DOCKETED	
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Project Title:	2028 Energy Code Pre-Rulemaking.
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Document Title:	2028 California Energy Code Measure Proposal – Nonresidential Buildings Photovoltaic and Battery Energy Storage System
Description:	Proposed 2028 Energy Code updates to the Photovoltaic and Battery Energy Storage System requirements for Nonresidential Buildings.
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MEMORANDUM

TO: 2028 Energy Code Pre-Rulemaking (25-BSTD-03)

FROM: California Energy Commission

SUBJECT: Nonresidential Buildings Photovoltaic and Battery Energy Storage System Proposed Updates for the 2028 Energy Code

DATE: June 26, 2026

The purpose of this memo is to outline the California Energy Commission's (CEC) reassessment of the nonresidential photovoltaic (PV) and battery energy storage system (BESS) regulations. This work is being undertaken to support proposed updates to the 2028 Energy Code. This reassessment is driven by economic changes, updated building energy model prototypes, shifts in energy accounting metrics, new climate data, and changes to federal tax incentives. Updated school and assembly building prototypes, informed by stakeholder input and more representative operating schedules, impact building load profiles, which affect PV generation, battery operation, and system sizing. Updated Long-term System Costs (LSC) for electricity, updated Source Energy metrics, new climate forecasts, and evolving PV and BESS cost trends also require a renewed cost-effectiveness evaluation.

Preliminary analysis indicates that solar remains cost-effective under most conditions, while BESS performance is highly dependent on cost assumptions and replacement cycles. The memo presents a proposed new sizing approach for PV and BESS and highlights key areas where stakeholder input is needed before finalizing the proposed 2028 code updates.

Governor Gavin Newsom signed Assembly Bill 130, which pauses new updates to the California Building Standards Code, including the Energy Code, that affect residential units until January 1, 2032. As a result, this analysis did not include high-rise multifamily buildings or hotels and motels.

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PURPOSE OF THE ANALYSIS

Since the 2025 Energy Code was developed, several factors were identified that affect the cost-effectiveness of the nonresidential PV and BESS standards within the Energy Code. These factors are described below and form the rationale for why the PV and BESS standards for these building types needed to be reexamined for the 2028 Energy Code.

Revised Prototypes. Recent stakeholder feedback suggested that representativeness of the school and assembly prototypes used in the 2025 Energy Code cycle could be improved. Staff gathered data from interested parties and based on that information, proposed to update the school and assembly building prototypes for the 2028 Energy Code cycle at the August 28, 2025 Energy Code Accounting Workshop (see Docket No. 25-BSTD-03).

The Department of the State Architect (DSA) communicated that the existing Small and Large School prototypes did not represent typical kindergarten through 12th grade public schools. In collaboration with DSA staff, occupancy levels and schedules for spaces in kindergarten through 8th grade (K-8) schools were developed using DSA data sources and experience, and interviews of school staff and other relevantantentities including Department of Education staff. As a result of that effort, the school prototype energy models were revised for the 2028 Energy Code cycle (Shadd, Dabbagh, & Athalye, 2025), and the analysis was presented at the August 28, 2025 Energy Code Accounting Workshop (see Docket No. 25-BSTD-03). Previously, two school prototypes were used for analyzing PV and BESS cost-effectiveness: Small School and Large School. The Small School is no longer in use and has been replaced with two prototypes, a K-8 School prototype and a High School prototype, with the Large School prototype now only being used for colleges. The new prototypes have several distinguishing features including the absence of enclosed corridors, inclusion of multipurpose spaces, detailed schedules of operation for classrooms and other spaces, including reduced hours in the summer, and revised plug loads. These features align the school prototypes more closely with newly designed school buildings in California.

These updates also change the load in schools and thus impact the PV and BESS sizing and operation.

Concerns were also raised that the current occupancy schedule for the assembly building prototypes did not represent key features of many of the assembly building types used in the Energy Code. As a result of staff's research, the assembly prototype was also updated and the analysis was presented at the August 28, 2025 Energy Code Accounting Workshop (see Docket No. 25-BSTD-03). The occupancy level and schedules, operating hours, and plug loads for spaces within the Assembly prototype were modified as part of the prototypes update for the 2028 Energy Code (Shadd, Dabbagh, & Athalye, 2025).

Fewer operating hours, and other changes in the newly designed prototypes, would likely result in higher exports from the PV system and BESS. Therefore, the PV and BESS standards for schools were revisited for the 2028 Energy Code.

Changes to Energy Accounting Framework. A new set of metrics was developed for the 2028 code cycle, including updates to Long-term System Cost (LSC) and updates to Source Energy (Landsman, Liu, & Price, 2025). The analysis was presented at the August 28, 2025 Energy Code Accounting Workshop (see Docket No. 25-BSTD-03). The 2028 electricity LSCs are higher in magnitude relative to the 2025 code cycle, largely because of higher electric retail rates. These higher electricity LSCs affect the cost-effectiveness of PV systems and BESS.

In addition, weather data used to represent California's climate zones was updated for the 2028 code cycle (Roth, et al., 2025). The new weather data relies on future forecasts of weather and is representative of future climate conditions expected in California. The resulting impact on prototype models was increased cooling demand and decreased heating demand. These changes to the building's energy consumption patterns may affect the operation of the PV system and BESS.

Changes to PV System and BESS Costs. Changes to federal law required PV projects to either begin construction by July 4, 2026, or be placed in service by December 31, 2027, to receive the 30% federal investment tax credit (ITC) for commercial PV systems. As a result, PV systems placed in service after January 1, 2029, when the 2028 Energy Code becomes effective, may not be able to claim and monetize the ITC. The 2025 Energy Code PV system and BESS cost-effectiveness analysis included the ITC.

A literature review of base PV and BESS costs showed that PV costs have either held steady or have increased slightly, whereas BESS costs have come down from the estimate developed for the 2025 Energy Code PV and BESS cost-effectiveness analysis (Saeed, Pennington, & Daemi, 2024). These changing costs for PV systems and BESS together with the impact of the removal of the ITC must be accounted for in the updated assessment of cost-effectiveness of PV systems and BESS.

SIZING ANALYSIS SCOPE AND APPROACH

2025 ENERGY CODE PV AND BESS REQUIREMENT SIZING APPROACH

The approach used in the 2022 and 2025 Energy Code to size PV systems and BESS responded to net energy metering (NEM) rules and other market conditions in place at the time. The 2025 approach intended to maximize self-utilization by limiting annual exported generation to 20% of the total annual onsite generation, then further reducing annual exports to 10% through the use of the BESS, which also simultaneously served to reduce the daily evening peak by discharging during evening hours (Saeed, Pennington, & Daemi, 2024). In this memorandum, this approach is referred to as the Total Annual Load with Export Limits approach. Table 1 describes the parameters used in sizing of the PV system and BESS for the 2025 Energy Code.

TABLE 1: 2025 ENERGY CODE PV AND BESS SIZING PARAMETERS

Parameter	Value
Sizing constraint	Size PV such that only 20% of annual generation is exported. Size BESS to further limit PV exports to 10% of generation.
Round-trip BESS efficiency	80%
Discharge Power	Total capacity / 4
Minimum State of Charge	20% of Total Capacity[1]
Maximum State of Charge	80% of Total Capacity
Timing of BESS Discharge	During Time-of-Use hours (4 pm – 9 pm)
Timing of BESS Charging	When surplus PV generation is available

Source: Saeed, Pennington, & Daemi, 2024

[1] The sizing of the battery for the 2025 Energy Code assumed that batteries never discharged below 20% of their full capacity; and never charged above 80% of their full capacity. Further, the cost-effectiveness analysis assumed batteries discharged to only 40% of full capacity as the extent of self-utilization was approximately the same as the difference between 40% and 80% of full charge. See Appendix D of (Saeed, Pennington, & Daemi, 2024) for more detail. The proposed approach for the 2028 Energy Code cycle allows battery discharge capacity between 80% and 20% of full capacity.

PROPOSED 2028 ENERGY CODE PV AND BESS REQUIREMENT SIZING APPROACH

Proposed Approach, Seasonal Median-Load-Day Minimum-Matching: In contrast to the Total Annual Load with Export Limits approach described above, the proposed approach is to size the PV system and BESS to result in a low level of exports to the grid consistently throughout the year. This is done by matching the PV size to the median of the loads that will occur during hours of PV generation for the season of the year with the lowest loads for the year. This approach can be thought of as sizing the PV to best fit the daytime loads of a seasonal median-load-day minimum (as described below), and meeting demand during times of high LSC costs. The annual generation export percentage is not limited to any set amount like in the 2022 and 2025 Total Annual Load with Export Limits approach. The final PV and BESS size was determined by whichever season had the smallest BESS for that building prototype and that climate zone. In this memorandum, this approach is referred to as the Seasonal Median-Load-Day Minimum-Matching approach.

The steps for implementing the proposed Seasonal Median-Load-Day Minimum-Matching approach are:

1. **Seasonal Median-Load-Day Minimum**: The procedure for determining a seasonal median-load-day minimum was to first divide the year into meteorological seasons[2]. Next, the day with the median total building prototype energy consumption during hours of PV generation was selected as the typical median load day for that season[3]. This was done for every climate zone for each building prototype.
2. **Best Fit PV**: Next a 1 kW PV system was modeled in each climate zone throughout the year to get the annual hourly profile of a unit-PV system. Then, to determine the unit-PV generation that corresponded to the seasonal median-load-day minimum, each hour of unit-PV generation was averaged over the typical minimum load day for that season, the 3 days prior, and the 3 days after, effectively determining a representative single-day profile of unit-PV generation for the seasonal median-load-day minimum, using a 7-day week's window around that day. This procedure helped to determine a representative profile

[2] National Oceanic and Atmospheric Administration defines Spring as March, April, May; Summer as June, July, August; Fall as September, October, November; Winter as December, January, February. https://www.noaa.gov/education/multimedia/infographic/infographic-meteorological-and-astronomical-seasons

[3] For example, for an office in climate zone 12, PV generation occurs as follows: 7a to 5p (Winter); 6a to 8p (Spring, Summer); 6a to 5p (Fall).

while eliminating anomalies in any particular day (for example, a cloudy day), and still capturing the solar characteristics around that day (for example, capturing that week's morning fog). The building prototype's consumption at the peak hour of PV generation was then determined. This was divided by the unit-PV generation at that hour to arrive at the seasonal median-load-day minimum PV size. Figure 1 illustrates the hourly energy consumption and PV generation for the seasonal median-load-day minimum in the summer in the medium office prototype in climate zone 3. It also illustrates hourly net LSC cost for the medium office prototype, accounting for the PV system reducing the building's electricity demand.

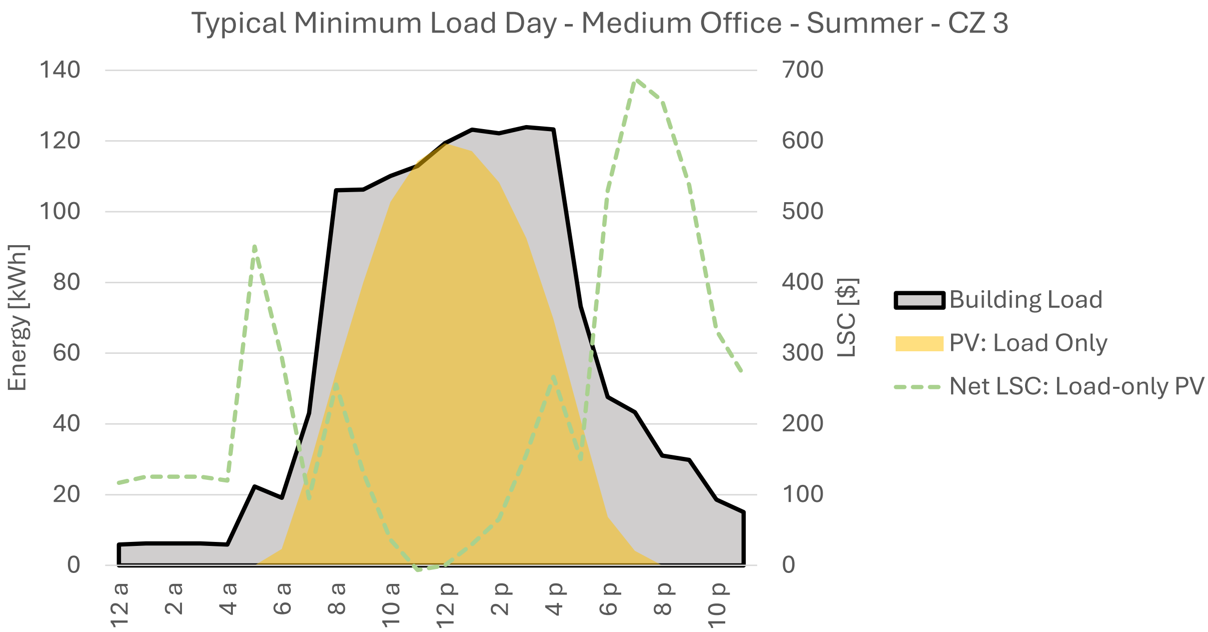

FIGURE 1: EXAMPLE OF SEASONAL MEDIAN-LOAD-DAY MINIMUM BEST FIT PV CALCULATION

- **Reduce Peak LSC**: Batteries were sized to reduce the costliest four hours of net LSC of the facility[4]. The BESS' power rating was set to reduce the LSC for these hours to be closer to the average LSC cost for that day.

  For example, if the average LSC of these peak LSC hours was $100, and the average for the day was $50, then the sum of the loads for the costliest four

[4] Research found that control systems which can predict future battery needs and charge and discharge to meet those needs are considered readily available in the market (Kelly & Liles, 2026).

hours were reduced by 50%. Then if the 50% load reduction totaled 400 kWh for those four hours, the batteries' power was set to 400 kWh/4 hours = 100 kW. The total storage would then be this power rating multiplied by four hours and divided by the round-trip efficiency of the BESS.

Next the PV was upsized to be able to provide this amount of charge on the Seasonal Median-Load-Day Minimum. The calculation expected that PV would be able to charge the BESS throughout the day while also serving the load of the building, except for times when the BESS was discharging.

An illustration of the summer typical minimum load day's total PV (building prototype load + BESS), BESS discharge energy, and final net reduction in LSC cost from PV and BESS is shown in Figure 2 for the medium office prototype in climate zone 3. Note that when a BESS discharges, it cannot be simultaneously charged. This is why the BESS discharge bars rest on top of the PV charge/discharge curve. A summary of the energy performance and BESS sizing parameters is provided in Table 2

- **Minimum Size over all Seasons**: Finally, the proposed PV system and BESS size was selected based on the PV-BESS system for whichever season had the smallest BESS for that building prototype and that climate zone. For example, schools have most of their load concentrated in the school year with much smaller loads during the summer. With the proposed approach the PV and BESS would be sized to these summer loads. During the school year this system would be substantially smaller than the school year loads, resulting in far less compensation than a system sized to the school year loads. However, the system would have very low exports in every season of the year, and would avoid large exports during the summer that would have occurred if the system had been sized to the school year loads.

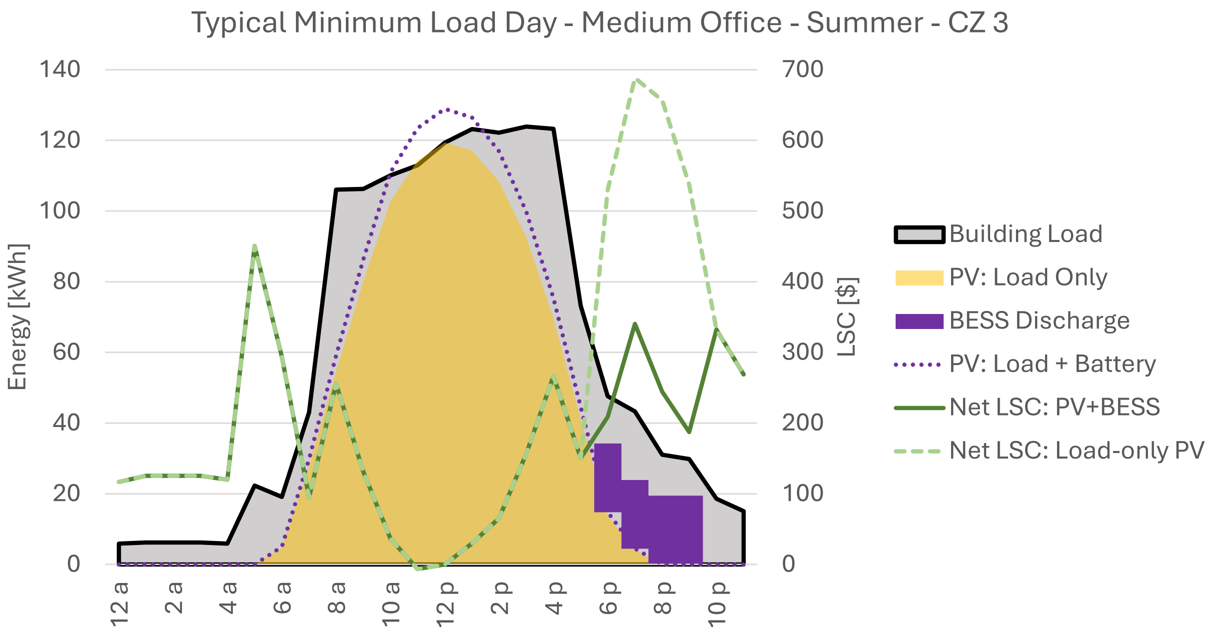

FIGURE 2: EXAMPLE OF SEASONAL MEDIAN-LOAD-DAY MINIMUM BESS SIZING CALCULATION

Note: During periods when the BESS is not discharging the "Net LSC – PV + BESS" overlaps with the "Net LSC – Load-only PV" lines, and looks like a dashed light green/dark green line.

TABLE 2: 2028 ENERGY CODE PV AND BESS SIZING PARAMETERS

Parameter	Value
Sizing constraint	Reduce building load for the four hours with the highest LSC closer to the average LSC for the day.
Round-trip BESS efficiency	89%
Discharge Power	Average of load reduction during the four hours with the highest LSC
Timing of BESS Discharge	During the four hours with the highest LSC
Timing of BESS Charging	On the typical day for each season, the amount of PV energy needed to charge the BESS fully is calculated. This energy is converted into a fraction of the total daily PV generation. The BESS is then charged throughout the day by this fixed fraction of the PV generation.

PV System and BESS Size Results

The PV system and BESS sizes derived from the proposed approach are listed in Table 3 through Table 5. PV system sizing results are provided for both PV only and PV with BESS scenarios because in certain instances, BESS are not cost-effective, and are not required, in which case only a PV system will be required. The PV system size for the PV-only case is smaller than that of the PV with BESS case since the PV-only case just meets the building loads, whereas the PV with BESS case has a larger PV system to charge the BESS after meeting the loads. Therefore, both PV-only and PV with BESS sizes are reported below.

TABLE 3: PROPOSED PV-ONLY SIZES [W/FT^2]

Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Exhibits & Events	1.49	1.23	1.10	1.39	1.25	1.08	1.38	1.19	1.02	1.76	1.36	1.16	1.48	1.27	1.18	1.07
Library	1.77	1.98	1.91	1.97	1.79	1.93	2.16	2.75	2.35	1.92	1.87	2.21	2.18	2.08	2.25	1.96
Religious Worship	0.72	1.01	0.68	0.78	0.73	0.60	0.82	0.95	0.66	1.10	0.91	0.83	0.62	0.71	1.04	0.62
Sports & Recreation	1.23	1.20	1.10	1.44	0.99	1.67	1.39	1.05	1.73	1.42	1.22	1.15	1.52	0.94	1.21	1.41
Large Office	2.96	2.73	2.66	2.74	2.65	2.99	2.67	2.77	2.65	3.09	2.85	2.76	3.31	2.80	2.96	2.33
Medium Office	3.15	2.76	2.87	3.05	2.85	2.74	3.02	3.60	3.29	3.32	3.01	3.11	3.17	2.87	3.93	3.36
Small Office	4.00	3.22	3.38	3.86	3.56	3.38	3.37	3.70	3.36	3.95	3.57	3.61	3.96	3.47	4.05	4.34
Restaurant	4.60	4.74	5.06	5.55	4.24	4.78	5.68	5.48	5.70	5.72	5.23	4.94	5.11	5.62	6.32	5.70
Large Retail	1.79	1.93	2.05	1.94	1.73	2.06	1.91	2.17	2.07	2.24	2.47	2.03	2.40	2.21	2.70	2.11
Medium Retail	2.28	2.09	2.04	1.93	2.08	2.15	2.07	2.42	2.65	2.35	2.55	3.06	2.33	2.30	2.90	2.11
Strip Mall	3.95	3.58	3.35	3.81	3.75	3.90	3.36	3.70	3.99	4.67	3.79	3.72	3.76	4.29	4.02	4.12
High School	0.72	0.50	0.46	0.79	0.52	0.83	0.60	1.02	1.01	1.20	1.43	0.67	1.45	1.72	2.63	0.54
K – 8 School	0.12	0.46	0.50	0.58	0.50	0.42	0.51	1.02	1.17	1.13	1.38	0.57	1.50	1.74	2.33	0.18
Large School	1.59	1.42	1.36	1.40	1.35	1.59	1.27	1.52	1.33	1.62	1.61	1.60	1.39	1.41	2.02	1.15
Warehouse	1.00	0.85	0.79	0.95	0.90	0.82	0.74	1.02	0.89	0.99	0.91	0.96	1.03	0.92	1.04	0.94

TABLE 4: PROPOSED PV SIZES FOR PV WITH BESS [W/FT^2]

Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Exhibits & Events	2.09	1.39	1.31	1.56	1.50	1.18	1.58	1.36	1.25	1.88	1.47	1.38	1.60	1.45	1.43	1.24
Library	1.82	2.52	2.43	2.48	2.34	2.35	2.54	3.25	3.07	2.59	2.82	2.96	2.89	2.42	2.94	2.17
Religious Worship	1.50	2.30	1.64	1.85	1.55	1.53	1.92	2.03	1.99	2.07	2.66	2.87	2.13	1.64	2.29	1.37
Sports & Recreation	1.80	1.89	1.63	2.32	1.63	1.75	2.22	1.86	2.30	2.02	2.06	1.79	1.88	1.64	2.09	1.97
Large Office	3.51	3.19	3.05	3.18	2.95	3.31	3.16	3.20	3.05	3.48	3.31	3.28	3.92	3.28	3.31	2.68
Medium Office	3.69	3.18	3.12	3.64	3.36	3.14	3.41	4.17	3.68	3.90	3.47	3.49	3.51	3.23	4.24	3.99
Small Office	4.80	3.70	3.72	4.50	4.24	3.98	3.87	4.28	3.85	4.44	4.17	4.20	4.47	3.99	4.77	4.93
Restaurant	5.72	5.80	6.15	6.71	5.31	6.00	7.19	6.78	6.75	6.92	6.24	5.93	6.33	7.00	8.07	7.57
Large Retail	2.37	2.51	2.58	2.39	2.33	2.50	2.47	2.75	2.63	2.82	3.14	2.61	3.06	2.73	3.38	2.77
Medium Retail	2.85	2.62	2.69	2.57	2.82	2.83	2.70	3.00	3.21	2.93	3.43	3.91	2.92	2.91	3.86	2.77
Strip Mall	4.68	4.35	4.34	4.87	4.71	4.70	4.04	4.67	5.11	5.56	4.62	4.58	4.75	5.21	5.11	5.27
High School	0.85	0.61	0.58	0.86	0.65	0.83	0.76	1.08	1.09	1.39	1.57	0.84	1.62	1.85	3.05	0.59
K - 8 School	0.22	0.49	0.50	0.67	0.56	0.44	0.52	1.06	1.22	1.48	1.56	0.73	1.80	1.85	2.85	0.23
Large School	1.92	1.78	1.68	1.68	1.62	1.92	1.54	1.82	1.60	1.90	1.88	1.89	1.65	1.70	2.30	1.37
Warehouse	1.26	1.01	0.95	1.22	1.14	0.99	0.96	1.28	1.12	1.21	1.15	1.18	1.34	1.17	1.23	1.10

TABLE 5: PROPOSED BESS SIZES [WH/FT²]

Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Exhibits & Events	1.44	1.53	1.52	0.90	1.53	0.99	1.39	1.14	1.57	1.38	1.84	1.71	1.60	1.58	1.64	1.43
Library	0.47	1.99	2.28	2.45	1.94	1.77	1.77	1.71	1.39	2.67	3.26	2.38	2.61	2.19	2.90	1.17
Religious Worship	3.95	4.81	4.39	5.11	3.84	4.33	4.50	4.34	4.95	4.44	5.60	4.29	4.64	4.97	4.84	3.73
Sports & Recreation	2.84	3.42	2.87	3.52	3.39	2.55	3.46	3.18	3.14	2.90	3.46	3.33	2.85	3.23	3.24	3.21
Large Office	2.11	2.02	1.89	1.98	1.65	1.68	2.13	1.90	1.93	1.77	1.75	2.33	2.11	2.18	1.87	1.81
Medium Office	2.31	1.93	1.54	2.87	2.30	1.96	1.87	2.17	1.84	1.87	2.06	1.76	1.72	1.87	1.34	2.84
Small Office	2.54	2.47	2.05	3.04	3.22	3.12	2.68	2.96	2.33	2.48	2.91	2.86	2.36	2.82	2.51	2.88
Restaurant	5.73	6.31	5.76	5.17	6.33	6.15	6.62	5.96	5.98	5.65	5.30	5.30	6.18	6.57	6.93	11.06
Large Retail	2.83	2.82	2.77	2.45	2.78	2.13	2.93	3.11	2.86	3.02	3.02	2.94	2.92	2.92	3.14	3.04
Medium Retail	2.85	2.67	3.26	3.44	3.40	3.42	3.32	3.09	3.04	3.16	3.92	4.90	2.74	2.94	4.10	3.63
Strip Mall	3.21	3.94	5.29	5.08	4.91	3.46	3.63	4.66	4.62	3.72	3.99	5.01	4.99	4.66	4.86	6.50
High School	0.62	0.49	0.50	0.50	0.59	0.34	0.66	0.46	0.63	1.76	1.59	0.86	1.78	1.15	2.02	0.26
K - 8 School	0.46	0.30	0.21	0.45	0.38	0.18	0.28	0.43	0.60	2.06	1.81	0.93	2.36	1.12	2.20	0.30
Large School	1.33	1.46	1.46	1.31	1.30	1.44	1.48	1.53	1.40	1.26	1.15	1.30	1.33	1.49	1.40	1.22
Warehouse	1.10	0.95	0.89	1.04	1.18	0.72	1.09	0.66	0.73	0.94	1.12	1.06	1.27	1.20	0.98	1.00

The ratio of the proposed requirement in the 2028 Energy Code to the current requirement in the 2025 Energy Code are listed in Table 6 through Table 8. Green entries indicate a smaller size than the current 2025 Energy Code requirement; blue entries indicate larger sizes than the current 2025 requirement. Entries labeled as "New" in the ratio tables indicate that there was no requirement for the 2025 Energy Code for comparison to the proposed sizing. A discussion of the size differences is provided in the next section.

TABLE 6: RATIO OF PROPOSED PV-ONLY SIZES TO 2025 ENERGY CODE SIZES

Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Exhibits & Events	43%	29%	30%	32%	33%	27%	32%	25%	22%	37%	27%	26%	30%	29%	22%	32%
Library	454%	61%	74%	61%	72%	70%	71%	79%	71%	52%	49%	67%	58%	62%	50%	69%
Religious Worship	17%	22%	19%	17%	20%	14%	18%	16%	12%	19%	15%	17%	11%	15%	14%	16%
Sports & Recreation	50%	61%	71%	71%	62%	91%	70%	40%	70%	55%	44%	52%	56%	44%	30%	78%
Large Office	114%	87%	103%	88%	102%	96%	85%	89%	85%	99%	91%	88%	106%	89%	78%	90%
Medium Office	122%	88%	111%	97%	110%	88%	96%	115%	105%	106%	96%	99%	101%	92%	103%	130%
Small Office	154%	103%	131%	123%	137%	108%	108%	118%	107%	126%	114%	115%	127%	111%	107%	168%
Restaurant	54%	51%	62%	58%	52%	55%	62%	54%	58%	56%	48%	51%	48%	58%	52%	67%
Large Retail	57%	55%	68%	54%	57%	63%	55%	57%	57%	59%	60%	56%	60%	60%	59%	66%
Medium Retail	73%	60%	68%	53%	68%	66%	60%	63%	73%	62%	62%	84%	58%	62%	63%	66%
Strip Mall	126%	103%	111%	106%	123%	119%	97%	97%	109%	123%	93%	102%	94%	116%	87%	128%
High School	57%	31%	36%	48%	41%	51%	37%	63%	62%	74%	88%	41%	89%	106%	107%	43%
K - 8 School	9%	28%	39%	36%	39%	26%	31%	63%	72%	69%	85%	35%	92%	107%	95%	14%
Large School	125%	87%	107%	86%	106%	98%	78%	93%	82%	99%	99%	98%	85%	87%	82%	91%
Warehouse	256%	193%	203%	216%	231%	186%	168%	232%	202%	225%	207%	218%	234%	209%	179%	241%

TABLE 7: RATIO OF PROPOSED PV SIZES TO 2025 ENERGY CODE SIZES FOR PV WITH BESS

Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Exhibits & Events	60%	32%	36%	36%	40%	29%	37%	28%	27%	39%	29%	31%	32%	33%	26%	37%
Library	467%	78%	94%	76%	94%	86%	84%	93%	92%	70%	74%	89%	76%	72%	65%	76%
Religious Worship	35%	49%	47%	41%	42%	36%	41%	34%	38%	37%	45%	58%	37%	35%	30%	35%
Sports & Recreation	73%	96%	106%	114%	102%	95%	112%	71%	93%	78%	75%	81%	69%	76%	52%	109%
Large Office	136%	102%	118%	102%	114%	106%	101%	102%	97%	111%	106%	105%	125%	105%	87%	103%
Medium Office	142%	102%	120%	116%	130%	100%	109%	133%	118%	125%	111%	112%	112%	103%	112%	154%
Small Office	185%	118%	144%	144%	164%	127%	124%	137%	123%	142%	133%	134%	143%	127%	126%	190%
Restaurant	67%	62%	75%	70%	65%	69%	79%	67%	69%	67%	58%	61%	59%	72%	66%	89%
Large Retail	75%	72%	86%	66%	76%	76%	72%	72%	72%	74%	77%	72%	77%	74%	73%	86%
Medium Retail	91%	75%	89%	71%	92%	86%	78%	78%	88%	77%	84%	107%	73%	78%	84%	86%
Strip Mall	149%	125%	144%	135%	154%	144%	117%	122%	140%	146%	113%	126%	119%	140%	111%	164%
High School	67%	37%	46%	53%	51%	51%	47%	66%	67%	85%	96%	52%	99%	113%	124%	46%
K - 8 School	17%	30%	39%	41%	44%	27%	32%	65%	75%	91%	96%	45%	110%	114%	116%	18%
Large School	151%	109%	132%	103%	128%	118%	94%	112%	98%	117%	115%	116%	101%	104%	94%	108%
Warehouse	323%	230%	244%	277%	292%	225%	218%	291%	255%	275%	261%	268%	305%	266%	212%	282%

TABLE 8: RATIO OF PROPOSED BESS SIZES TO 2025 ENERGY CODE SIZES

Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Exhibits & Events	71%	70%	78%	38%	71%	41%	55%	44%	59%	50%	63%	70%	54%	52%	45%	67%
Library	112%	25%	34%	32%	31%	26%	25%	21%	17%	31%	40%	31%	34%	29%	33%	16%
Religious Worship	159%	190%	224%	188%	164%	140%	136%	115%	139%	117%	139%	140%	114%	138%	88%	140%
Sports & Recreation	200%	311%	338%	275%	349%	189%	251%	181%	183%	157%	168%	233%	136%	184%	96%	253%
Large Office	New	34%	39%	34%	34%	28%	36%	32%	33%	30%	30%	39%	36%	37%	26%	37%
Medium Office	New	33%	31%	49%	47%	33%	32%	37%	31%	32%	35%	30%	29%	32%	19%	58%
Small Office	New	42%	42%	51%	66%	53%	45%	50%	39%	42%	49%	48%	40%	48%	35%	59%
Restaurant	117%	137%	136%	105%	145%	136%	143%	118%	119%	104%	93%	106%	109%	112%	99%	239%
Large Retail	134%	138%	144%	120%	144%	105%	148%	144%	129%	131%	121%	134%	120%	114%	105%	141%
Medium Retail	134%	131%	170%	169%	176%	169%	168%	143%	138%	138%	157%	224%	113%	115%	137%	169%
Strip Mall	151%	193%	276%	249%	254%	171%	183%	216%	209%	162%	160%	229%	205%	181%	163%	302%
High School	New	14%	19%	15%	22%	10%	19%	13%	18%	51%	46%	25%	52%	34%	39%	10%
K - 8 School	New	9%	8%	13%	14%	5%	8%	13%	17%	60%	53%	27%	69%	33%	43%	11%
Large School	New	43%	55%	38%	49%	42%	43%	45%	41%	37%	34%	38%	39%	43%	27%	46%
Warehouse	New	207%	212%	226%	281%	157%	237%	143%	159%	204%	244%	230%	276%	261%	161%	238%

Seasonal Median-Load-Day Minimum

Discussion

As shown in Table 6 through Table 8, the proposed approach's PV system and BESS sizes varied relative to the 2025 Energy Code. An investigation of the causes of these differences is discussed below. The discussions are divided into various phenomena. These phenomena could be applicable to a building prototype, to a climate zone, or to combinations of building prototype and climate zone.

PV-Only Sizing

Meeting Load of Seasonal Median-Load-Day Minimum Versus Meeting Total Annual Load with Export Limits: Because the proposed approach targets meeting, at least, the lowest Seasonal Median-Load-Day Minimum, not meeting the total annual loads with export limits, the proposed sizes are generally smaller than the current standards. The differences between the magnitude of PV generation for the previous approach versus the proposed approach for the medium retail building prototype in climate zone 3 for the same day is provided in Figure 3 and Figure 4, which shows that the proposed sizes are smaller. This trend was true for most of the results.

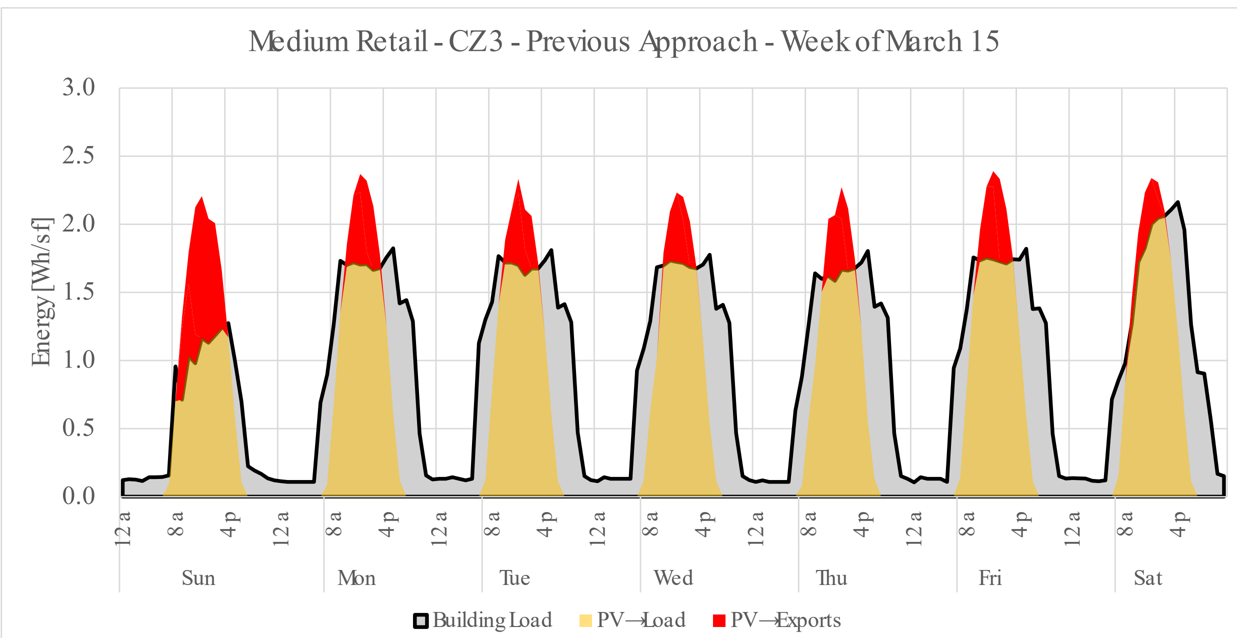

FIGURE 3: EXAMPLE OF PV ONLY SIZING BY PREVIOUS APPROACH EXCEEDING SEASONAL MEDIAN-LOAD-DAY MINIMUMBUILDING LOADS

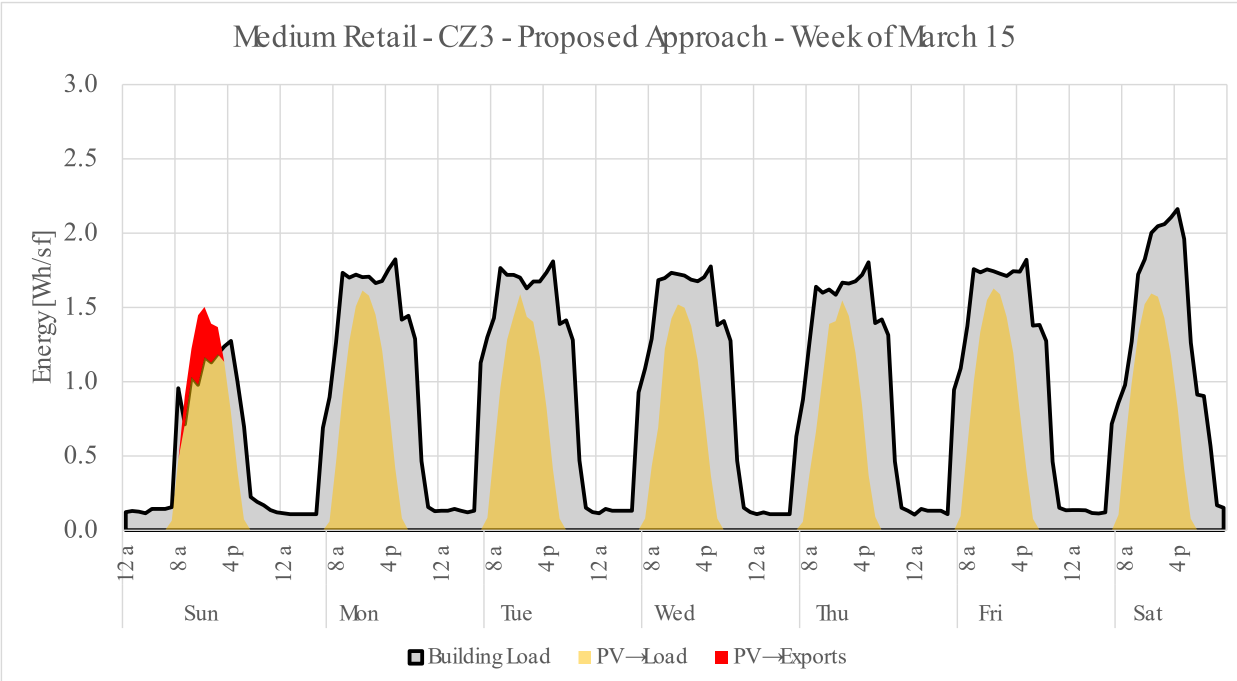

FIGURE 4: EXAMPLE OF PV ONLY SIZING BY PROPOSED APPROACH MEETING SEASONAL MEDIAN-LOAD-DAY MINIMUMBUILDING LOADS

Weekend Export-limiting versus Weekday Load-Matching: In certain cases, the 2025 Energy Code sizing approach resulted in almost 100% self-utilization of the annual hourly building loads during weekdays with exports occurring almost exclusively on the weekends. As a result, the export limit on the PV size was solely impacted by the building's consumption during the weekend and was not responsive to variation in the building's consumption during weekdays. That is, the building's consumption during the weekdays could exceed the PV generation by a significant amount due to the annual hourly building loads and the previous approach would arrive at the same size to limit the weekend exports. An example for the small office prototype in climate zone 3 is provided in Figure 5. Monday through Friday PV generation is well below the prototype load so self-utilization is 100 percent.

In contrast, the proposed approach for these cases is characterized by Seasonal Median-Load-Day Minimum for weekday hours of PV generation. The proposed approach focuses on meeting a seasonal typical weekday load, resulting in sizes that are higher than the previous approach in certain cases. An example is provided in Figure 5 for comparison with Figure 6.

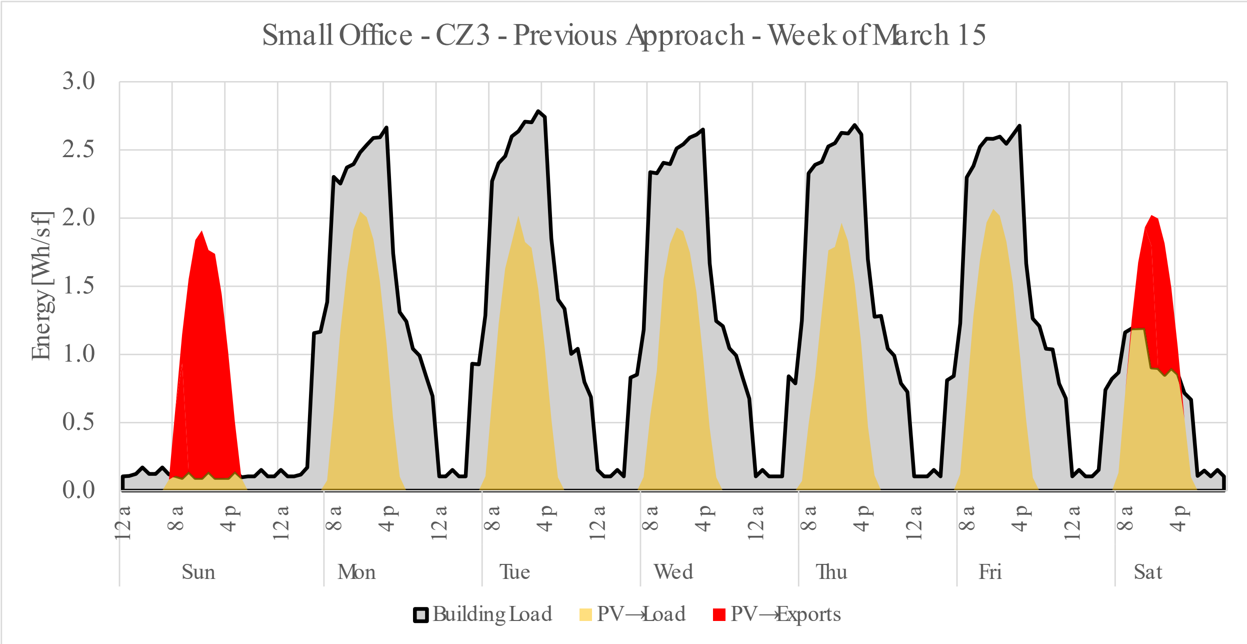

FIGURE 5: EXAMPLE OF PREVIOUS APPROACH WHERE PV GENERATION DOES NOT MEET WEEKDAY LOADS DUE TO WEEKEND EXPORT CONSTRAINTS

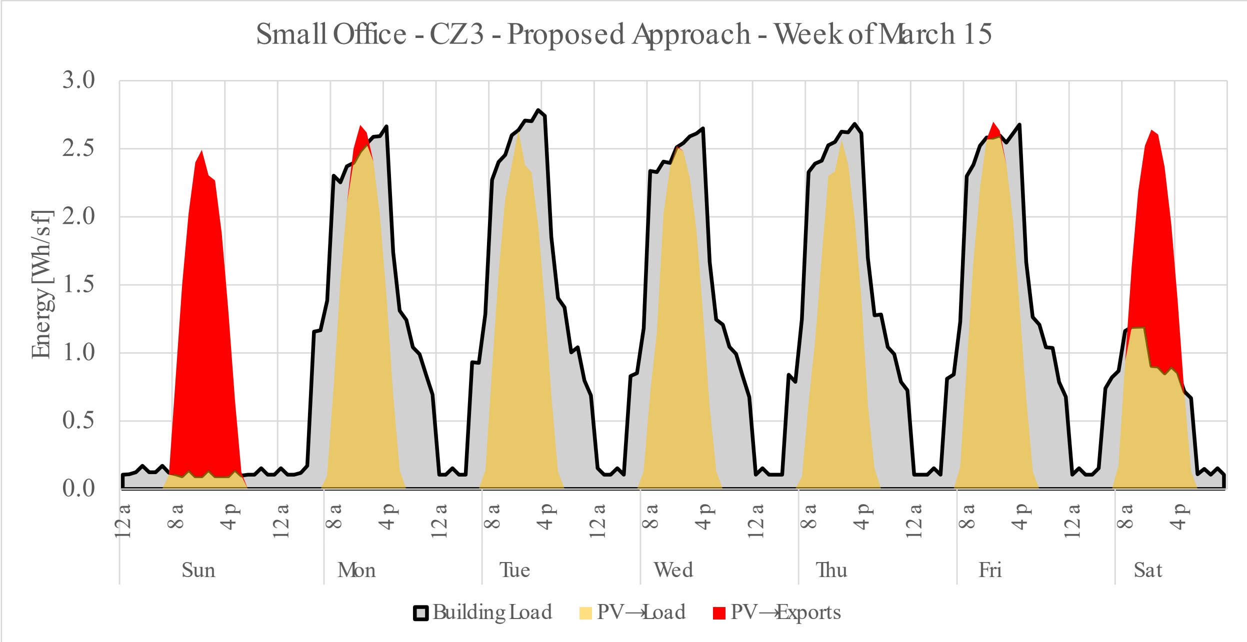

FIGURE 6: EXAMPLE OF PROPOSED APPROACH SIZED TO MEET WEEKDAY LOADS

Apart from the remaining cases mentioned in this section, this phenomenon accounted for the cases in the retail and warehouse prototypes where the proposed approach's sizing as shown in Table 6 was larger than the current requirement.

Libraries in Climate Zone 1: The previous requirement for libraries in climate zone 1 was based on the 2022 Energy Code (Athalye et al., 2021)(Saeed, Pennington, & Daemi, 2024). Libraries were placed in a category which included many building types and used the sizing from the Warehouse prototype's analysis. The Warehouse prototype had the lowest requirement (0.39 W/sf) of all the prototypes that were analyzed at the time of that analysis.

Since then, a Library prototype was developed. The Library prototype was analyzed for the 2025 Energy Code cycle where cost-effective revisions to the sizing were found for all climate zones except for climate zone 1 (Saeed, Pennington, & Daemi, 2024). So, the 2022 requirement of 0.39 W/sf in climate zone 1 remained for the 2025 Energy Code.

In the proposed analysis, the sizing for climate zone 1 is similar to that of the other climate zones. It is only in comparison to the previous requirement that the sizing seems to be an outlier.

Offices: PV system sizes for all office prototypes were different than the current PV system sizes. Figure 7 shows the ratio of PV system size for the proposed Seasonal Median-Load-Day Minimum-Matching approach compared with the 2025 Total Annual Load with Export Limits approach for all office prototypes and all climate zones. Figure 7 bins this data into ranges and shows the frequency of cells in Figure 7 (number of cells divided by total number of cells in Table 6) in each PV size ratio.

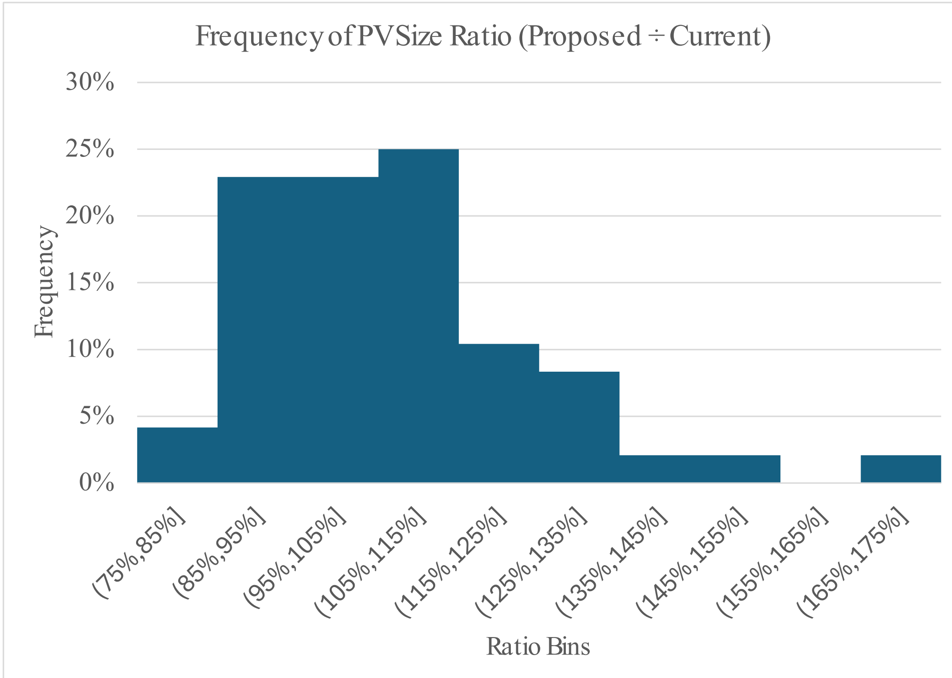

FIGURE 7: HISTOGRAM OF PV SIZE RATIOS COMPARING SIZES UNDER PREVIOUS AND PROPOSED APPROACHES ACROSS ALL CLIMATE ZONES AND ALL OFFICE PROTOTYPES

Where the results are smaller than the size in the current standards, trends are as described in the Meeting Load of Seasonal Median-Load-Day Minimum Versus Total Annual Load with Export Limits section. Where the results are near the current size, the differences between the two methodologies netted to similar sizes (71% of the proposed PV system sizes were within 15% of the current PV standards). The trends in Figure 8 and Figure 9 show for a medium office building in climate zone 12 that when the previous and proposed methodologies resulted in similar PV system sizes, the size of PV system that meets annual hourly loads and limits exports to 20 percent of generation happens to follow closely the size of PV system that meets the load of the seasonal median-load-day minimum during the week.

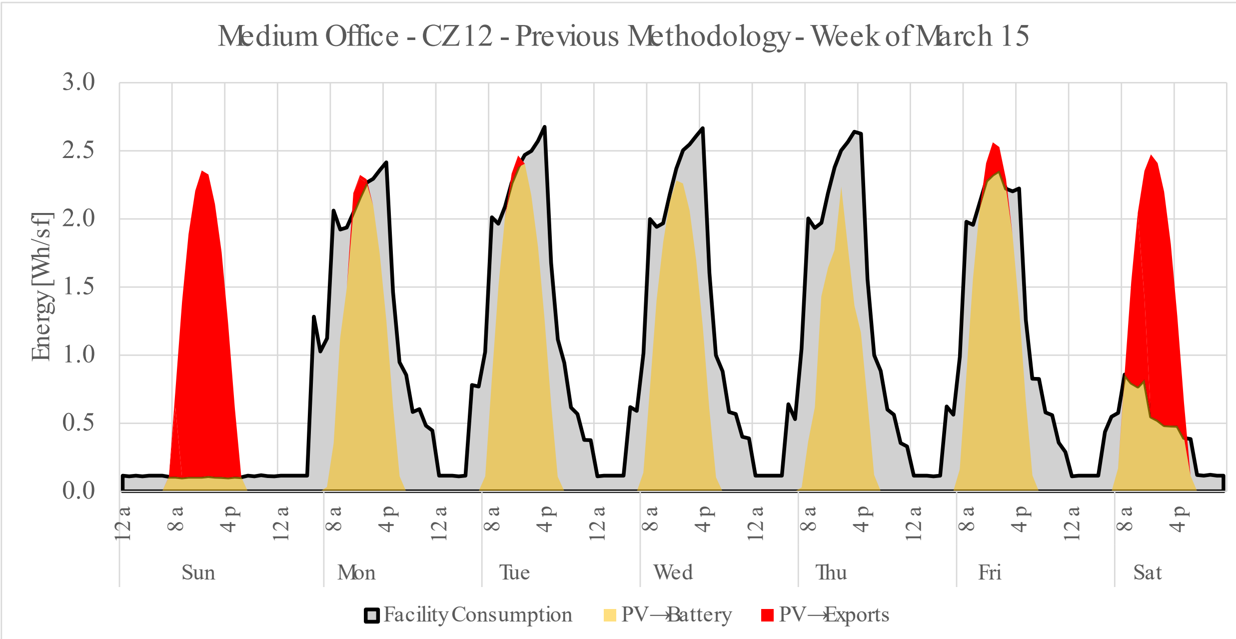

FIGURE 8: EXAMPLE OF PREVIOUS APPROACH RESULTING IN SIMILAR PV SIZE TO THE PROPOSED APPROACH

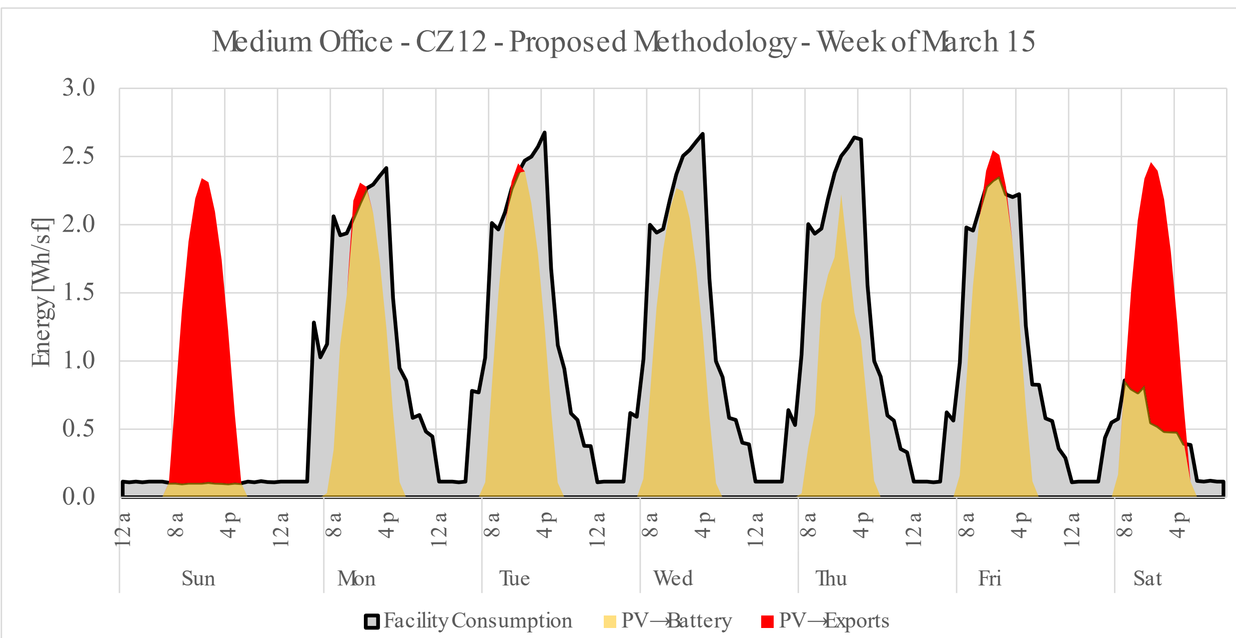

FIGURE 9: EXAMPLE OF PROPOSED APPROACH RESULTING IN SIMILAR PV SIZE TO THE PREVIOUS APPROACH

Strip Mall: The Strip Mall prototype has higher loads than the other retail prototypes. The strip mall prototype is comprised of small stores which have negligible storage, office, and support spaces in contrast to large and medium retail stores. Therefore, a strip mall store's lighting and equipment load densities are higher overall for the building. In addition, the spaces are small enough that they are allowed by the Energy Code to use constant-volume heating, ventilation and air conditioning (HVAC) equipment, in contrast to large and medium retail buildings which are required to have variable-air volume systems. Table 9 lists the portion of space types by prototype. Because of these higher loads, the Strip Mall has larger per square foot PV system and BESS standards compared to other retail prototypes.

TABLE 9: INTERIOR LOADS BY SPACE TYPE IN RETAIL PROTOTYPES

Space Type	Large Retail	Medium Retail	Strip Mall	LPD [W/sf]	EPD [W/sf]
Retail Sales Area (Retail Merchandise Sales)	68%	83%	100%	0.95	1
Office Area (>250 square feet)	1%	-	-	0.6	1.5
Storage, Commercial/Industrial (Warehouse)	19%	17%	-	0.4	0.2
Lobby, Main Entry	8%	1%	-	0.7	0.5
Restrooms	3%	-	-	0.65	0

Schools in Warmer Climate Zones: For K-8 and high schools, the previous 2025 Energy Code analysis was different in two ways. It used the Small School prototype rather than the K-8 and high school prototypes used for the proposed approach, and it used the Total Annual Load with Export Limits approach for sizing PV.

Using the proposed approach of meeting the load of the seasonal median-load-day minimum rather than the Total Annual Load with Export Limits under the 2025 approach, the net effect was that for most climate zones the PV sizing was reduced, but for a few cases it increased. Figure 10 and Figure 11 illustrate the case for a small school in climate zone 15 where the proposed approach's PV system sizing is larger than the previous approach. What effectively happens is that the summer loads are significant enough to require a larger size than is required under the previous 2025 Total Annual Load with Export Limits approach.

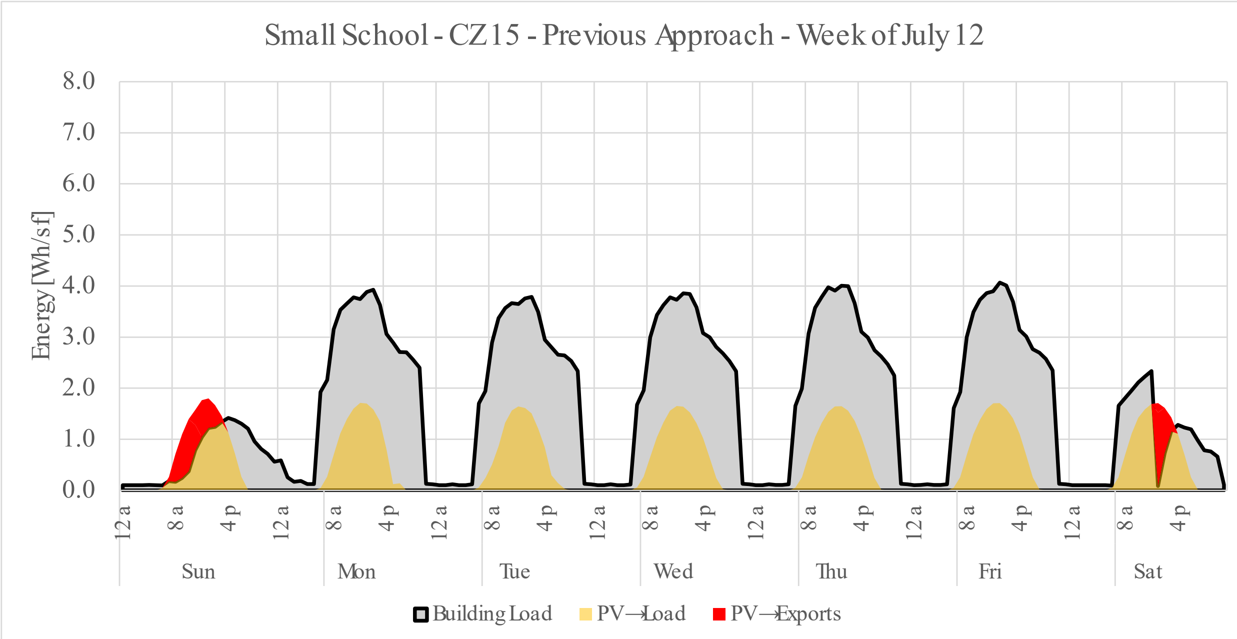

FIGURE 10: EXAMPLE OF PREVIOUS APPROACH FOR PV SIZING IN SCHOOLS IN WARMER CLIMATE ZONES

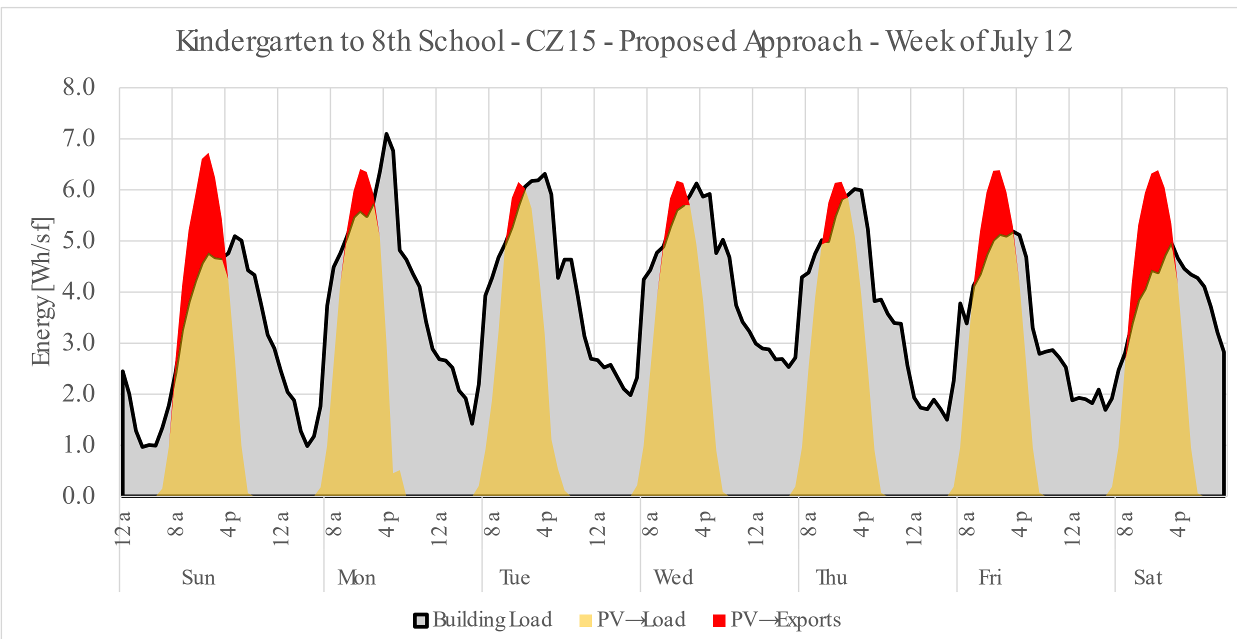

FIGURE 11: EXAMPLE OF PROPOSED APPROACH FOR PV SIZING IN SCHOOLS IN WARMER CLIMATE ZONES

PV with BESS Sizing

To understand the BESS sizing differences between the previous Total Annual Load with Export Limits approach and the proposed Seasonal Median-Load-Day Minimum-Matching approach, an evaluation of cases is discussed below. Note that the previous approach used different round-trip efficiency, and timing for BESS charge and discharge.

About half of the prototypes had reduced BESS size and the other half had increased BESS size.

Previous Total Annual Load with Export Limits approach versus Proposed Seasonal Median-Load-Day Minimum approach: Under the proposed approach, exhibit and event spaces, libraries, offices, and schools had smaller BESS sizes than the previous 2025 Energy Code approach. They had seasonal median-load-day minimum weekday loads during BESS discharge hours that were less than the annual hourly loads with limited exports in the previous 2025 Energy Code approach. Figure 12 and Figure 13 illustrate an example of this for a small office in climate zone 3. The difference in ranges for the BESS State of Charge is representative of the difference in BESS size between the two approaches.

The 2025 Energy Code BESS requirement for office in climate zone 3 equates to a maximum state of charge of ~3.9 W/sf[5]. In Figure 12, the BESS achieves its maximum state of charge on Sunday morning, and the system exports PV generation during Sunday. The BESS discharges to ~3.6 W/sf on Sunday evening, and then discharges to its minimum state of charge, ~1.0 W/sf, during the time-of-use period on Monday. The BESS remains at this minimum state of charge until Saturday morning, when it is charged to its maximum state of charge again.

In contrast, in the proposed approach shown in Figure 13, the maximum state of charge is ~1.7 W/sf and the BESS charges and discharges during each weekday.

[5] Minimum rated usable battery capacity is defined by Equation 140.10-C in the 2025 Energy Code. For a battery for an office in climate zone 12 with 80% round trip efficiency, the minimum rated usable energy capacity is ~4.7 W/sf.

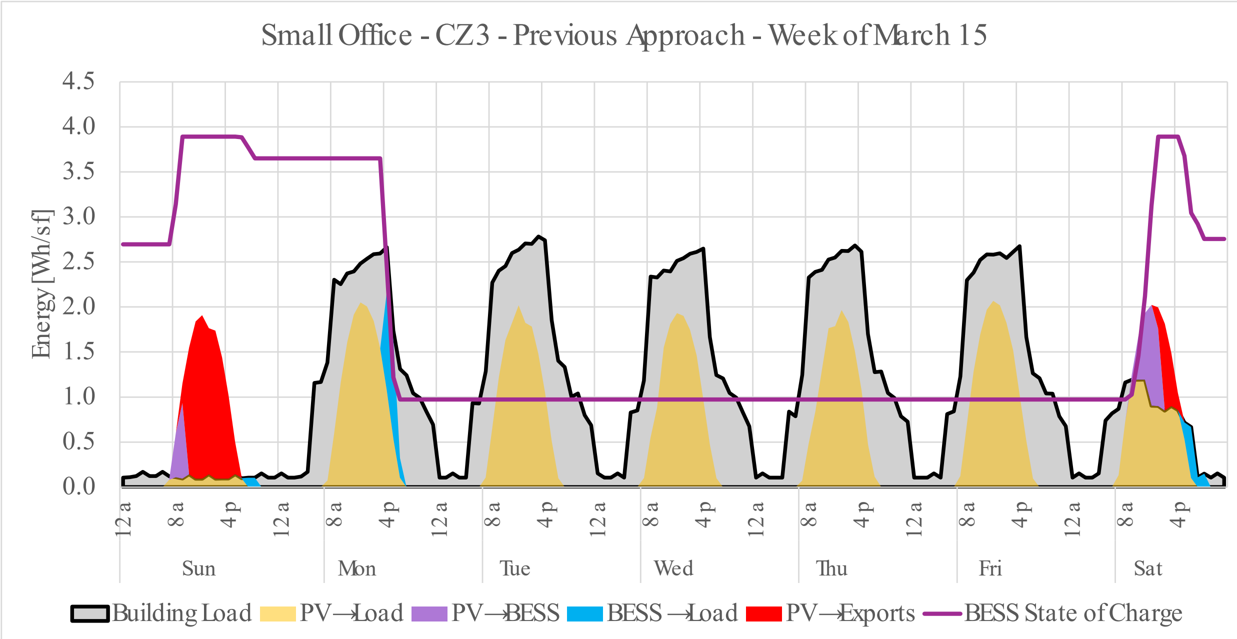

FIGURE 12: EXAMPLE OF BESS UTILIZATION WHEN LIMITING WEEKEND EXPORTS UNDER PREVIOUS APPROACH

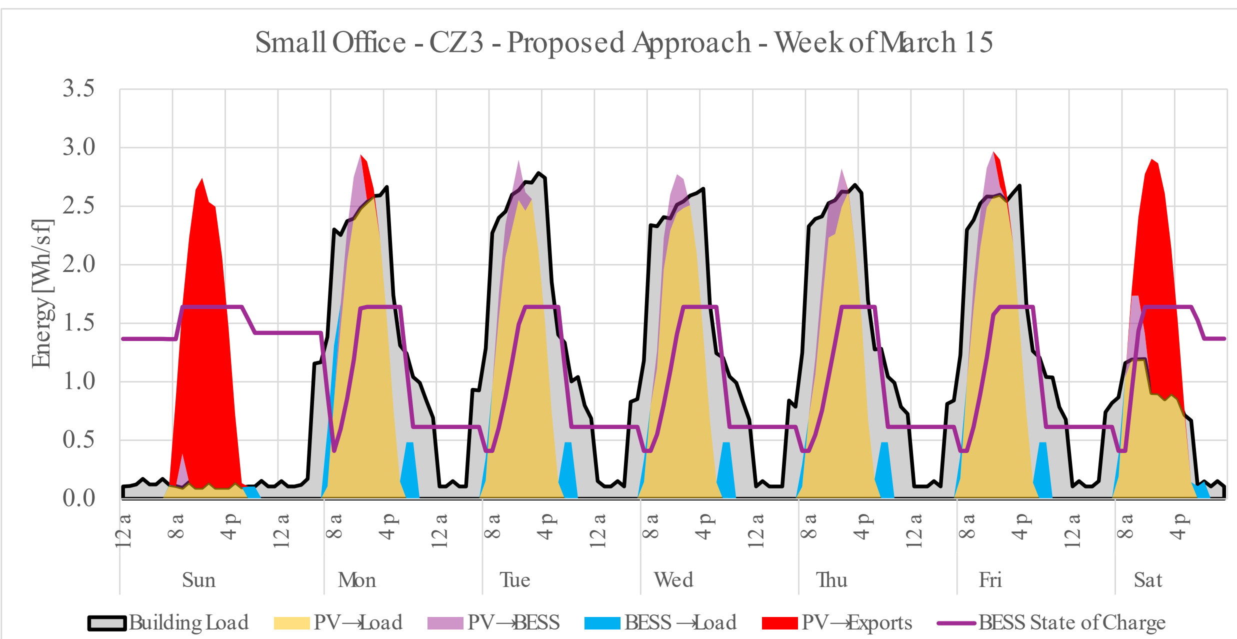

FIGURE 13: EXAMPLE OF BESS UTILIZATION WITH WEEKDAY LOAD MATCHING UNDER PROPOSED APPROACH

Morning- and Evening-Loaded Occupancies: For retail and restaurant occupancies there are substantial loads in the evenings. For sports and recreation and religious worship[6] occupancies, there are substantial loads in the evenings and mornings.

The previous 2025 Total Annual Load with Export Limits approach based the BESS size on limiting the exports from a PV system that generates more energy than the load during the day. The proposed seasonal typical minimum weekday load-matching approach instead sizes the BESS to meet these evening and night loads when PV generation is not available. The net outcome for these occupancies is that batteries are larger for the proposed approach and better match the building's needs.

Examples of these cases for a medium retail building in climate zone 3 are shown in Figure 14 and Figure 15.

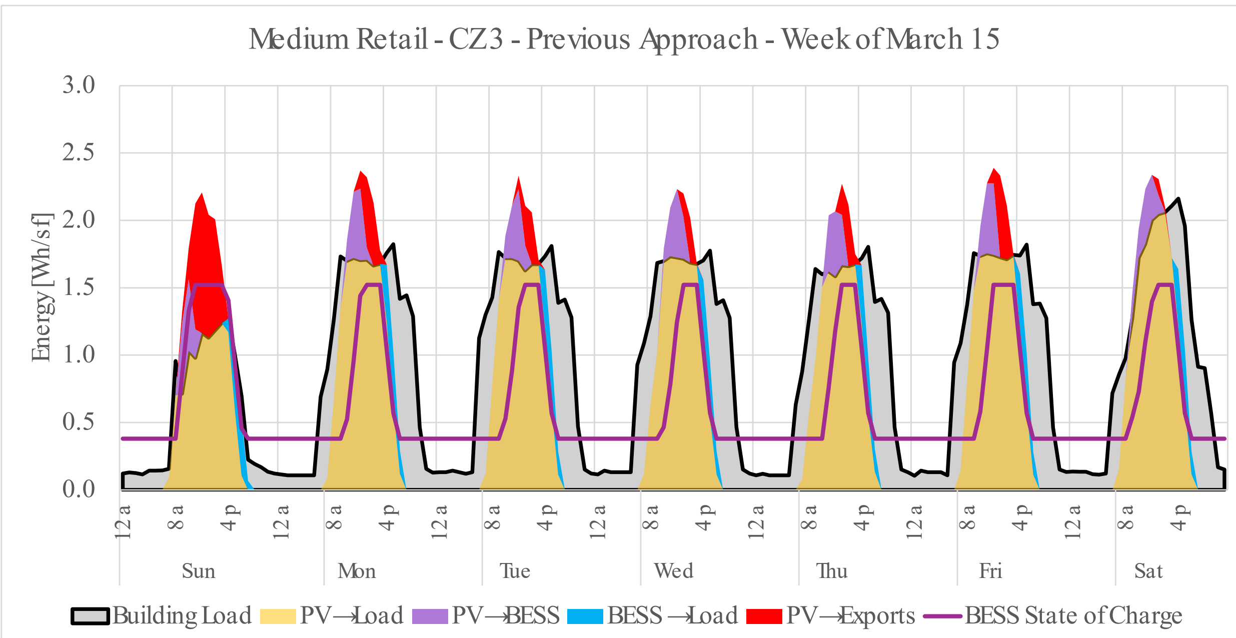

FIGURE 14: EXAMPLE OF BESS UTILIZATION IN EVENING-LOADED OCCUPANCY UNDER PREVIOUS APPROACH

[6] Religious worship spaces in California were found to regularly have weekday- and weekend-evening services. (Shadd, Dabbagh, & Athalye, 2025)

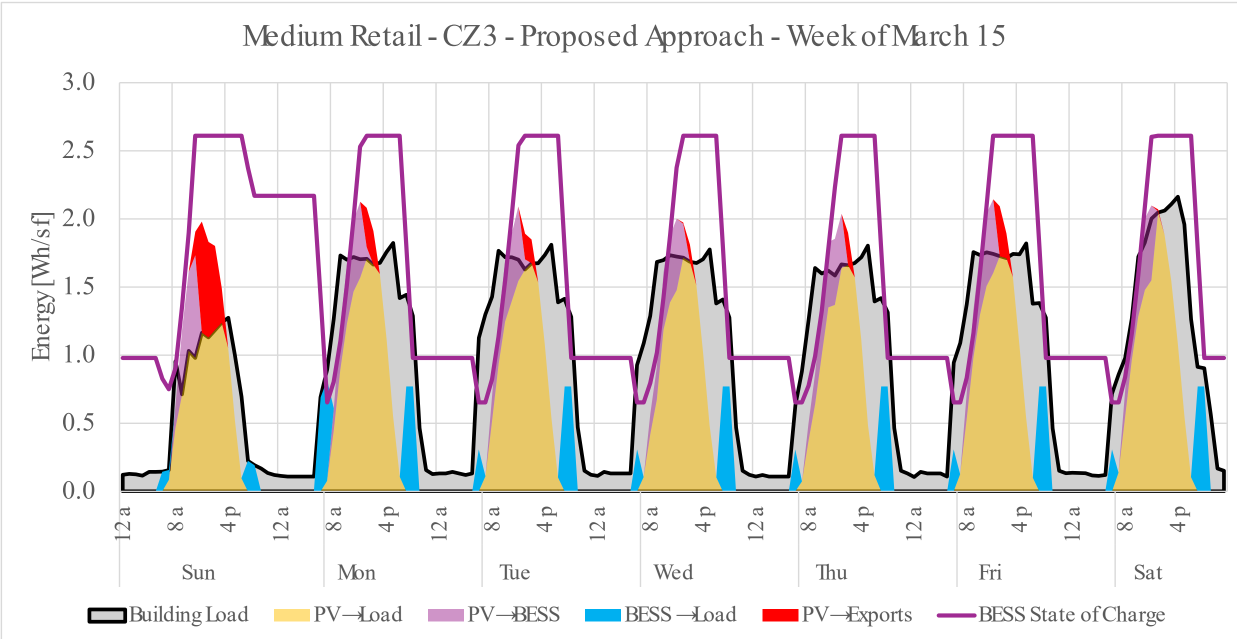

FIGURE 15: EXAMPLE OF BESS UTILIZATION IN EVENING-LOADED OCCUPANCY UNDER PROPOSED APPROACH

The 2025 Energy Code building prototypes for Religious Worship and Sports and Recreation were characterized by continuous loads from morning until night with a high peak. In contrast, the revised prototypes have peak occupancies in the morning, evening, and weekends, with low occupancy during the day (Shadd, Dabbagh, & Athalye, 2025).

The previous Total Annual Load with Export Limits approach with the 2025 Energy Code prototypes only required diverting PV power to the BESS during the morning hours to limit exports. The new prototypes with the proposed seasonal typical minimum weekday load-matching approach charges the BESS during the day to meet the evening, and part of the morning loads.

The net effect is that a BESS to limit exports for the previous prototype was smaller than one to meet the peak loads of the new prototype. An example of this for the Religious Worship prototype in climate zone 12 is shown in Figure 16 and Figure 17. The Sports and Recreation prototype performed very similarly.

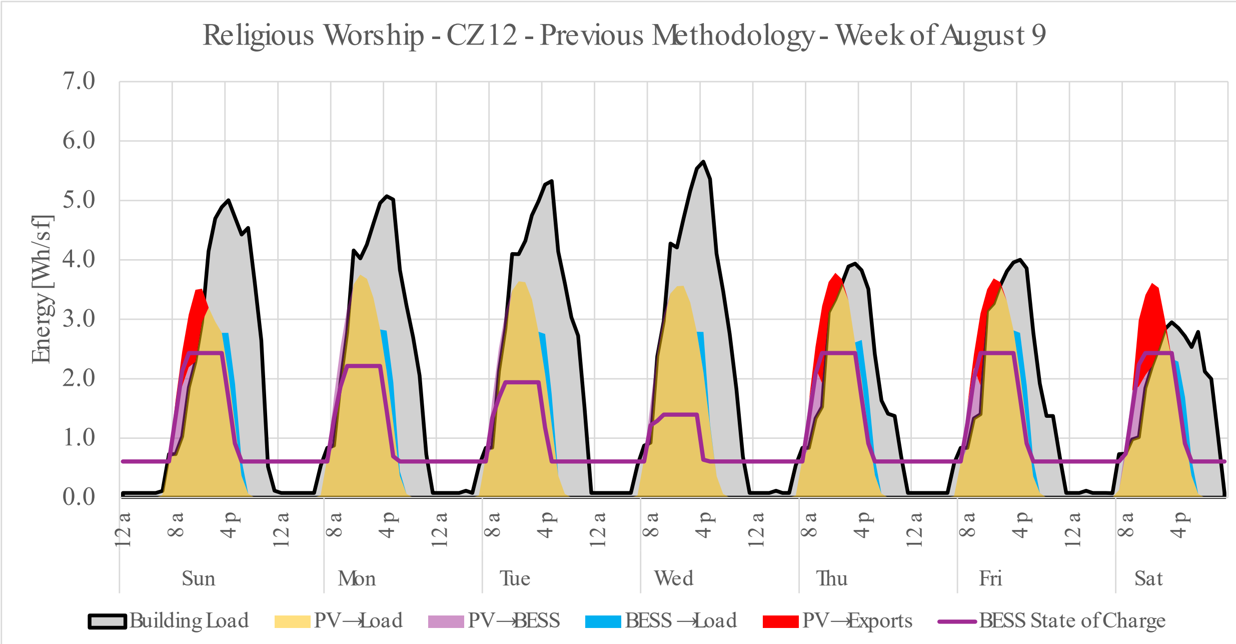

FIGURE 16: EXAMPLE OF BESS UTILIZATION IN MORNING- AND EVENING-LOADED OCCUPANCY UNDER PREVIOUS APPROACH

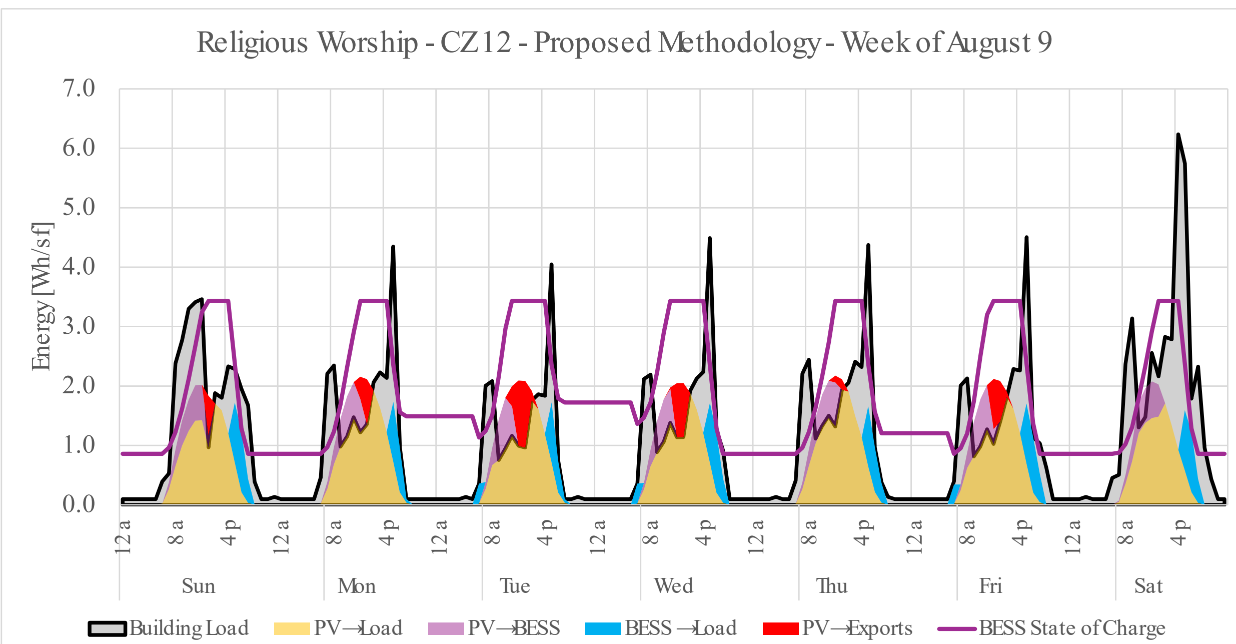

FIGURE 17: EXAMPLE OF BESS UTILIZATION IN MORNING- AND EVENING-LOADED OCCUPANCY UNDER PROPOSED APPROACH

Warehouse: Warehouse exports for the previous Total Annual Load with Export Limits approach occurred on the weekends so the BESS was sized to limit those exports and only discharged on Monday. With the proposed Seasonal Typical Minimum Weekday Load-Matching approach, the BESS discharge targets the high morning-hour consumption and cycles every weekday. This is shown for a warehouse in climate zone 3 in Figure 18 and Figure 19.

The net effect is that the proposed approach results in a larger BESS.

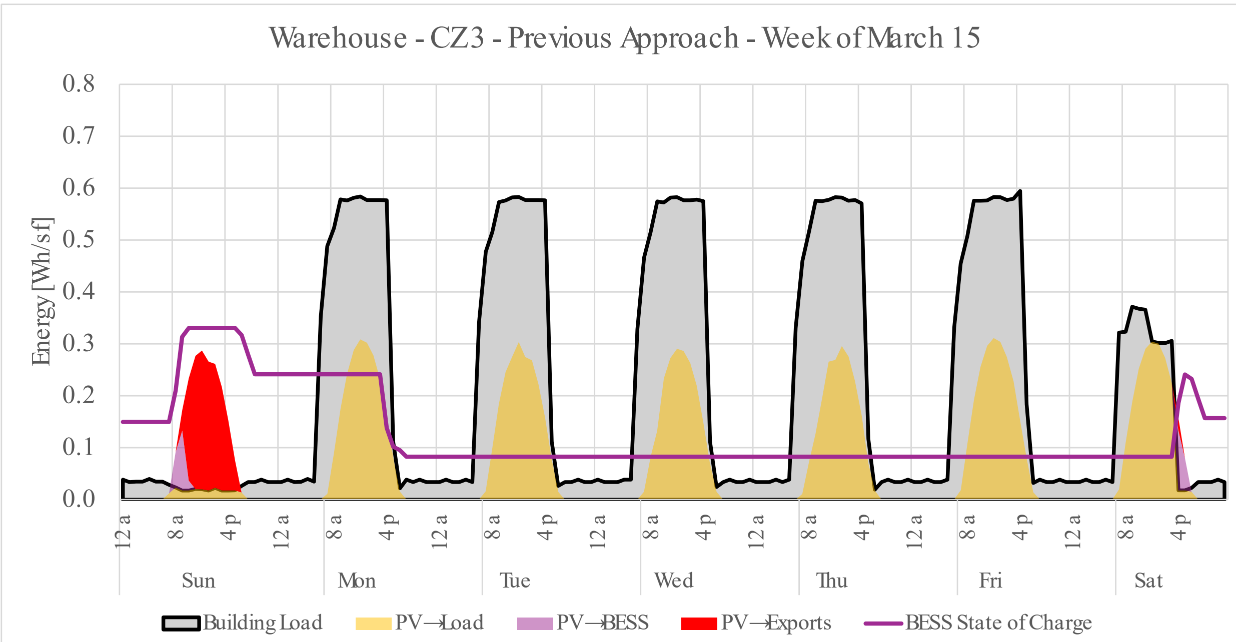

FIGURE 18: EXAMPLE OF BESS UTILIZATION IN PREVIOUS APPROACH FOR WAREHOUSE

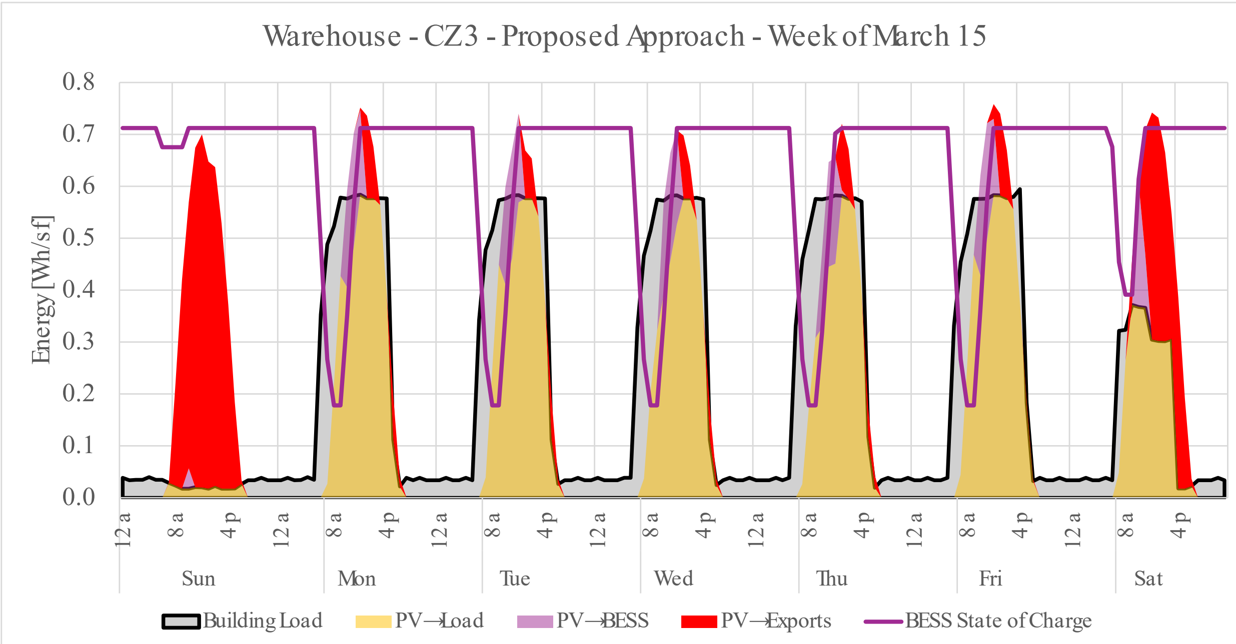

FIGURE 19: EXAMPLE OF BESS UTILIZATION IN PROPOSED APPROACH FOR WAREHOUSE

COST-EFFECTIVENESS ANALYSIS

PV AND BESS INSTALLED COST

The costs for PV and commercial BESS for the 2028 Energy Code were updated from the latest available published studies from the National Lab of the Rockies (NLR, formerly NREL), which were based on analysis of NEM interconnect data and other sources (Cole, 2025) (Feldman, 2025). These studies provided costs up to year 2024. A Solar Energy Industries Association report (Solar Energy Industries Association, 2026) stated that commercial PV system costs had risen by 10% from 2024 to 2025, and therefore, a 10% adjustment was applied to the 2024 costs. We request input on how California costs may vary from nationwide costs.

ITC cost reductions were excluded from the cost analysis. Inverter costs, maintenance costs, and replacement costs for the inverters were included in the analysis. The PV panels are expected to have a 30-year life, whereas inverters are expected to have a 10-year life with two replacements in the 30-year analysis period.

PV System Cost

For PV system cost as a function of system capacity (kW), the study applies results for median PV system costs (Feldman, 2025), summarized in Table 10 below. The first cost of a standalone PV system without BESS storage, adjusted for inflation to 2029 dollars, is shown in Table 11 in the Inflation Adjustment column. The life-cycle cost estimates for PV include two inverter replacements over the 30-year measure life and include a modest maintenance budget for panel cleaning.

TABLE 10: MEDIAN COMMERCIAL PV SYSTEM COSTS, 2024$

System Range	DC System Size	Median Cost
2.5-10 kW	6.25	$4.27
10-100 kW	55	$3.70
100-500 kW	300	$2.72
500 kW-1 MW	750	$2.06
1-5 MW	3000	$1.76

Photovoltaic system installation costs can be shared with commercial BESS costs when the two systems are installed together. NLR (Ramasamy, 2022) estimates that due to reduced labor costs, the total installation cost for a combined PV and BESS can be reduced by as much as 20%. For this study, a 15% reduction in installation costs was used. For PV systems installed with commercial BESS, the lifecycle costs are shown in Table 12 below.

TABLE 11: COMMERCIAL STANDALONE PV LIFE-CYCLE COSTS ($/W)

	Base Price	Customer Acquisition Cost Adjustment	2024-2029 Price Forecast	Inflation Adjustment	Inverter Cost	Maintenance Cost	Total Cost
Capacity, kW	2024 (2024 $)	2024 (2024 $)	2029 (2029 $)	2029 (2029 $)	2029 (2029 $)	2029 (2029 $)	2029 (2029 $)
5	4.78	4.60	5.10	5.91	0.20	0.059	$6.171
10	4.30	4.12	4.59	5.32	0.20	0.029	$5.546
25	3.74	3.56	3.99	4.62	0.20	0.012	$4.833
50	3.36	3.18	3.59	4.16	0.20	0.006	$4.362
75	3.16	2.98	3.37	3.91	0.20	0.004	$4.110
100	3.02	2.84	3.23	3.74	0.20	0.003	$3.941
200	2.72	2.54	2.90	3.36	0.20	0.001	$3.563
500	2.36	2.18	2.52	2.92	0.20	0.001	$3.123
1000	2.12	1.94	2.27	2.63	0.20	0.000	$2.828
5000	1.66	1.48	1.77	2.05	0.20	0.000	$2.254

Columns: Customer Acquisition Cost Adjustment deducts $0.18/W for avoided customer acquisition costs for newly constructed buildings; 2024-2029 price forecast applies SEIA 2024-2025 cost adjustment and NRL conservative[7] forecast from 2025-2029; Inflation Adjustment applies 3.0% annual inflation adjustment.

TABLE 12: PV LIFE-CYCLE COSTS, AC-COUPLED WITH BESS ($/W)

	PV Standalone Cost	PV Cost With PV/BESS Combined Discount	Inverter Cost	Maintenance Cost	Total Cost
Capacity, kW	2029 (2029 $)	2029 (2029 $)	2029 (2029 $)	2029 (2029 $)	2029 (2029 $)
5	5.91	5.03	0.20	0.059	$5.284
10	5.32	4.52	0.20	0.029	$4.749
25	4.62	3.93	0.20	0.012	$4.140
50	4.16	3.53	0.20	0.006	$3.739
75	3.91	.3.32	0.20	0.004	$3.524
100	3.74	3.18	0.20	0.003	$3.380
200	3.36	2.86	0.20	0.001	$3.059
500	2.92	2.48	0.20	0.001	$2.684
1000	2.63	2.23	0.20	0.000	$2.434
5000	2.05	1.75	0.20	0.000	$1.946

[7] NLR’s “Conservative” solar photovoltaic (PV) cost projection model assumed "business-as-usual." Technology improves incrementally, but no massive transformative breakthroughs or regulatory leaps take hold.

Commercial BESS Costs

Commercial BESS costs were updated from forecasts for BESS storage (Cole, 2025) and removed the customer acquisition costs (Ramasamy, 2022) as was done in previous cost-effectiveness studies (Saeed, Pennington, & Daemi, 2024). For this current study, to determine costs for BESS smaller than 100 kWh, equipment costs of commercial batteries on the market were used, primarily the Enphase 10 kWh BESS (Solartech, 2025), with a 20% contractor markup. Figure 20 shows the trend of first cost versus capacity for these BESS sizes. Installation costs for the small commercial BESS category were $7,000 for the 10 kWh system and an additional $2,000 for each 10 kWh cost increment (Solartech, 2025).

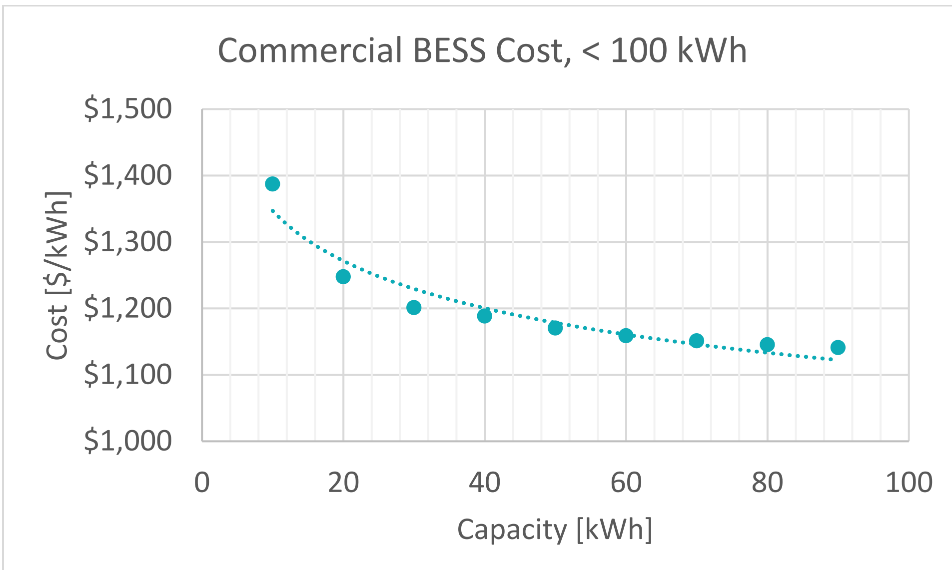

FIGURE 20: SMALL COMMERCIAL BESS COSTS

A fixed adjustment for avoided customer acquisition cost (Ramasamy, 2022) was applied and the moderate price forecast from NLR (Feldman, 2025) was used to forecast prices to 2029. The moderate forecast was selected due to the observed rapid drop in 4-hour storage prices in recent years (Bloomberg NEF, 2026).

The commercial BESS storage lifecycle cost incorporates replacements of the BESS cells every 10 years. Discounted costs after ten years and twenty years after the initial installation were applied. The replacement installation also applies an 18% reduction in labor costs for the replacement, based on NLR (formerly NREL) estimates. Table 13 shows the standalone BESS first costs for commercial BESS.

Table 14 shows first costs and life-cycle costs for commercial batteries coupled with PV systems. As discussed above, installation of BESS with a PV system reduces the installed cost by 15% (shown in the column PV-Coupled BESS Discount). The installation costs for replacement batteries are lower because not all hardware needs replacement – only the BESS cell packs are replaced.

TABLE 13: COMMERCIAL STANDALONE BESS FIRST COSTS, $/KWH (NO REPLACEMENT COSTS INCLUDED)

	BESS First Cost	CAC Adjustment	2026-2029 Price Forecast	First Cost
Capacity, kWh	2026 $	2029 $	2029$	2029$
10	1240	$926	822	898
20	990	$833	739	808
30	906	$802	712	778
40	865	$786	698	763
50	840	$777	690	754
60	823	$771	684	748
70	811	$766	680	743
80	802	$763	677	740
90	795	$760	675	738
100	569	$538	477	521
200	512	$496	440	481
500	445	$438	389	425
1,000	400	$397	352	385
5,000	313	$312	277	303
10,000	281	$281	249	273

Note: CAC – Customer acquisition cost

TABLE 14: COMMERCIAL PV-COUPLED BESS LIFECYCLE COSTS ($/KWH)

Capacity, kWh	BESS First Cost	CAC Adjust.	2026-2029 Price Forecast	Prevailing Wage Adjust.	Standalone BESS Cost	PV-Coupled BESS Discount	Repl. BESS Cost	Lifecycle BESS Costs
	2026 $	2026 $	2029$	2029$	2029$	2029 $[1]	2029 $	2029 $
10	1240	926	822	822	898	763	624	1,387
20	990	833	739	739	808	687	561	1,248
30	906	802	712	712	778	661	540	1,201
40	865	786	698	698	763	648	530	1,188
50	840	777	690	690	754	641	523	1,170
60	823	771	684	684	748	635	519	1,159
70	811	766	680	680	743	632	516	1,151
80	802	763	677	677	740	629	514	1,145
90	795	760	675	675	738	627	512	1,141
100	569	538	477	477	521	443	362	955
200	512	496	440	440	481	409	334	771
500	445	438	389	389	425	362	295	696
1,000	400	397	352	352	385	327	267	623
5,000	313	312	277	277	303	257	210	525
10,000	281	281	249	249	273	232	189	442

1. Source: Ramasamy V., 2022. U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, with Minimum Sustainable Price Analysis: Q1 2022.

Note: CAC – Customer acquisition cost

ANNUAL MODELING

Approach

The general operational characteristics for the proposed approach for PV and BESS sizing is summarized in Table 2. Because the proposed sizing procedure was based on the operational characteristics of the selected season, there were some differences in approach for the charging and discharging controls used in determining the cost-effectiveness of the proposed sizing versus the procedure used for sizing in Proposed Sizing section. In particular, the operating characteristics for the system needed to be determined during the seasons that were not used for sizing. These operational characteristics are described below.

In addition, other parameters were changed to ensure that the cost-effectiveness calculation resulted in a minimum benefit-to-cost ratio.

Seasonal Charge and Discharge Control: To approximate predictive control of the charging and discharging of the BESS, the modeling of the fraction of PV generation that was needed to charge the BESS, and the times of BESS discharge were modified only once per season. As described below, it was expected that the most cost-effective BESS is one that would be cycled daily to offset the four hours with the highest LSC. So, the charge fraction was set to fill the BESS to meet the load for the four hours with the highest LSC during that season.

PV Fraction Needed to Charge BESS: For the season with the minimum typical load day that was selected for PV sizing, the portion of PV that was used to charge the BESS was sized to meet the load for the four hours with the highest LSC, as described in the Proposed Sizing section. For the other seasons, the charge fraction for the BESS was set so that it would cycle daily to offset the four hours with the highest LSC.

Discharge during low PV Generation: For the season with the minimum typical load day that was selected for PV sizing, the timing of BESS discharge was as described in the Proposed Sizing section. Specifically, the BESS was discharged to offset the four hours with the highest LSC. For other seasons, the BESS was not allowed to discharge when the PV generation was greater than 40 percent of the building load. A 40 percent reduction is considered a reasonable minimum reduction in annual load by a PV system (Kelly & Liles, 2026). This limit ensured that the BESS was discharged only in times of low solar PV generation. The BESS was discharged during the peak net LSC hours outside of those hours.

Reduced Operating Range: The operating range of the BESS was set to between 20 and 80 percent of total capacity. This range is considered a common moderate range to optimize BESS life (Kim & Shin, 2023).

No BESS replacement: Two sets of energy and cost models were performed, one with BESS replacement at 10-year intervals over the 30-year analysis period and one where the BESS was never replaced. Since BESS replacement every 10 years is optional, the scenario without BESS replacement was evaluated to ensure that requiring a BESS at year 1 with no further replacements was still cost-effective. The scenario assumed that the owner completely discontinued the use of the BESS instead of replacing it or continuing to use it at reduced capacity. Since batteries have higher costs than PV systems per unit of energy provided to a building, the cost effectiveness is higher for the scenario without BESS replacement than for the scenario with BESS replacement. The results shown in Table 16 are for the scenario with no BESS replacement.

Results

The results for cost-effectiveness of the PV-only and the PV-with-BESS scenarios are provided in Table 15 and Table 16. Cost-effectiveness is represented by the benefit-to-cost ratio (BCR) as defined by dividing the LSC savings by the system costs. Green entries indicate benefit-to-cost ratios greater than one (benefits greater than costs); blue entries indicate BCRs less than one.

As discussed above, batteries have higher costs than PV systems per unit of energy provided to a building. The overall effect is that for the scenario where the BESS was not replaced after 10 years, the cost savings from not replacing the BESS outweighed the loss of the LSC savings from replacing the BESS. So, BCRs for the case where the BESS was not replaced were higher than for the scenario where the BESS was replaced.

TABLE 15: BENEFIT-TO-COST RATIO FOR PROPOSED PV-ONLY SIZING

Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Exhibits & Events	1.24	1.52	1.57	1.64	1.62	1.68	1.61	1.63	1.70	1.62	1.52	1.57	1.56	1.79	1.74	1.62
Library	1.50	1.80	1.86	1.96	1.93	1.97	1.91	1.88	1.98	1.95	1.77	1.85	1.83	2.10	2.03	1.91
Religious Worship	1.21	1.44	1.48	1.59	1.54	1.55	1.53	1.56	1.59	1.61	1.46	1.51	1.45	1.68	1.68	1.52
Sports & Recreation	1.18	1.38	1.42	1.51	1.45	1.47	1.46	1.45	1.52	1.51	1.39	1.43	1.42	1.60	1.56	1.50
Large Office	2.24	2.70	2.76	2.93	2.89	2.94	2.86	2.88	2.98	2.95	2.70	2.78	2.76	3.10	3.10	2.79
Medium Office	1.66	2.01	2.04	2.18	2.13	2.17	2.13	2.15	2.23	2.21	2.02	2.07	2.07	2.33	2.33	2.08
Small Office	1.21	1.49	1.53	1.61	1.58	1.61	1.57	1.59	1.64	1.63	1.49	1.53	1.53	1.73	1.73	1.51
Restaurant	1.40	1.68	1.75	1.85	1.80	1.86	1.79	1.80	1.89	1.85	1.68	1.73	1.71	1.98	1.93	1.78
Large Retail	2.35	2.79	2.91	3.07	3.00	3.11	2.98	3.01	3.14	3.10	2.84	2.90	2.90	3.33	3.25	3.00
Medium Retail	1.74	2.03	2.13	2.22	2.22	2.27	2.18	2.19	2.28	2.25	2.06	2.08	2.10	2.42	2.35	2.18
Strip Mall	1.58	1.89	1.96	2.07	2.04	2.09	2.01	2.03	2.13	2.04	1.91	1.96	1.95	2.23	2.12	2.02
High School	1.82	2.04	2.09	2.22	2.19	2.16	2.13	2.17	2.27	2.27	2.11	2.14	2.18	2.44	2.53	2.26
K - 8 School	1.28	1.64	1.66	1.80	1.71	1.76	1.71	1.76	1.82	1.84	1.73	1.70	1.78	2.00	2.10	1.67
Large School	1.77	2.14	2.18	2.33	2.27	2.31	2.23	2.29	2.35	2.36	2.18	2.22	2.23	2.50	2.54	2.21
Warehouse	1.43	1.69	1.71	1.84	1.80	1.78	1.74	1.74	1.82	1.79	1.70	1.74	1.76	1.98	1.95	1.80

TABLE 16: BENEFIT-TO-COST RATIO FOR PROPOSED PV WITH BESS SIZING (NO BESS REPLACEMENT AFTER 10 YEARS)

Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Exhibits & Events	1.20	1.41	1.47	1.65	1.56	1.60	1.55	1.59	1.59	1.64	1.39	1.45	1.50	1.64	1.61	1.51
Library	1.61	1.75	1.75	1.85	1.91	1.91	1.88	1.91	2.04	1.80	1.64	1.80	1.75	1.97	1.91	1.94
Religious Worship	0.91	1.09	1.05	1.18	1.13	1.11	1.14	1.22	1.28	1.36	1.20	1.24	1.16	1.23	1.38	1.15
Sports & Recreation	1.02	1.22	1.22	1.29	1.25	1.33	1.24	1.26	1.34	1.33	1.22	1.20	1.25	1.31	1.38	1.35
Large Office	2.29	2.80	2.83	3.00	3.01	3.05	2.92	2.97	3.13	3.10	2.81	2.82	2.84	3.14	3.24	2.87
Medium Office	1.70	2.07	2.13	2.18	2.21	2.21	2.20	2.21	2.33	2.30	2.06	2.15	2.15	2.37	2.48	2.09
Small Office	1.23	1.49	1.56	1.61	1.56	1.57	1.57	1.60	1.67	1.66	1.50	1.55	1.58	1.69	1.76	1.51
Restaurant	1.31	1.59	1.65	1.76	1.68	1.75	1.67	1.75	1.81	1.78	1.62	1.68	1.64	1.89	1.86	1.56
Large Retail	2.18	2.59	2.72	2.95	2.87	3.00	2.74	2.84	3.02	2.95	2.75	2.77	2.79	3.13	3.17	2.84
Medium Retail	1.60	1.88	1.93	2.03	2.08	2.06	1.96	2.03	2.15	2.08	1.89	1.82	2.01	2.22	2.21	2.01
Strip Mall	1.51	1.78	1.73	1.91	1.86	1.98	1.88	1.95	2.07	1.99	1.81	1.82	1.81	2.07	2.00	1.82
High School	1.84	2.02	2.04	2.30	2.14	2.29	2.07	2.30	2.37	2.15	2.03	2.06	2.14	2.52	2.61	2.40
K - 8 School	1.08	1.66	1.73	1.80	1.71	1.83	1.74	1.85	1.91	1.69	1.64	1.57	1.70	2.04	2.10	1.52
Large School	1.80	2.14	2.17	2.35	2.31	2.30	2.24	2.35	2.39	2.43	2.25	2.25	2.25	2.44	2.60	2.25
Warehouse	1.37	1.62	1.62	1.73	1.67	1.72	1.59	1.71	1.77	1.71	1.61	1.65	1.63	1.83	1.87	1.71

NEXT STEPS

This memo proposes a new sizing approach for the PV and BESS standards to support updates for the 2028 Energy Code and provides updated cost and cost-effectiveness calculations. The CEC requests input on key parameters and inputs used in the analysis, including responses to the following questions.

QUESTIONS FOR STAKEHOLDERS

1. How are commercial PV systems and BESS sized?
2. Is the proposed PV and BESS sizing approach for seasonal Median-Load-Day Minimum matching consistent with industry practice for systems designed for load shifting? If not, please describe how it should be changed?
3. For commercial PV system and commercial BESS storage costs, what are the customer acquisition costs for newly constructed buildings, either as a line item ($\$/ft^2$) or as a fraction of the total cost?
4. How do costs for commercial PV systems and BESS in California vary from nationwide costs?
5. What is the expected useful life of a commercial BESS, under typical charging and discharge cycles (number of cycles or years)?
6. What is the minimum capacity commercial BESS that is available and practical for commercial buildings?
7. What is a typical minimum and maximum state of charge for batteries installed in commercial buildings?
8. What is a typical roundtrip efficiency for BESS installed in commercial buildings?
9. What are typical BESS charging and discharging control strategies for combined PV and BESS systems (Time-Of-Use, energy arbitrage, peak shaving, traditional predictive, AI predictive, other). If possible, please provide a ranking of the stage of adoption of these technologies: 1 (innovators), 2 (early adopters), 3 (early majority), 4 (late majority), 5 (laggards). Please also explain how the strategy works.

CODE LANGUAGE DEVELOPMENT

The next step is to collect input from the public on the questions above, and any other related input. The public's input will help inform the CEC's update of the analysis. Once the final analysis has been completed, a final report will be published. Proposed code language reflecting the final analysis will be published with the measure report. Additional code language will also be developed to reflect updates to the PV and BESS system specifications (such as BESS round-trip efficiencies).

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