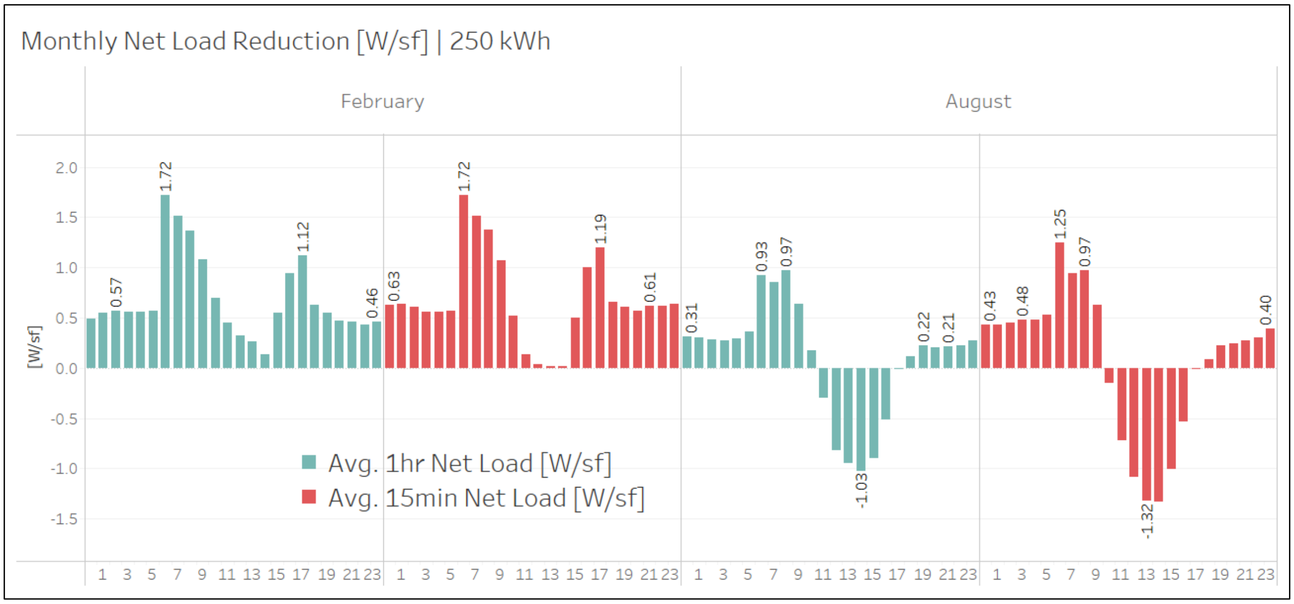


Figure 23: Timestep evaluation of monthly net load reduction with a 250-kWh battery in a commercial building in W/sf of 1-hour and 15-minute evaluation periods

A 250-kWh battery, the analysis in the 15-minute timesteps requires higher power intensity in the morning for both months and in the summer shows a larger export of power in the middle of the day.

Results of the 500-kWh battery are shown in Figure 24 for the same two months, February and August.

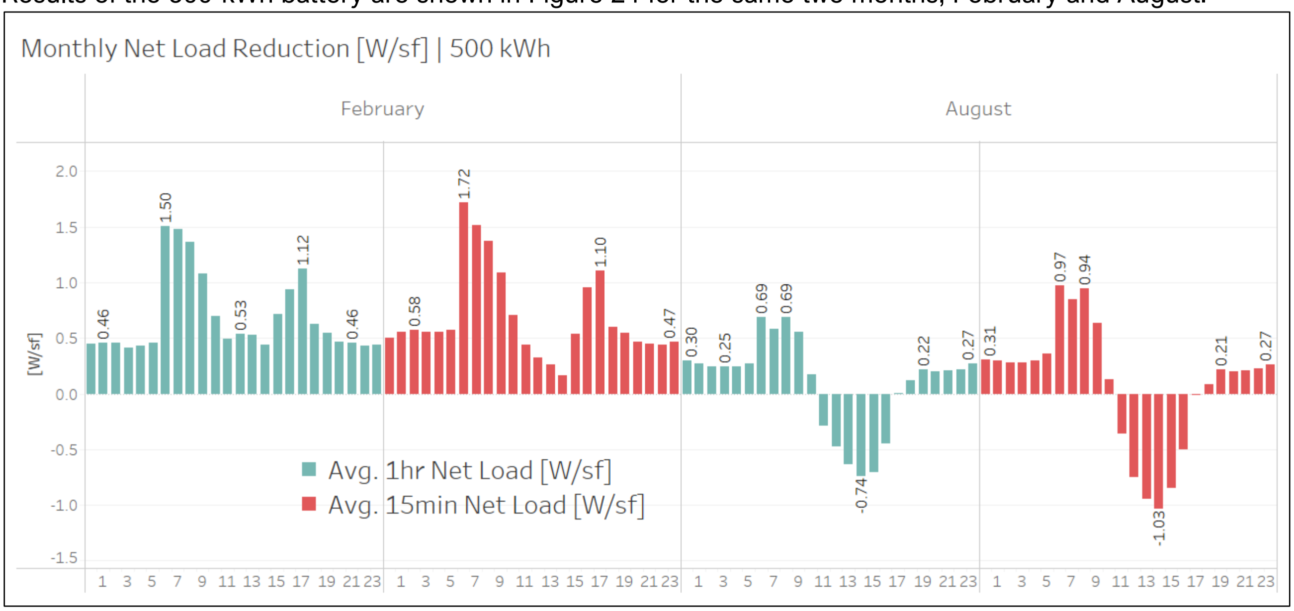


Figure 24: Timestep evaluation of monthly net load reduction with a 500-kWh battery in a commercial building in W/sf of 1-hour and 15-minute evaluation periods

Increasing to a 500 kWh battery resulted in the same pattern as the 250 kWh, with 15-minute timesteps showing higher power intensity in the mornings and a more dramatic spike of power requiring imports at 6am and 7am when compared to the 1-hour analysis. The mid-day export remains the same higher level of export required for the 1-hour analysis estimates.

Key Findings & Recommendations

The study performed two investigations and analyses for this report. The first focused on understanding the impact of different battery control strategies on annual energy use. The second focused on analyzing an operational building data set using 15-minute and 1-hour timesteps to understand the impact of each timestep on the onsite solar PV and the batteries. The key findings and recommendations for enhancements to the Title 24 compliance software are provided below.

Key Findings

1. The current battery control strategies used by the Title 24 compliance software for time of use control do not represent how actual battery systems are able to be configured and operated in today's battery market.
2. Some battery systems can control how solar PV is utilized, to either charge the battery first or serve building loads in real time. Charging the battery first allows the system the greatest energy shift during a Time of Use period. Based on observations, charging the battery first was the default option for all batteries with for all Time of Use controls.
3. The study used a model of a single-family residential home to review and evaluate six battery control strategies. Self-Consumption resulted in the highest energy cost and the lowest carbon emission savings of those six. While other control strategies are available to reduce energy costs, most users would not have enough information to estimate when to use the battery to get the most value.
4. Under the estimated NEM 3.0 rates compared with NEM 2.0 rates, to achieve a reduction in annual energy costs for the simulated single family home would require solar plus a battery system, where under NEM 2.0, solar alone would have substantially reduced costs. With NEM 2.0 rates, the evaluated house and largest solar + battery system was able to reduce costs by 88%, whereas under NEM 3.0, this would reduce costs by 71%, based on energy costs only, and by only 41% when adding the proposed monthly solar interconnection fee with energy costs.
5. The increased resolution of the energy analysis to 15-minute timesteps from the traditional model of 1-hour intervals can lead to better predictions of potential spikes in peak power demand and quantify the benefits and solutions that electric batteries can provide.
6. With a 15-minute interval analysis, a building with solar PV and battery may still need to import or export power at critical times throughout the day, which would not be visible with only 1-hour analysis. The analysis above 15-minute intervals can lead to under-representing grid requirements for buildings with battery systems and provide inaccurate data to building designers as they size systems to reduce peak load at critical times of the day and year.

Recommendations

1. Revise compliance software for any time of use control, not allowing back feeding to the energy grid beyond the current building power load predicted by the energy model and making the default time of use strategy reflect Strategy 1 in this report.
2. Include a new time of use control strategy so the user can specify prioritizing their building or battery for solar PV charging.
3. Create an ability to run non-compliant configurations of battery controls with functionality to select multiple control strategies by the month and within the year. The current time of use control strategy only deploys during summer months, defined as July through September. While options evaluated in this report show small changes in the compliance margin of controls, the lack of functionality in residential software to evaluate different control strategies can create a barrier to wider market adoption.

4. Add a lower limit at which point the battery can be deployed and depleted. Based on a literature review of leading product manufacturers, most products include a lower limit for reserve or backup power of 10% to 20% in some instances and do not fully discharge.
5. Change the timesteps, from 1-hour to 15-minutes, to accurately account for battery controls and solar PV energy use. Current energy modeling software runs at sub-hourly intervals when determining building loads, and this evaluation should be aligned to increase resolution and accuracy.

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