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Reimagining Photovoltaic and Battery Storage Sizing in Energy Codes: Requirements at the Space Function Level

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Abstract

Photovoltaic (PV) and battery storage prescriptive requirements for nonresidential new construction in California's energy code are specified based on the type of building and do not account for diversity in space floor areas that may be found in buildings of the same type. To improve the way energy codes specify PV and battery sizes, a new method was developed that provides a space function-based approach to PV and battery sizing. This new method uses three modules to (a) optimize PV and battery systems to meet export targets, (b) create a relationship map linking modeled systems to spaces, and (c) proportionally distribute the building level PV and battery to modeled spaces. Collectively, these modules create a framework that can be used to specify energy code PV and battery storage sizing requirements based on space function and relative floor area of various spaces in a building model.

Introduction

Building operations are estimated to be 26% of global energy related emissions (IEA, 2023). As electrification increases and energy demand is estimated to increase by 57% by 2050, continued growth in renewables is required (EIA, 2023). On-site photovoltaic (PV) and battery storage are known solutions that can reduce a building's energy demand on the grid. While PV and/or battery requirements in energy codes for newly constructed buildings are relatively new, California has had them since the 2019 energy code edition (2019 Title 24, Part 6). California's energy code specifies PV and battery sizes based on climate zone and building type. This approach is generally accepted and is also being used in the national model energy codes—IECC and ASHRAE Standard 90.1. One limitation of this approach is that it limits the PV and battery requirement to only those building types that have been listed in the requirement; other building types may have the same spaces—for example, offices, corridors, restrooms, etc.—but they are not required to install PV and battery systems. Another limitation is that PV and battery sizing based on building type does not adjust the system size to the loads of a specific building because the space floor areas and space types are likely to be different in a specific building than those used in the analysis performed to set the requirement.

To improve sizing of PV and battery systems for specific buildings and projects, a new approach was envisioned that was based on the spaces within a building or project (analogous to the well-known space-by-space approach for specifying lighting power found in Title 24, Part 6, Table 140.6-C). The intent was that if PV and battery storage demands could be determined and specified at a space function level, the prescriptive requirements could more accurately track the loads of a specific building and the requirements could be expanded to all building types.

A framework was developed in Python (Python 2023) consisting of three modules that process hourly energy model results to support space function-centric PV and battery storage sizing:

1. The first module optimizes building-level PV and battery system sizes for prototype energy models based on generation and export targets.
2. The second module combines a model's disparate outputs into a single relationship map stored as a JSON file. This map contains the relationships between the model's electric end-uses (lighting, receptacle, process, HVAC, and water-heating), and the building's spaces.
3. The last module utilizes the relationship map to allocate building and system level energy consumption to each modeled space. Finally, optimized PV and battery storage sizes are proportionally divided into the spaces consistent with space energy consumption.

At a high level, our workflow utilizes energy model results and parameters to output PV and battery storage sizes for modeled space functions.

Currently, numerous methods are available for PV and battery storage optimization. Some approaches focus on peak power output, (Navabi, et al. 2015) while other approaches include PV and battery cost optimization (Borkowski, et al. 2023 & Symeonidou, et al. 2021). Our case focused on several specific criteria used within California measure development, including excess PV export limitations and restrictions on battery discharge hours. These specifications required the development of this unique approach to meet the project goals.

The building energy analysis software used for the analysis was California Building Energy Code Compliance (CBECC) (CBECC, 2023), which provides a user interface for defining spaces and systems for a whole building energy simulation model for energy code compliance analysis. One limitation of this software is that the user-defined structures and systems are not easily accessible to software outside of CBECC. The second module solves this problem by creating a relationship map of a CBECC model's systems and spaces, using both CBECC model inputs and EnergyPlus outputs. With this extracted relationship map, a third-party software can be used to analyze the interconnectivity of modeled systems and spaces to further understand the influences of systems (such as PV and battery) on space functions.

The third module leverages the building's relationship map (created in the preceding module) to redistribute building and system level energy consumptions to the space function level. While some sources focused specifically on machine learning and optimization of the whole design space (Bass, et al. 2023), our proposed approach specifically allocates electric end-use energy into modeled space functions. As an extension of the second module, the third module distributes system-level energy consumption into a building's various spaces, thereby allowing a space-centric analysis of energy consumption within models. Using the same energy proportions, we also proportionally split building-level PV and battery storage sizes into space levels.

Collectively, the three modules provide a robust framework allowing for further exploration of space function-centric PV and battery storage requirements. We demonstrate how space function requirements may be generated from this workflow on a watts per square foot (W/sqft) and watt-hours per square foot (Wh/sqft) basis for PV and battery storage sizing, respectively. Our framework's sample results present significant differences for building-level and space-level PV and battery sizing. Our conjecture is that the space-level sizing approach more accurately tracks the building loads. The proposed framework could assist code language development for more tailored PV and battery storage sizing requirements, both locally and nationally.

Simulation Approach

The State of California has been developing its own energy code since 1978. Over time, the state has invested significant time and effort on how to best approach PV and battery storage sizing within the energy code. There is a problem of oversupply of energy from renewable resources — in particular, from PV — on the grid during midday, followed by a peak demand period between 4 pm and 9 pm when the solar resource goes to zero. The new Net Billing Tariff (NBT), (CPUC, 2022) introduced by rule by the California Public Utilities Commission (CPUC) significantly limits compensation for exported renewable generation to the grid from behind the meter PV installations. Therefore, from a cost-effectiveness perspective, it is vitally important to maximize on-site utilization of PV generation and minimize grid exports.

For this PV and battery measure development, 90% of total PV generation was set to be utilized by the building, and no more than 10% of PV generation could be exported to the grid. California has different battery control options per Title 24, Part 6, Joint Appendix (JA) 12.2, which regulate battery charging based on PV generation and high-priced hours of the day (Title 24, Part 6, Section JA12.2.3.2 2022). These specifications in JA12 were used to set time-of-use control criteria for this analysis to restrict battery charging only from on-site PV generation, and to restrict battery discharge for building consumption only. By also limiting battery discharge to highest priced hours between 4 p.m. and 9 p.m., battery cost-effectiveness was maximized. These and other California sizing criteria were considered in the analysis framework and were consistent with the approach used in the development the nonresidential PV and battery requirements introduced in the 2022 Energy Code (Athalye, et al. 2021).

The models used in this analysis were developed for California code enhancement measures and adhere to prescriptive requirements in the 2022 Energy Code. The modeling software used was CBECC, which is designed to handle non-residential and multifamily buildings in all 16 California climate zones. Our framework utilized a combination of CBECC's hourly energy outputs, as well as relational information of modeled spaces and systems, represented in Figure 1.

The workflow for our proposed approach begins by using simulation results from a CBECC model and ends after allocating building-level PV and battery sizes to each space in proportion to a space's overall energy consumption. The three modules described below each capture key aspects used in the workflow: construct whole-building PV and battery sizes for the model (Module #1), extract information from model results (Module #2), allocate energy consumption to spaces, and proportionally distribute whole-building sizes to spaces (Module #3).

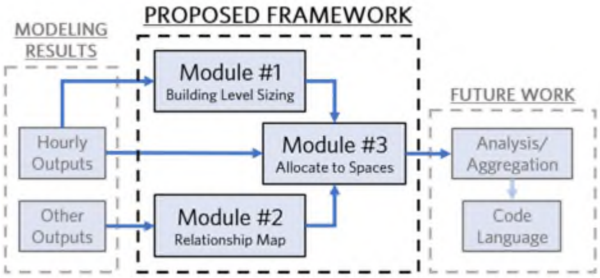

Figure 1: Scope of the proposed framework. Three modules take input from modeling results and provide information that can be used in code language.

Module #1 - Export Targeting & Sizing Optimization

The first module was developed to optimize PV and battery storage size for a given energy model to meet the export criteria, and other aforementioned criteria and constraints. We started by modeling a single PV array of 1 kWh power output in all 16 climate zones. Next, we scaled the hourly PV output for each building model to yield a size such that 80% of annual PV generation is used to power the building's electric loads. The remaining 20% of the scaled PV generation was then split between battery storage charging (10%) and PV exports sold back to the utility (10%) per similar California code measures.

Next, to set battery storage sizing to charge using 10% of annual PV generation, we developed a Python class to replicate the functionality of an actual battery. Based on measure specifications, we specified the battery to have a round trip efficiency of 80% (Title 24, Section JA12.2.2.1 2022), max charge and discharge duration of four hours under full load, and discharge time from 4 p.m. to 9 p.m. (Title 24, Section JA12.2.3.2 2022). The initial battery unit size of 1,000 kWh was similarly scaled such that 10% of PV generation charged the battery under normal building operation.

The described scaling of PV and battery sizes relies on Tol's Python optimization tool (Tol 2023). Tol's script uses the line search and bisection methods to target the desired goals of 80% building PV self-utilization and 10% PV generation towards battery charging. In the export targeting workflow, we first created a simple function to calculate annual building self-utilization of scaled annual PV generation. We then passed this function to Tol's optimization tool to iterate on PV size until 80% of PV generation is utilized directly by the building. After finding the scaled PV size, we introduced a battery to similarly be scaled until the battery size allowed charging using 10% of PV generation that is not already used directly by the building. The scaling module was used to iterate battery sizes until 10% of annual PV generation was used to charge the battery.

Scaling PV and battery storage for an energy model at the whole-building level was the first step of our space-centric framework approach. The next modules were developed to further examine CBECC model parameters and allocate scaled sizes to the spaces modeled.

Module #2 - Extracting a CBECC Model Map

We then developed a module that reads additional CBECC result files to reconstruct a relational map of user-defined spaces and systems. We started by looking at two output files of the proposed energy model: the 'HVACSecondary.csv' file and VentilationExhaust.csv' file. Both files contained model-specific relational information including spaces, space types, thermal zones, HVAC systems, HVAC components, etc. See Table 1 for detailed information pulled from the files.

Table 1: CBECC output files and their relational information used to construct a map between a model's systems and spaces.

VentilationExhaust.csv	
Story	Name
	Qty
Space	Name
	Qty
	Space Function
	Thermal Zone
	Floor Area
	Story
Thermal Zone	Name
	System

HVACSecondary.csv	
Air System	Name
	Qty
Zone System	Name
	Qty
Terminal Units	Name
	Qty
	System
	Thermal Zone
Cooling and/or Heating Coils	Name
	System
	Thermal Zone
Fans	Name
	System
	Thermal Zone

After parsing space and system information in Table 1 above, we joined the various pieces of information into a single structured map stored as a JSON file. This data was used to map system components and configurations to spaces and space functions. This model reconstruction and mapping module was vital to dynamically understand how individual systems were constructed, and how various systems serve spaces. The next module utilizes this model-specific relationship map to proportionally allocate system level energy consumption down to space-level.

Module #3 - Allocating System Energy to Spaces

With the ability to programmatically replicate the building model information, we had the capability to relate system level information to space functions. The third module utilized the output of Module #2 to allocate/break down different aspects of system energy to each space function. To do this, four key energy distribution methods were identified to effectively approximate how much system energy was provided to spaces or other systems in the model. See Table 2 for a list of distribution system types identified for the analysis.

Table 2: List of a system's potential distribution methods used to proportionally distribute system energy to the spaces or other systems they serve.

Distribution System Type	Distribution Method
Domestic Hot Water	Water Flow
HVAC Heating Hot Water	Coil Heat Exchange
HVAC Condenser/Chilled Water	Coil Heat Exchange
HVAC Air System	Air Flow

These different methods of distribution, if found in a model, trigger a simple intermediary analysis for each hour of the day to proportionally distribute hourly system energy. This analysis, found the hourly proportion of a system's distribution method to understand how much energy s subsequent system or space used. As an example, see Figure 2 where a heat pump heating hot water (HHW) system was used as reheat for both a rooftop AC unit and individual terminal units. For each hour of the day, we summed total heat exchanged between each heating coil in the system (i.e. at the AC unit and various terminal units). Isolating each coil, we determined the percentage of exchanged heating energy of each coil in the HHW system. Therefore, a portion of HHW energy consumption was given to the AC system, and the spaces' terminal units. Using airflow as a different distribution method, the total AC unit energy consumption was similarly passed to the terminal units, and therefore to the spaces.

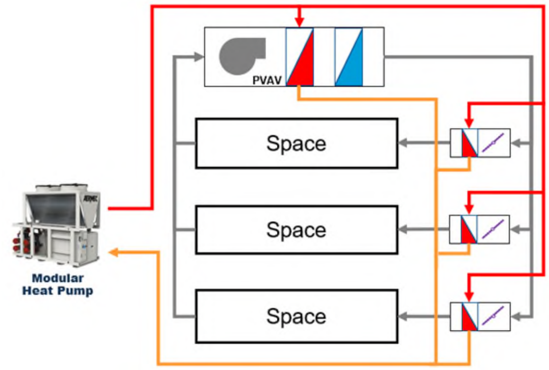

Figure 2: Example HVAC system where a heating hot water (HHW) reheat system serves AC and terminal units. Energy consumption from the HHW and AC systems is proportional to the systems and/or spaces they serve.

With this module, the energy consumption of each system type was proportionally allocated to the connected spaces at an hourly scale. For this work, lighting systems were not applicable to this module because direct hourly energy consumption of the spaces was already aggregated into a single column output for each space containing energy from lights, plug loads, etc. The output of this third module yielded energy consumption by space, which was then used to proportionally distribute PV and battery storage sizes based on each space's total percentage of energy consumption.

Space Level Sizing Workflow

The three modules operate together to determine the PV and battery sizing for each space in a given model. Recall the goal of this work was to make progress toward developing sizing requirements at a space function level within California. Per model, Module #1 yielded a scaled building-level PV and battery storage systems to target export criteria; Module #2 created a map between modeled systems and spaces; Module #3 analyzed hourly system energy consumption and proportionally distributed consumption to connected systems & spaces. Lastly, with each space's total associated energy consumption, PV and battery storage sizes derived from Module #1 were proportionally associated with spaces and space functions.

Results

Three modules were developed for a framework that reimagines how PV and battery storage requirements could be sized at a space function level. Our conjecture was that space-centric sizing could better track building loads, which would allow for more tailored sizing for building design diversities. Using prototype models developed for California code measure work, we present results from Module #1's building-level optimization of PV and battery sizing, as well as aggregated space-level sizing results from Module #3 per floor area. Because a large amount of information was generated by the modules considering 12 prototypes and 16 climate zones, we present results only from climate zone 12. (Full results are found in the appendix as noted.)

Module #1 Building-Level Sizing Results

The optimized building-level PV and battery storage system sizing for each prototype model is shown in Table 3 below. This structure of W/sqft and Wh/sqft is comparable to existing tables found in 2022 Title 24, Part 6, Tables 140.10-A, and 140.10-B for PV and battery sizing, respectively. The battery round-trip efficiency factor required in the Title 24 tables is already integrated into the battery optimization process within Module #1 at 80%.

Table 3: Module #1 optimized PV and battery storage sizes for each baseline prototype in climate zone 12.

Prototype	PV Size [W/sqft]	Battery Size [Wh/sqft]
Assembly - Exhibit	4.44	2.41
Assembly - Library	3.32	7.75
Hotel - Small	2.05	1.07
Office - Large	2.49	6.41
Office - Medium	3.15	7.67
Office - Small	3.91	8.81
Restaurant - Small	9.73	4.95
Retail - Large	3.64	2.18
Retail - Medium	4.01	2.39
Retail - Strip Mall	5.89	3.35
School - Large	1.13	2.72
School - Small	2.16	5.69

Module #2 & #3 Space-Level Results

CBECC model outputs of a given prototype generate the relational mapping file from Module #2. Results of Modules #1 and #2 are both passed to Module #3 which splits the optimized PV and battery storage sizes proportionally into modeled spaces and space types based on space-specific hourly energy consumption. Table 4 is an aggregated example showing the organization of space function sizing per floor area. In this table, all similar space functions between all prototypes were combined and averaged (an approach which is scrutinized in the next section). Results for all climate zones are found in Table A-2 of the appendix.

Table 4: Aggregated and averaged PV and battery storage sizes for all space functions within tested models for climate zone 12.

Space Function	PV [W/sqft]	Battery [Wh/sqft]
Auditorium Area	3.14	2.94
Classroom, Lecture, Training, Vocational Areas	1.86	4.81
Convention, Conference, Multipurpose and Meeting Area	4.68	8.09
Corridor Area	0.59	1.32
Dining Area (Cafeteria/Fast Food)	3.37	4.82
Electrical, Mechanical, Telephone Rooms	4.23	6.01
Exercise/Fitness Center and Gymnasium Areas	0.89	2.57
Hotel Function Area	3.82	1.72
Hotel/Motel Guest Room	1.80	1.05
Kitchen/Food Preparation Area	10.06	11.38
Laundry Area	6.59	3.07
Library (Reading Area)	2.46	5.52
Library (Stacks Area)	3.10	7.22
Lobby, Main Entry	3.54	5.30
Museum Area (Exhibition/Display)	6.44	3.55
Office Area (>250 square feet)	2.92	4.73
Restrooms	0.74	1.18
Retail Sales Area (Retail Merchandise Sales)	4.88	2.86
Storage, Commercial/Industrial (Warehouse)	1.24	0.77
Theater Area (Motion Picture)	3.39	1.75

PV and Battery Sizing using Framework Results

Though our framework ends by creating a space-centric sizing table comparable to Table 4, we provide an example how a space-centric PV and battery storage sizing approach can capture greater variation in building design diversity. To start, let's assume an authority having jurisdiction (AHJ) used the proposed space-centric framework from this paper to analyze hundreds of representative or prototype building models to yield newly codified prescriptive PV and battery requirements represented by values in Table 4. By simply multiplying the requirements by total space function floor area, and summing all space functions, results can be seen represented in Table 5 (divided by total building floor area, found in Table A-1), which reference the California base prototypes used in the analysis. This table is intentionally comparable to existing building level requirements in the existing Title 24, Part 6 2022 energy code and will be scrutinized in the next section.

Table 5: Prototype level sizing built from space-function requirements of PV and battery storage per sqft, for climate zone 12.

Prototype	PV Size [W/sqft]	Battery Size [Wh/sqft]
Assembly - Exhibit	4.32	4.31
Assembly - Library	3.01	6.66
Hotel - Small	1.82	1.37
Office - Large	2.92	4.73
Office - Medium	2.92	4.73
Office - Small	2.92	4.73
Restaurant - Small	6.71	8.10
Retail - Large	3.93	2.64
Retail - Medium	4.27	2.52
Retail - Strip Mall	4.88	2.86
School - Large	1.74	3.59
School - Small	1.82	3.84

However, what if space types and sizes differ in other designs? Let's say a designer in the assumed AHJ is designing a large school with alternate spaces, but with the same footprint as that used in the Table 5 'School – Large' prototype. Represented in Table 6, one option shows an alternate school design with no gym, and another alternate design with no kitchen or dining spaces.

Using a space-centric framework, these different but valid design options with equivalent floor area yield different building-level PV and battery sizes. The design with no gym and larger kitchen, dining, and libraries, yields 31% larger PV and 17% larger battery storage sizes compared to the base building prototype design. Conversely, by removing kitchen and dining areas, and increasing auditorium, gym, and library area, we see reductions of PV and battery size by 9% and 4% respectively. With these two examples alone, there is a difference of ~150 kW for on-site PV, and ~15 kWh in on-site battery storage, demonstrating that space-level requirements do make a difference in PV and battery system sizing.

Table 6: Examples of alternate floor area (sqft) space distributions of 'School – Large'. Light gray cells are floor areas that differ from the base prototype.

Space Name	Base Prototype	No Gym	No Kitchen or Dining
Auditorium Area	10634.8	10634.8	*12403.1*
Classroom, Lecture, Training, Vocational Areas	74400.0	74400.0	74400.0
Corridor Area	49728.8	49728.8	49728.8
Dining Area (Cafeteria/Fast Food)	6716.7	*23902.8*	*0.0*
Electrical, Mechanical, Telephone Rooms	7362.6	7362.6	7362.6
Exercise/Fitness Center and Gymnasium Areas	34702.7	*0.0*	*40472.8*
Kitchen/Food Preparation Area	2325.0	*8274.0*	*0.0*
Library (Reading Area)	9041.7	*20609.3*	*10545.1*
Office Area (>250 square feet)	11452.8	11452.8	11452.8
Restrooms	4520.8	4520.8	4520.8
Total Floor Area	**210885.9**	**210885.9**	**210885.9**

Discussion

These results suggest that prescriptively sizing PV and battery capacities from a space function level could help more accurately size equipment during the construction process and more accurately track loads during building operation. However, for this framework to become most useful, it is important to understand limitations, potential pitfalls, and even alternate uses of the modules.

As an optimization approach for generation and export targets, Module #1 was developed to match requirements and goals of California. Another AHJ could modify this module with their own targets and battery control requirements to meet their specific needs. Though we chose to scale and optimize based on unit PV arrays generated in a CBECC model, hourly unit PV results could be generated from other models as desired. Likewise, an AHJ could also replace the entirety of

Module #1 with another optimization approach, so long as they output hourly results to pass to the remaining modules. This flexibility and interchangeability allows our framework to accommodate diverse needs for developing PV and battery storage requirements.

Whole building optimization results from Module #1, found in Table 3, are structured similarly to existing 2022 Title 24, Part 6 energy code Section 140.10. A. Though we used a comparable analysis approach, we do see some discrepancies. A few notable changes that may result in these differences are updated weather files (i.e. newer weather information that begin to reflect anthropogenic global warming effects), and models adhering to more restrictive natural gas requirements compared to the existing 2022 code. Gas heating was allowed for buildings under existing code but is not allowed for the next code cycle, which was our baseline used in this paper. Such a change from natural gas heating to electric-sourced heating could result in the larger sizing requirements found under the proposed module.

Module #2 can be very useful to replicate a CBECC model structure for further studies in other tools. The relationship map can support more extensive analysis to understand how different systems, beyond PV and battery, affect different spaces within a building model. The ability to further analyze CBECC model results and parameters in a third-party software can enhance BEM processes and analyses.

In Module #3, we looked at select cases for energy distribution of each system: air flow, water flow, and coil heat exchanged. There are likely other systems we have not encountered in our prototype models, which may have alternate distribution methods that require an expanded approach to distribute energy to spaces. As needed, these other distribution methods can be integrated into our framework to capture the full scope of a new project.

Results of Module #3 provide a space usage breakdown of PV and battery systems for individual models, which can be used for further aggregation and analyses of choice. Though this paper presented averaged results in Table 4, a simple average is neither recommended nor reliable way to aggregate results of multiple building types. The key reason being operational and occupancy schedule diversity. For example, office spaces within schools versus office buildings would see different energy requirements throughout a given time period. Taking a simple average between these different building types would skew results away from the intended load tracking. A possible solution to this could include a grouping of similarly scheduled models for a more tuned analysis and aggregation of results. Additionally, more statistically advanced analyses could be done on a larger dataset of models to better understand space function consumption and variation. Depending on the extent of such analysis results, codifying such results may lead to larger prescriptive requirement tables additionally requiring general building type (for schedule/occupancy) as well as climate and space function to best track loads for varying building designs.

Though our approach was originally developed for prescriptive on-site PV and battery system requirements, aspects of the modules and/or aggregated results could also be incorporated into performance requirements. For example, if extensive analysis leads to a large table, performance approaches could perform an automatic table lookup. Even better could be the incorporation of our Module #1 optimization approach into a standard model execution. CBECC, for example, currently sizes PV and batteries using different table lookups. Incorporating similar Module #1 logic into the modeling software, the user interface could allow for key adjustments to both generation and export targets and battery operation to run an optimization for performance model code compliance. Using aspects of this framework in both prescriptive and performance could create a larger impact on new construction energy consumption.

Conclusion

An alternative to traditional whole-building PV and battery sizing typically used by energy codes was developed, which reimagined how PV and battery storage could be prescriptively sized to better capture diversity of space types and the space floor areas within a given building or project. To achieve this goal, we developed a framework consisting of three modules that collectively provide optimized PV and battery storage system sizes at the space level. This new space-by-space approach to sizing PV systems was described in this paper, along with the procedure used to perform the analysis. This procedure could be easily applied to other jurisdictions to improve sizing requirements for PV and battery systems in energy codes.

The first module in the framework optimized whole building PV and battery storage sizes using hourly results to meet target export criteria. Specific generation and export targets as well as battery control options were used to scale up unit PV and battery sizes to best track loads of the model.

In the second module, we developed an approach which reads various CBECC result files to construct a relational map of modeled systems and spaces. This key module successfully extracted the model information to a relationship map stored as a JSON file, which was passed to the third module to programmatically map energy consumption from systems to spaces.

Using the output from the first two modules, the third module translated system level energy consumption to each space function via three possible distribution methods: water, air, and coil heat exchange. The focus of our framework ends by proportionally distributing the optimized building level PV and battery storage sizes from the first module to the space level based on and space's associated energy consumption.

In summary, our space-centric framework consists of three modules to streamline an analysis process to enhance energy code PV and battery sizing requirements. As the sector trends toward deeper electrification, increased building demand on the grid may result in the inability of electricity suppliers to provide enough energy at peak demand. Developing requirements for PV and battery storage system installations can help reduce building energy demand and support continual energy service in the future. By providing a framework which reimagines code requirements at a space function level, PV and battery storage systems can more accurately track building loads, reducing material waste and grid exports. At scale, adopting our space-centric approach to a national energy code could share these advantages across the building sector.

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Appendix

Table A-1: Prototype models and their space functions used in the sample analysis for space function-centric PV and battery storage sizing.

Prototype	Space Function	Sqft
Assembly Exhibit	Auditorium Area	2221.8
	Convention, Conference, Multipurpose and Meeting Area	2668.7
	Museum Area (Exhibition/Display)	1776.6
	Theater Area (Motion Picture)	2225.5
Assembly Library	Convention, Conference, Multipurpose and Meeting Area	649.8
	Library (Reading Area)	3898.8
	Library (Stacks Area)	7797.6
	Lobby, Main Entry	649.8
Hotel Small	Corridor Area	9855.8
	Electrical, Mechanical, Telephone Rooms	351
	Hotel Function Area	2619.2
	Hotel/Motel Guest Room	27270.9
	Laundry Area	1053
	Office Area (>250 square feet)	1404
Office Large	Office Area (>250 square feet)	498587.8
Office Medium	Office Area (>250 square feet)	53628
Office Small	Office Area (>250 square feet)	5502.1
Restaurant Small	Dining Area (Cafeteria/Fast Food)	1250.5
	Kitchen/Food Preparation Area	1250.5
Retail Large	Lobby, Main Entry	20250
	Office Area (>250 square feet)	3000
	Restrooms	6750
	Retail Sales Area (Retail Merchandise Sales)	164000
	Storage, Commercial/Industrial (Warehouse)	46000
Retail Medium	Lobby, Main Entry	129.2
	Retail Sales Area (Retail Merchandise Sales)	20474
	Storage, Commercial/Industrial (Warehouse)	4089.1
Retail Strip Mall	Retail Sales Area (Retail Merchandise Sales)	9375
School Large	Auditorium Area	10634.8
	Classroom, Lecture, Training, Vocational Areas	74400
	Corridor Area	49728.8
	Dining Area (Cafeteria/Fast Food)	6716.7
	Electrical, Mechanical, Telephone Rooms	7362.6
	Exercise/Fitness Center and Gymnasium Areas	34702.7
	Kitchen/Food Preparation Area	2325
	Library (Reading Area)	9041.7
	Office Area (>250 square feet)	11452.8
	Restrooms	4520.8
School Small	Classroom, Lecture, Training, Vocational Areas	12056
	Corridor Area	5844.8
	Dining Area (Cafeteria/Fast Food)	2859.7
	Electrical, Mechanical, Telephone Rooms	446.5
	Office Area (>250 square feet)	2201.4
	Restrooms	1004.6

Table A-2: Aggregated and averaged space-level PV and battery storage results for all climate zones.

	PV Size [W/sqft] Battery Storage Size [Wh/sqft]															
Climate Zone:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Space Name																
Auditorium Area	2.41	2.98	2.5	3	2.57	2.86	3.07	3.55	3.26	3.56	3.66	3.14	3.62	3.07	4.5	2.53
	2.42	2.84	2.37	2.8	2.43	2.79	2.94	3.33	3.08	3.61	3.44	2.94	3.57	3.16	4.59	2.6
Classroom, Lecture, Training, Vocational Areas	1.36	1.76	1.41	1.84	1.4	1.62	1.85	2.18	1.85	2.39	2.42	1.86	2.52	2.09	3.28	1.51
	3.15	4.67	3.7	4.75	3.52	4.08	4.53	5.42	4.74	6.32	6.13	4.81	6.35	5.77	7.69	4.08
Convention, Conference, Multipurpose and Meeting Area	3.41	4.39	3.6	4.62	3.51	3.88	4.02	4.93	4.73	5.23	5.51	4.68	5.49	4.79	6.62	4.01
	6.85	8.43	7.52	8.15	7.08	7.6	7.51	8.48	8.44	8.99	8.95	8.09	8.47	8.59	10.17	8.67
Corridor Area	0.43	0.53	0.42	0.57	0.42	0.51	0.57	0.69	0.61	0.74	0.77	0.59	0.79	0.66	1.08	0.49
	0.8	1.18	0.9	1.27	0.84	1.05	1.21	1.5	1.32	1.77	1.77	1.32	1.81	1.6	2.18	1.08
Dining Area (Cafeteria/Fast Food)	2.35	3.2	2.66	3.32	2.65	3.02	3.32	3.77	3.4	3.88	4.01	3.37	4.05	3.55	4.82	2.57
	3.35	4.73	4.08	4.79	3.98	4.3	4.7	5.19	4.87	5.8	5.66	4.82	5.76	5.61	6.44	3.69
Electrical, Mechanical, Telephone Rooms	3.75	4.05	3.54	4.08	3.51	3.91	4.26	4.68	4.26	4.8	4.94	4.23	5.05	4.28	5.93	3.76
	4.5	5.95	4.97	5.87	4.79	5.57	6.04	6.92	6.25	7.79	7.28	6.01	7.55	7.05	9.23	5.4
Exercise/Fitness Center and Gymnasium Areas	0.61	0.8	0.58	0.82	0.59	0.77	0.88	1.12	0.94	1.17	1.13	0.89	1.16	0.86	1.7	0.61
	1.56	2.26	1.59	2.29	1.55	2.02	2.31	3.12	2.63	3.47	3.16	2.57	3.35	2.45	4.57	1.67
Hotel Function Area	2.08	3.5	2.75	3.61	2.93	3.54	3.7	4.51	4.13	4.38	4.34	3.82	4.36	3.56	5.33	2.67
	1.09	1.41	1.18	1.6	1.19	1.54	1.65	1.9	1.88	2.09	2.04	1.72	2.17	1.89	2.84	1.29
Hotel/Motel Guest Room	1.6	1.66	1.48	1.75	1.48	1.61	1.67	1.9	1.81	1.91	2.03	1.8	2.02	1.83	2.41	1.6
	1	0.94	0.87	1.02	0.93	0.98	0.99	1.09	1.09	1.2	1.26	1.05	1.28	1.34	1.64	0.98
Kitchen/Food Preparation Area	9.42	9.73	8.61	9.8	8.62	9.08	9.62	10.53	9.96	10.65	11.16	10.06	11.08	9.75	12.51	8.66
	10.81	11.58	10.42	11.25	10.39	11.09	11.43	12.45	11.81	13.26	12.25	11.38	12.89	12.1	14.53	10.64
Laundry Area	5.61	6.32	5.64	6.31	5.7	6.26	6.5	7.11	6.71	6.91	7.12	6.59	7.12	6.16	7.74	5.62
	2.77	2.76	2.55	2.95	2.66	2.98	3.04	3.31	3.28	3.58	3.56	3.07	3.68	3.71	4.56	2.71
Library (Reading Area)	2.14	2.4	1.98	2.36	1.92	2.11	2.36	2.68	2.43	2.78	2.79	2.45	2.83	2.4	3.3	2.1
	4.4	5.65	4.63	5.26	4.4	4.84	5.08	5.95	5.66	6.37	5.83	5.52	5.87	5.31	6.91	4.8
Library (Stacks Area)	2.56	3.05	2.45	3.03	2.35	2.59	2.9	3.27	3.09	3.44	3.51	3.1	3.5	3.13	4.2	2.64
	5.55	7.41	6.04	6.97	5.75	6.25	6.38	7.39	7.4	7.84	7.4	7.22	7.13	7.01	8.26	6.38
Lobby, Main Entry	2.72	3.35	2.76	3.51	2.71	3.03	3.24	3.75	3.67	3.9	4.14	3.54	4.13	3.64	4.84	3.08
	4.73	5.48	4.99	5.26	4.61	4.84	4.86	5.4	5.73	5.78	5.86	5.3	5.54	5.73	6.66	5.74
Museum Area (Exhibition/Display)	5.44	6.28	5.46	6.25	5.53	5.85	6.2	6.81	6.66	6.78	7.06	6.44	6.95	6.22	5.64	3.96
	3.22	3.31	3.01	3.53	3.3	3.56	3.74	3.79	3.94	4.07	4.3	3.55	4.31	4.71	3.99	2.53
Office Area (>250 square feet)	2.47	2.84	2.41	2.87	2.4	2.67	2.89	3.23	2.96	3.26	3.36	2.92	3.39	2.83	3.8	2.47
	3.67	4.82	4.07	4.67	3.97	4.37	4.54	5.18	4.88	5.5	5.31	4.73	5.29	4.72	5.76	4.01
Restrooms	0.68	0.73	0.62	0.72	0.61	0.65	0.71	0.82	0.74	0.84	0.87	0.74	0.87	0.74	1.01	0.72
	0.93	1.09	0.88	1.06	0.84	0.94	1	1.14	1.06	1.29	1.85	1.18	1.4	1.54	2	1.54
Retail Sales Area (Retail Merchandise Sales)	4.3	4.71	4.1	4.8	4.16	4.39	4.62	4.97	4.87	4.92	5.27	4.88	5.21	4.88	5.84	4.25
	2.9	2.68	2.57	2.65	2.58	2.64	2.61	2.72	2.84	2.89	3.12	2.86	3.08	3.26	3.69	2.82
Storage, Commercial/Industrial (Warehouse)	1.12	1.11	0.91	1.23	0.87	0.93	1.03	1.21	1.15	1.22	1.44	1.24	1.41	1.35	1.7	1.05
	0.78	0.66	0.6	0.71	0.61	0.58	0.61	0.68	0.69	0.75	0.91	0.77	0.89	0.95	1.16	0.73
Theater Area (Motion Picture)	2.31	3.2	2.63	3.3	2.78	3.03	3.22	3.79	3.58	3.77	4	3.39	3.93	3.41	5.02	2.65
	1.32	1.52	1.3	1.7	1.43	1.67	1.77	1.85	1.9	2.02	2.17	1.75	2.19	2.07	3.02	1.57