CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Harmonized Resilience at Roosevelt Village

A model for equitable, replicable, grid-responsive urban housing

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Harmonized Resilience at Roosevelt Village - A Model for Equitable, Replicable, Grid-responsive Urban Housing is the final report for EPC-21-030 conducted by the Association for Energy Affordability, David Baker Architects, Center for the Built Environment, Rocky Mountain Institute, Taylor Engineering, The Engineering Enterprise, and Lawrence Berkeley National Laboratory. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

The Harmonized Resilience at Roosevelt Village project presents a cost-effective, low-carbon, grid-interactive design for a 6-story 71,000-square-foot mixed-use affordable housing development in San Jose, California. Exceeding the California Energy Commission's (CEC) Next EPIC Challenge criteria, the design can sustain critical loads in both common areas and apartments during power outages for most of the year and curtail 94 percent of daily peak energy use during peak hours (4:00 p.m. to 9:00 p.m.). Right-sizing a centralized solar-plus-storage microgrid in tandem with daily peak reductions lowers the required battery system capacity to 2.6 kilowatt-hour (kWh) per apartment. This is still enough to preserve in-unit critical services for most of the year and sets a new resilience standard for multifamily buildings that is especially valuable for supportive housing.

Informed by resident and staff focus groups as well as techno-economic analysis, this zero-emission design prioritizes economic benefit, operational simplicity for nonprofit ownership, and minimal resident disruption through reliance on proven technologies. Compared to an all-electric LEED project meeting 2022 California Building Energy Efficiency Standards (Title 24), the design reduces annual energy by 23 percent, operational carbon emissions by 70 percent, and embodied carbon by 17 percent.

Meeting the Next EPIC Challenge criteria imposes a 5 percent cost premium to the baseline design (without incentives); this is manageable from a societal perspective but exceeds acceptable levels in the current, highly competitive affordable housing finance environment. For this reason, a key goal of the project was to offer a broadly applicable design framework for dense mid-rise housing in near-coastal urban centers and to validate its recommendations through two additional case studies. A key part of this effort was to identify design and policy strategies that align affordable housing needs with grid decarbonization goals, while minimizing barriers to market transformation. These included thermal storage load shifting, maximizing PV size, and using modest (but not oversized) battery capacity, combined with policy measures, like metering reform, rate reform, and valuing non-energy benefits.

Keywords: affordable housing, battery storage, building decarbonization, demand response, distributed energy resources, energy efficiency, energy management system, virtual net energy metering, zero-emission buildings

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Background

Unlocking the United States building stock as a grid resource, capable of morphing load profiles to accommodate variable renewable generation, is critical to achieving a reliable grid and affordable energy transition, with estimates of savings up to $107 billion per year compared to business-as-usual power system buildout (Langevin et al. 2023). At the same time, the evolving climate presents escalating threats of severe weather occurrences and consequent power failures that necessitate planning by building developers, designers, and operators. This situation raises new inquiries regarding effective strategies to attain these results, the associated costs, the beneficiaries, and the obstacles to broad implementation.

The housing sector currently possesses low-carbon, scalable solutions that mitigate carbon emissions and enhance resilience during climate disruptions. However, the integration of these technologies presents significant challenges, particularly due to their complexity, for owners and operators, and the need for precise coordination with other measures. For instance, battery energy storage system (BESS) sizing often fails to account for the intricacies of system integration with other technologies capable of peak reduction or demand management. Strategic consideration of BESS sizing in coordination with other low-carbon and grid-responsive technologies can address upfront cost concerns, enabling broader adoption and scalability. This project is designed to address these integration challenges, fostering greater accessibility and broader adoption of these technologies across the multifamily housing sector.

In 2022, the Association for Energy Affordability received funding to design and plan the Harmonized Resilience at Roosevelt Village project as part of the California Energy Commission's (CEC) Next EPIC Challenge: Reimagining Affordable Mixed-Use Development in a Carbon-Constrained Future. A collaborative team that included nonprofit developer First Community Housing, David Baker Architects, the Center for the Built Environment, Rocky Mountain Institute, Taylor Engineering, The Engineering Enterprise, and Lawrence Berkeley National Laboratory modified an existing affordable mixed-use design that fulfills 2022 California Building Energy Efficiency Standards (Title 24), to further meet a futuristic set of grid-interactive criteria, consisting of radical load shifting, on-site power generation, and resilience capabilities.

Project Purpose and Approach

The vision for the Harmonized Resilience at Roosevelt Village project was to create a design that would provide meaningful resilience for vulnerable, very-low-income, and formerly homeless senior (55+) residents while enabling the efficient and cost-effective demand-side flexibility needed to meet the challenges of tomorrow's energy landscape. The project offers a cost- and carbon-optimized technology package for urban, mid-rise affordable housing that consumes no grid electricity for residential end-uses between 4:00 p.m. and 9:00 p.m. every day of the year, sustains critical load backup power to the apartments in addition to the house meter, shares utility bill benefits of the central photovoltaic (PV) and storage systems with residents, and provides economic incentives for residents to reduce energy consumption.

The study project consists of a 6-story, 71,000-square-foot, mixed-use, wood-framed podium building on a 0.42-acre site near downtown San Jose, California. This scale of housing typifies what is most common in urban areas, where the highest concentration of affordable housing is found (for example, the Los Angeles, Bay Area, and Sacramento metropolitan areas).

The project team integrated distributed energy resource (DER) technologies thoughtfully and cost-effectively, creating a model that can be replicated across similar communities to decarbonize the grid and maximize resilience for the facility and its residents. Proving financial viability for this project relied on guiding principles developed by the team to reduce demand, shift load, and integrate DERs, before sizing battery components for resilience or rate arbitrage. For buildings like Roosevelt Village, located in urban areas where power outages are relatively less common, this represents a novel approach that departs from industry practice, where conventional approaches to battery sizing for backup power prioritize meeting rare worst-case outage conditions occurring less than 3 to 5 percent of the year.

At Roosevelt Village, when multiple investments prioritized shifting loads out of the peak window every day, it informed a right-sized battery design. The final design integrates a suite of high-performance yet simple building technologies, including slimline packaged heat pumps, triple-pane low-solar heat gain coefficient glazing, Aeroseal-sealed envelopes achieving 1 air change per hour at 50 Pascals, high-density batt insulation (R-21), induction cooking, and LED lighting with smart controls and low-flow fixtures to minimize domestic hot water loads. A centralized ultra-low global warming potential refrigerant (carbon dioxide) heat pump system, with a swing tank, integrated with phase-change material to increase storage by one-third, is co-located with battery systems to enable thermal recovery from battery inefficiencies and passive battery cooling. A centralized dedicated outside air system ventilation system (4 fans for 74 units) eliminates rooftop ductwork, reduces maintenance, and leverages the heat recovery ventilator with bypass functionality for efficient, compressor-free air tempering. The centralized solar and BESS, coupled with a virtual net energy metering interconnection, avoids the costs of physically allocating and managing distributed storage among 74 apartments and enables a 94-percent curtailment of the whole building's daily energy consumption, for a submetered building. Although battery storage is not physically allocated to residents' meters, in-unit critical loads, such as refrigeration, filtered fresh air, power for devices, comfort control, and cold and hot water (until the hot water storage is exhausted), can be supported continuously by on-site resources for most of the year. This establishes a radical level of resilience for any multifamily building and is particularly of high value for supportive housing.

This study fulfilled and exceeded the CEC requirements (see Table ES-1) while balancing results for 1) resident resilience and health, 2) utility cost reduction for residents and owners, 3) lifecycle cost, and 4) operational and embodied carbon. EnergyPlus was used to evaluate a range of energy efficiency, energy recovery, and load management strategies, including various heating, ventilation and air conditioning and hot water system options. Xendee, a DER optimization software, was then used to optimize the best combination of load-reduction measures paired with on-site generation, thermal storage, and BESS. A comprehensive engagement process involving property management, on-site services staff, residents, and a technical advisory committee — comprising nonprofit developers, researchers, engineers, utility representatives, and product vendors — was integral to defining resilience goals and identifying critical loads for backup power.

Table ES-1: Next EPIC Challenge Minimum Design Requirements Versus Proposed Design

Minimum Design Requirements	Proposed
All-electric building	**Complies:** The project design does not include any gas equipment, appliances, or infrastructure.
A minimum of 20% of the building's peak load must be available to be temporarily managed or curtailed to respond to grid conditions.	**Exceeds:** The proposed design can shift 35% of the building's (gross) peak load in response to grid conditions using domestic hot water storage, without curtailing services for residents.
The residential load during the 4:00 p.m. to 9:00 p.m. period must be met through a combination of on-site renewables, storage, and load management.	**Exceeds:** All of the residential load and part of the nonresidential load are met according to this breakdown by strategy: Energy efficiency: 10% Peak load management: 14% Thermal storage: 32% Battery + PV 38%
All residential end uses must be controlled through the home energy management system and must respond to real-time price signals.	**Complies** (semi-voluntary approach): Occupants will be able to automatically control major in-unit loads with smart plugs and smart thermostats (OhmConnect) and voluntarily control all loads in response to "OhmHour" notifications and informational lighting real-time signals.
Microgrid controllers must be interoperable with DER aggregation platforms such as virtual power plants.	**Complies:** Only controllers capable of interfacing with California Independent System Operator-approved demand response providers will be installed.
The building must be able to island from the main grid during an outage and be able to shed discretionary loads for Tier 1 critical and Tier 2 priority loads.	**Complies:** The electrical design enables backup power for in-unit loads, support services, and building access and safety.
The microgrid must be sized for indefinite renewable-driven backup power of Tier 1 critical loads.	**Complies:** The battery is sized to accomplish renewables-driven backup power 98.6% of the year, and an electric vehicle truck boosts this coverage to 99.9%.

Minimum Design Requirements	Proposed
20% of all parking spaces must have vehicle-to-grid chargers, and 100% of spaces to be electric vehicle-ready.	**Complies:** 1 of 4 spaces has a bidirectional charger to serve the maintenance vehicle and provide Tier 1 outage support.

Source: The Association for Energy Affordability

Knowledge Transfer and Market Scaling

Roosevelt Village offers a cost-effective, low-carbon, and climate-resilient affordable housing model, utilizing proven technologies with low barriers to adoption, making it practical for nonprofit ownership to operate and maintain. As a result of the design phase, the project team developed a blueprint for architects, engineers, and developers to meet the futuristic carbon and resilience requirements for similar projects in mild climates. The team submitted these guidelines as a Market Transformation deliverable for publication in summer 2025. Throughout 2023 and 2024, the team conducted outreach activities to inform building industry stakeholders about these recommendations, specifically, presenting on panels for the American Council for an Energy-Efficient Economy Summer Study, the United States Green Building Council Smart Building Summit, Living Future, and the Center for the Built Environment Industry Advisory Board Meeting.

Design Phase Findings and Recommendations

Key Results

Table ES-2 provides a snapshot of the savings of the proposed design that met or exceeded all minimum design requirements. Key achievements are compared to a Title 24 design and are cost-competitive to receive a 4-percent tax credit under the Tax Credit Allocation Committee.

Tier 1 Critical loads supported:

- MERV 15 filtered fresh air to all apartments
- In-unit lighting, ceiling fan, and outlet
- In-unit refrigeration
- Hot and cold-water supply
- Barrier-free building access
- Internet communications
- Elevators and emergency lighting
- Basic office functions and security

Tier 2 Critical loads supported:

- Hot water heat pumps
- Central Wi-Fi routers
- Office lighting and heating, ventilation and air conditioning
- Community room plugs
- Security cameras
- Informational lighting

Table ES-2: Design Phase Performance Results

Design Phase Performance Results	Improvement Over Title 24 Baseline (%)	Value
Owner utility bill savings	100%	$6,856/year saved
Resident utility bill savings	86%	$950/year per unit saved
Annual GHG operating emissions savings	71%	71 MT CO_2e avoided annually
Net embodied emissions	3%	50 MT CO_2e saved
Life-cycle total emissions reduction (30 years)	36%	1,066 MT CO_2e saved
Peak demand managed without battery storage	70%	105,256 kWh/year
Grid purchase reduction from 4:00 p.m. to 9:00 p.m. peak (annual total)	94%	9,680 kWh/year purchased
Annual energy savings	23%	17 kBtu/SF/year
Percent of year Tier 1 loads sustained	99.8%	364 days
Percent of year Tier 1 and Tier 2 loads are sustained during a 24-hour outage	97.2%	355 days

GHG = greenhouse gas; kBtu/SF/year = thousand British thermal units per square foot per year; kWh = kilowatt-hours; MT CO_2e = metric tons of carbon dioxide equivalent
Source: Energy and Emissions Report

Design Phase Lessons

Design Integration of Distributed Energy Resources

Above Code Energy Efficiency

Finding: Efficiency measures that reduce peak periods limit the need for batteries and thus become more cost-effective when designing for the grid interactivity requirements of the Next EPIC Challenge.

Recommendation: The efficiency measures outlined in Title 24, including standard upgrades such as induction cooking and ceiling fans, consistently deliver value. Additional measures can be evaluated through straightforward cost-benefit analyses, which concentrate on minimizing evening and extreme weather loads to facilitate the use of smaller battery and PV systems.

Thermal Storage

Finding: Shifting domestic hot water thermal storage outside of the daily peak period (4:00 p.m. to 9:00 p.m.) and into the solar generation window was the single most impactful measure and cost-effective load-management strategy, eliminating one-third of the daily 4:00 p.m. to 9:00 p.m. peak at a modest incremental cost. Most importantly, thermal storage of central domestic hot water cannot be leveraged in the current compliance software, pushing developers to invest in batteries or high-cost efficiency measures to meet compliance.

Recommendation: The central heat pump water heater technology is advancing towards enhanced compatibility with load shifting. Numerous manufacturers have begun implementing the Consumer Technology Association-2045 standard, enabling the reception of load-up and shed commands for effective load shifting. It is advisable for programs and code development organizations to promote thermal storage as a preferable option over battery storage, facilitating designers and operators in maximizing the use of domestic hot water. For instance, straightforward scheduling strategies, such as incrementally adjusting setpoints during solar hours, will emphasize the utilization of off-peak, low-carbon electricity. More sophisticated control mechanisms could leverage real-time cost and/or emissions data to refine heat pump performance. Existing tools, like the EcoSizer, are already available for sizing central heat pump water heater systems tailored for load shifting, and incorporating bonus compliance credits for increasing domestic hot water storage and heat pump capacity to facilitate load shifting should be relatively straightforward. A basic equation could be integrated into the compliance software to provide credits for system designs that align with modeled domestic hot water demands, and even uncomplicated control setpoint scheduling methods can yield substantial cost and carbon reductions.

PV Generation

Finding: Despite challenges like the duck curve (a graphical representation of daily electricity demand patterns influenced by solar energy generation) and net energy metering rollbacks (reduction in financial benefits that homeowners with solar panels receive for excess electricity they send back to the grid), maximizing PV generation rather than up-sizing battery capacity remains essential for meeting 100 percent of 4:00 p.m. to 9:00 p.m. daily load shifting and resilience goals, especially in mid-rise buildings with limited rooftop space.

Recommendation: Due to the relative cost-effectiveness of PV compared to batteries, prioritizing PV through strategies like rooftop canopies, carports, optimized orientation, and space-constrained sizing is typically the most economical approach to reducing the lifecycle cost and carbon emissions.

Battery System Sizing

Finding: Right-sizing a central battery in tandem with daily peak (4:00 p.m. to 9:00 p.m.) reductions enabled by other technologies (most notably, thermal storage) reduced the required battery system capacity to just 2.6 kilowatt-hours per apartment

Recommendation: As the industry scales battery deployment, this integrated approach of demand reduction, load shifting, and strategic DER integration offers a financially viable pathway to meaningful resilience without the prohibitive costs of conventional emergency-only sizing strategies.

The distribution of load diversity among apartments and any commercial areas within the building enables central systems (such as PV panels, batteries, and domestic hot water systems) to be more compact and generally less expensive than the total cost of individual systems needed for each apartment to meet equivalent goals, excluding heating, ventilation and air conditioning. Furthermore, these setups have also mitigated the expenses, materials, and upkeep associated with the physical allocation and management of distributed storage across 74 apartments.

Resilience

Finding: A battery sized to reduce 4:00 p.m. to 9:00 p.m. grid purchases by 94 percent that achieved 96.4 percent annual resilience coverage is more than enough capacity to deliver what residents value most — safety and mobility in common areas plus enough sustaining basic, critical in-unit functions for residents during a 24-hour outage virtually any day of the year. This added only 5 percent to total construction costs, which is in stark contrast to conventional approaches to battery sizing that would require 17 times battery capacity, and 6 times cost increases for 100 percent backup power coverage.

Recommendation: Programs looking to deploy battery storage at scale should prioritize eliminating barriers to robust and meaningful backup power solutions for multifamily buildings, which has a secondary benefit to the grid, rather than mandating grid-tied battery systems through the energy code, which has no direct benefit to the property.

Vehicle-to-Building

Finding: A battery storage capacity that is 2 to 7 times greater is required to accommodate the most severe 2 to 5 percent of annual loads during an average year, particularly during extended periods of cloudiness. By utilizing vehicle-to-building technology, the final 3 to 5 percent of essential annual loads can be met with grid power, significantly reducing costs as compared to traditional stationary storage.

Recommendation: There is a necessity to enhance the availability of bidirectional electric vehicles and chargers in the market, as well as to investigate a comprehensive array of innovative strategies to address the most challenging annual loads, which frequently render battery storage economics unattainable for affordable housing.

Finding: Despite eliminating annual nonresidential utility expenses and decreasing resident utility costs by 90 percent, the projected 30-year lifecycle expenses of the proposed design exceed those of the baseline Title 24 building under Net Energy Metering 2.0 and are even greater under Net Energy Metering 3.0. This difference in costs underscores that current electricity rates, when evaluated in isolation, do not offer adequate economic justification for the incorporation of distributed energy infrastructure in urban housing. The addition of approximately $200 per ton for the social cost of carbon (SCC) significantly influenced the reduction in lifecycle costs.

Recommendation: A more thorough investigation into the SCC and non-energy benefits pertaining to physical and mental health, as well as to the hazard resilience of resident communities, is essential to assess the long-term financial viability of incorporating grid decarbonization in multifamily housing. The discovery that the economic viability of a microgrid solution in this housing category may depend on its resilience advantages should guide the formulation of programs and policies, given the significant variation in risk profiles among urban communities.

Market Availability of Microgrid Technologies

Finding: Only one or two vendors expressed interest in small- to medium-sized microgrid projects (approximately 200 kilowatts) like the microgrid for this project. Even after identifying a microgrid provider, the ability of microgrid technologies to integrate smoothly with commercially available building management systems presented a challenge.

Recommendation: It is essential to acknowledge the market for products catering to the multifamily sector, which includes third-party providers capable of offering mid-size microgrid solutions (BESS ranging from 100 to 800 kilowatts). Furthermore, there must be an emphasis on the ability of technologies to integrate smoothly with commercially available building management systems and other smart devices, ensuring compatibility, ease of use, and enhanced demand management control for lighting, central ventilation, and hot water systems.

Policy Barriers

Finding: Thirty eight percent of the incremental up-front costs for the recommended design that meets the Next EPIC Challenge requirements were associated with virtual net energy metering infrastructure, electrical equipment, and microgrid components that could be eliminated if master metering were allowed.

Recommendation: Consider revising the policy to permit multifamily buildings to utilize master metering (with the possibility of tenant submeters to proportionately bill residents according to their energy consumption). This could significantly lower the initial expenses associated with the deployment of solar PV systems, battery storage, and microgrid solutions, while also facilitating a more equitable distribution of the advantages of these systems among tenants.

Advanced Construction

Finding: Following an assessment of volumetric modular and mass timber construction, it is evident that traditional wood-frame construction techniques are already highly optimized in terms of labor and time, representing a low-carbon solution for urban housing. Nevertheless, there exist opportunities to enhance material utilization through improved structural design and coordination, which could lead to further reductions in costs and resource impacts. Furthermore, prefabricated solutions for subcomponents show potential for lowering expenses and enhancing quality, particularly in areas that significantly affect human experience and health, while presenting less risk and causing less disruption to the industry compared to volumetric modular methods. Additionally, utilizing location-specific low-carbon concrete mixes can result in substantial decreases in overall embodied carbon.

Recommendation: Further explore a full range of emerging industrialized approaches and encourage partnerships between interest groups and the trades to move towards energy-efficient solutions that also involve less bespoke on-site construction.

CHAPTER 1: Introduction

Goals and Objectives

In 2022, the California Energy Commission's (CEC) Next EPIC Challenge: Reimagining Affordable Mixed-Use Development in a Carbon-Constrained Future awarded 12 teams throughout the state to develop a design for a real, affordable mixed-use development that provides radical load shifting, on-site power generation, and resilience capabilities. In responding to the CEC challenge as a design-phase grant awardee, the Association for Energy Affordability received funding for the Harmonized Resilience at Roosevelt Village project (Roosevelt Village), in partnership with nonprofit developer First Community Housing, David Baker Architects, the Center for the Built Environment, Rocky Mountain Institute, Taylor Engineering, The Engineering Enterprise, and Lawrence Berkeley National Laboratory. The team envisioned a scalable model to provide meaningful resilience for vulnerable, low-income, and formerly homeless residents while enabling the efficient and cost-effective demand-side flexibility needed to meet and exceed the CEC minimum design requirements:

- All building end-uses must be electric (no gas consumption allowed).
- A minimum of 20 percent of the building's peak load must be temporarily managed or curtailed to respond to grid conditions.
- The building's residential load during peak demand hours, 4:00 p.m. to 9:00 p.m., must be met through a combination of on-site renewables, on-site storage, and load management.
- All residential end uses must be controllable through the home energy management system and capable of responding to real-time pricing signals.
- The microgrid controller(s) must be interoperable with distributed energy resource (DER) aggregation platforms such as virtual power plants.
- The building(s) must be able to island from the main grid during an outage and be able to shed discretionary loads to provide power to Tier 1 critical loads (10 percent of peak load) and Tier 2 priority loads (25 percent of peak load).
- The microgrid must be sized for indefinite renewable-driven backup power of Tier 1 critical loads using any combination of on-site renewables, on-site storage, and load management.
- Twenty percent of all parking spaces associated with the development must have electric vehicle (EV) charging stations that can respond to grid and building signals.
- All remaining parking spaces must be EV-ready, meaning they must have a dedicated electrical circuit with the capacity to eventually become a charging station.

The implicit suggestion of the CEC's challenge is that multifamily buildings are a critical sector for serving the need for grid stability and a focus on affordable housing in particular stands to benefit low-income communities. However, although the benefits of decarbonization are clear, the challenging economics of constructing new affordable housing and the sensitivity of non-profit property owners to new technologies, especially those that don't align with the priorities of operators, complicate understanding the potential benefits. The project team observed this uncertainty play out as nonprofit developers navigated the roll-out of battery requirements in the 2022 California Energy Code without the tools to determine their economics. This is why a critical component of the Roosevelt Village project was to look beyond the Next EPIC Challenge requirements and determine which investments, or combination of investments, would provide the most reliable overlap between affordable housing needs and grid decarbonization goals, and to offer a replicable model posing the fewest barriers to market transformation.

Site

Roosevelt Village consists of a 6-story, 71,000-square-foot, mixed-use, wood-framed podium building on a 0.42-acre site near downtown San Jose, California, and typifies housing that is most common and cost-effective to finance and construct today in urban areas, where the highest concentration of affordable housing exists. It also presents inherent constraints for on-site DERs, such as a small roof footprint and zero-lot-line condition, common for projects in dense urban areas.

The project was designed to offer housing and supportive services to very-low-income and formerly homeless seniors. The proposed site was in both a disadvantaged community (75 to 80 percent disadvantaged community per CalEnviroScreen 3.0, Senate Bill 535) and a low-income community (Assembly Bill 1550) with strong access to open space, transit, and amenities. This location is ideal for enhancing convenience and access to everyday necessities for seniors (aged 55 and up) and others who may otherwise have limited mobility options. The development is planned to offer free car share and city bike share memberships to further reduce barriers to human-powered and carbon-free transportation.

Figure 1: Rendering of Roosevelt Village, 995 East Santa Clara Ave, San Jose, California

Source: David Baker Architects

CHAPTER 2: Project Approach

To meet and exceed the CEC's zero energy emissions goals, the project team utilized multiple simulation tools in tandem to determine how different combinations of investments would perform compared to the baseline, minimally code-compliant design. Results were optimized for: 1) resident resilience and health; 2) utility cost reduction for residents and owners; 3) lifecycle cost; and 4) operational and embodied carbon. A detailed discussion of the modelling process and diversity assumptions can be found in an Energy and Emissions Report (Duarte et al. 2023).

Baseline Design

A baseline energy model for Roosevelt Village was constructed using EnergyPlus, based on measured data from existing multifamily buildings with resident characteristics similar to those of the Roosevelt Village project, including daily and hourly electricity consumption datasets at the building or apartment level from multiple sites. This baseline meets the specifications of a standard-practice project under the 2019 code for San Jose, which is all-electric (local requirement), using ENERGY STAR appliances, LED lighting, and heat pump water heating. The baseline energy use intensity (EUI) was estimated to be 23 thousand British thermal units per square foot (kBtu/SF).

Because there is limited hourly measured data available, the project team supplemented the measured data with the Pacific Northwest National Lab multifamily reference whole-building energy model. The combination of these data informed the typical peak electrical load and diversity factor across apartments by hour of day. First Community Housing established a construction cost driven largely by a per-unit construction cost that was competitive for a 4-percent tax-credit funded project in California. A schematic design phase project cost estimate came to $48,000,000, relatively close to the $620,000/unit cost target. The cost target and construction estimate in this report represent a snapshot in time only and are most valuable relative to each other.

Proposed Design Approach

The primary objective of the project was to concentrate efforts on the integration of technologies and methodologies that have shown potential and possess low barriers to adoption within the housing construction sector. These technologies should also be feasible for a nonprofit owner to manage and maintain, without disrupting or controlling the daily routines of residents. The comprehensive strategy to fulfill CEC requirements, particularly to address building electricity consumption during the peak hours of 4:00 p.m. to 9:00 p.m., utilizing on-site resources includes: (1) a 56-percent reduction in loads during the peak hours through a combination of energy efficiency, thermal storage, and load management strategies, as previously outlined; (2) the optimization of solar PV output through the use of an elevated canopy; and (3) the provision of an electrochemical battery that is appropriately sized to cover the remaining energy demands of the apartments. This encompasses the additional heating and cooling requirements during the most extreme summer and winter design conditions (specifically, high energy demands and minimal solar PV generation).

Initially, the team evaluated the performance results from a range of potential strategies for energy efficiency, energy recovery, and load management using EnergyPlus. This evaluation included various options for heating, ventilation, and air-conditioning (HVAC) systems, as well as hot water systems. Individual energy efficiency technologies were incorporated into the proposed design if they:

1. Cleared an initial bar of having a simple payback of 30 years max.
2. Showed a strong 4:00 p.m. to 9:00 p.m. load reduction potential.
3. Did not (significantly) increase embodied carbon.
4. Offered similar or reduced project complexity.
5. Were feasible to install within the timeframe of the grant's Build phase.

Then, combining only the most cost-effective efficiency measures into a single package, the team employed Xendee, a cost-carbon optimization tool, to find the optimal investments in more emerging and expensive measures compared to additional battery capacity. Optimizing DERs alongside packages of load-reduction, load shift, and thermal storage measures has not been done before, particularly in an affordable housing context.

Life cycle cost analysis within Xendee incorporated up-front costs estimated in partnership with Roberts Obayashi, the project's general contractor, at a schematic-design level of development and refined based on coincident projects going out to bid. This analysis was accompanied by a multi-stage engagement process with property management, on-site services staff, and residents from a similar property to define resilience goals for the property and critical loads for backup power. A technical advisory committee of nonprofit developers, researchers, engineers, utility representatives and product vendors assisted the study.

Stakeholder Engagement Process

Climate resilience planning was an early component of the Community Engagement Plan, beginning with a meeting with Family and Community Health departments to review forecasts of extreme weather and other hazards. This site is most vulnerable to heat waves, wildfire smoke days, and short-term power outages, although longer, one- to three-day, outages are possible with major storms and earthquakes. Riverine flooding must also be mitigated by elevating the ground floor and installing flood control features at the transformer.

The team then interviewed residents at Leigh Ave Apartments — a nearby property with the same resident population — about their concerns regarding hazards in general and power outages in particular. The critical functions that mattered most to residents were refrigeration to preserve personal food items and medicines, followed by general safety in communal areas, in particular building access, corridor lighting, and elevator operation. Charging of motorized chairs and medical equipment, internet communications, and basic office functions were also highlighted by staff as priority emergency services.

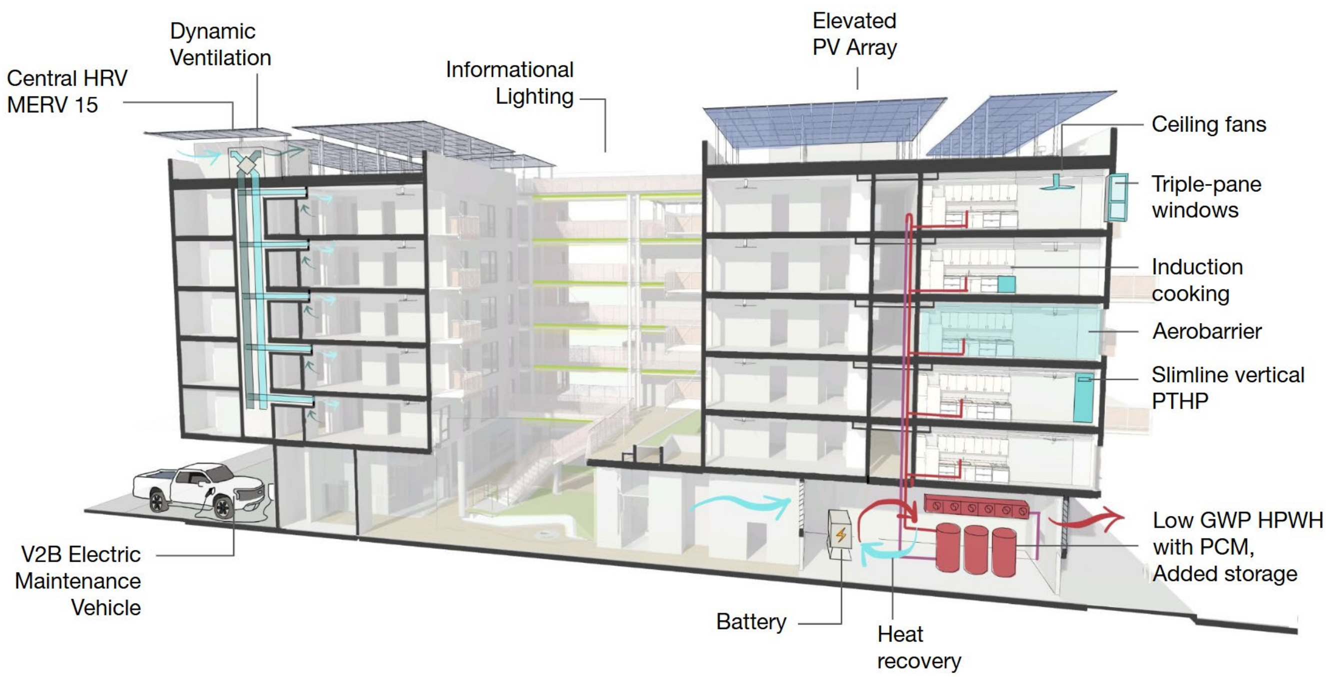
Stakeholder feedback also strongly underscored the general priority of selecting systems that can be serviced by on-site maintenance personnel, to support robust operations generally, but particularly during emergencies.

Design Strategies for Integrating Conventional and Emerging Energy Technologies

Energy Technology Package

All technologies presented in the final design (Figure 2) were evaluated against the previously mentioned criteria, and only the top contending technologies are discussed in this final report. See the Emerging Technologies Report (Appendix D) for more details on selection criteria and optimization process, including a discussion of technologies analyzed but not adopted.

Figure 2: Proposed Innovations for Roosevelt Village



Source: The Association for Energy Affordability

End-Use Energy Efficiency

Designing for radical grid interactivity makes additional efficiency measures beyond Title 24 (T24) compliance more cost-effective measures that reduce battery size by producing savings during the daily peak window (4:00 p.m. to 9:00 p.m.), reduce priority loads, or reduce power consumption during extreme weather conditions. Because CEC requirements could not be met without a sizable investment in the fixed costs of microgrid infrastructure, the financial viability of the project depended on comparing the relative impacts of individual measures on annual cost savings (Figure 3) and avoided battery cost (Figures 4 and 5). Avoided battery cost is approximated, using two "near peak" days in summer and winter (the day after the peak, when DER resources are most constrained). Each measure's impact reflects its higher avoided kilowatt-hours (kWh) from those days. This impact is highly dynamic. Overall, optimization around these metrics resulted in proposed efficiency measures that, compared to the baseline T24 model, leave only 38 percent of the annual consumption during 4:00 p.m. to 9:00 p.m. remaining for PV and battery systems to cover.

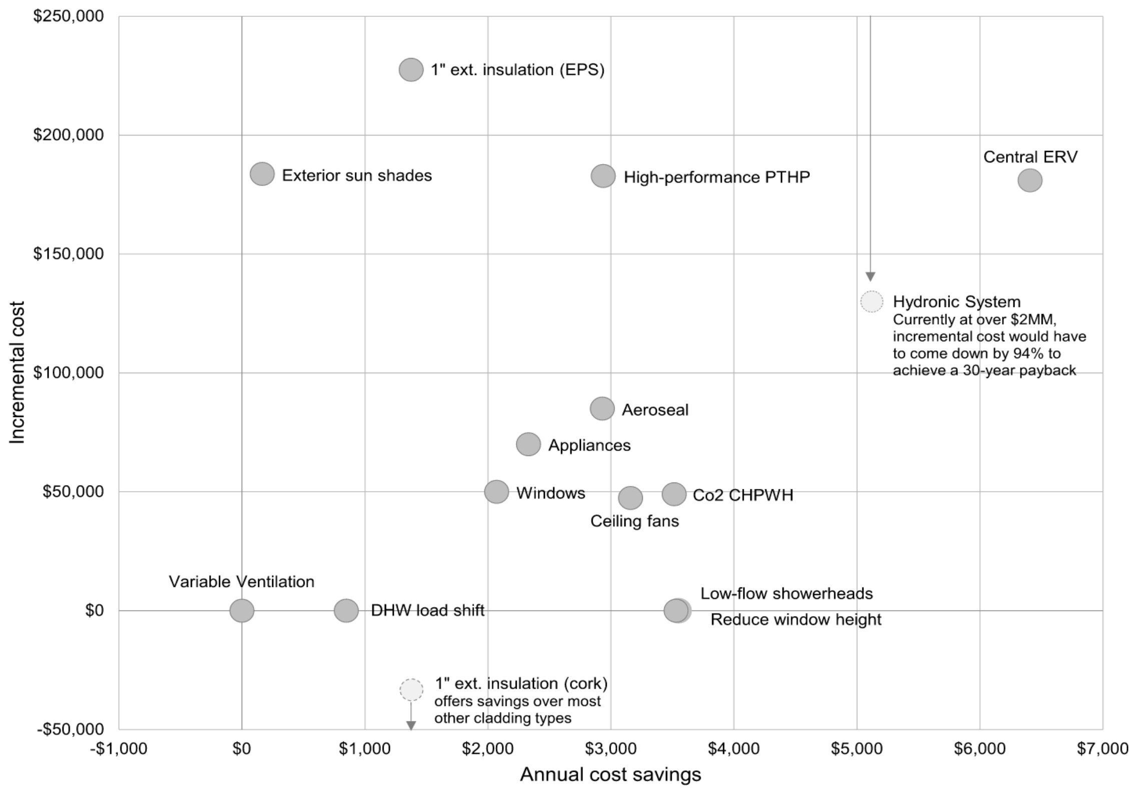
The final design included simple measures like slimline packaged heat pumps, reduced air infiltration to 1 air changes per hour at 50 Pascals, using Aeroseal, triple-pane windows with low solar heat gain coefficient (SHGC), high-density R-21 fiberglass batt insulation, induction cooking, ceiling fans, and several other load management strategies (see next section). Further reductions are achieved through LED lighting, smart lighting control systems, and low-flow fixtures to reduce domestic hot water (DHW) demand served by a central SanCO_2 heat pump system with one-third more storage and 20 percent more capacity than a standard design due to the addition of a phase change storage/swing tank. The system is co-located with the building's battery systems to recover heat associated with battery inefficiency and to cool the batteries in warm weather, reducing losses due to the battery's thermal management system.

The centralized ventilation system removes all visible ductwork on the roof and enables the implementation of superior, more durable filters, significantly decreasing maintenance requirements. Rather than employing a fan or several ventilation fans for each unit, only four fans are utilized to serve all 74 units. These fans feature direct drives with electronically commutated motors, enhancing both efficiency and reliability. The heat recovery ventilator (HRV) operates without compressor-based conditioning, utilizing heat recovery to moderate the incoming air flow, and includes a bypass for times when heat recovery is not advantageous.

Fully leveraging the thermal storage potential of the central water heater is the single most impactful measure, eliminating one-third of the 4:00 p.m. to 9:00 p.m. peak at a modest incremental cost (Figures 3 and 4). Adding heat recovery to the central dedicated outdoor air system (DOAS) was also beneficial; although this is an expensive measure, the ability to eliminate compressor-based tempering and reduce load during peak winter nighttime hours proved cost-effective and advantageous in terms of operational resilience. A bypass on the heat recovery is included to admit cooler outside air during summer, when economizing can help offset compressor-based cooling. Ceiling fans, additional air sealing, and variable ventilation offer strong peak load reductions (especially during 4:00 p.m. to 9:00 p.m.) at relatively low up-front cost.

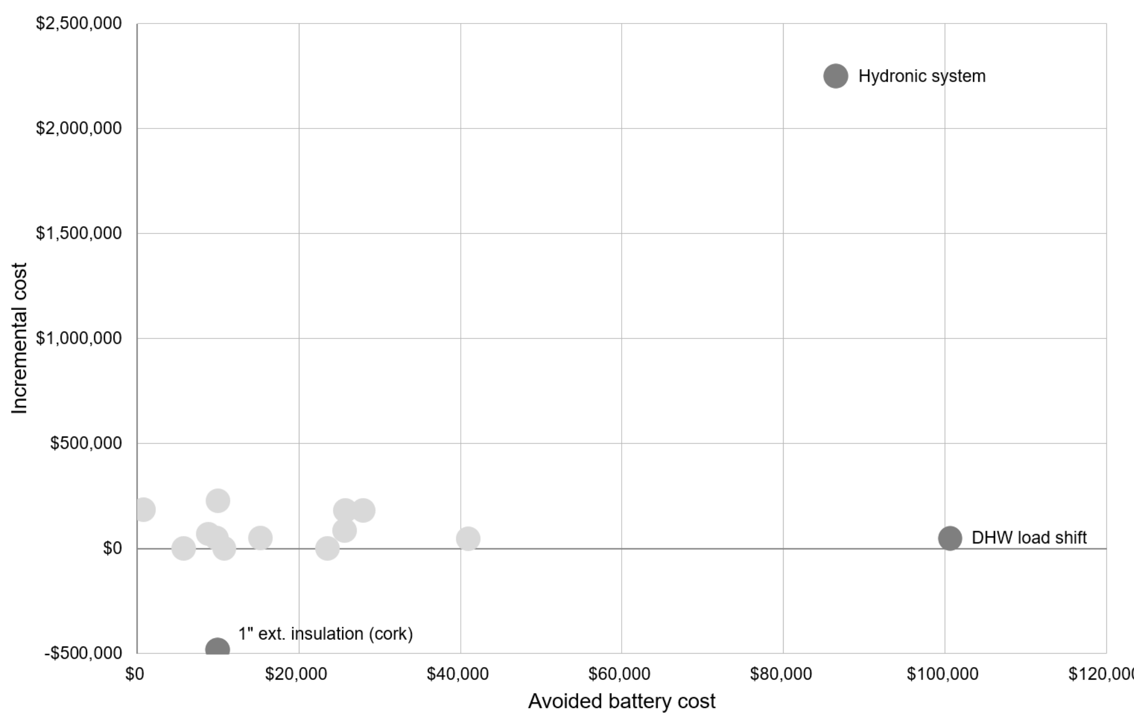
Due to the relatively minor heating and cooling loads, coupled with the already efficient standard building envelope, there are few envelope and thermal storage strategies aimed at these loads that are beneficial in terms of lowering life-cycle costs (LCC) or emissions. The addition of one-inch expanded polystyrene continuous insulation and external metal sunshades has a minimal effect on demand and incurs a significantly high initial cost, as illustrated in Figure 3 (the same applies to carbon payback).

Figure 3: Incremental Cost Versus Annual Cost Savings of Simulated Design Measures



Source: The Association for Energy Affordability

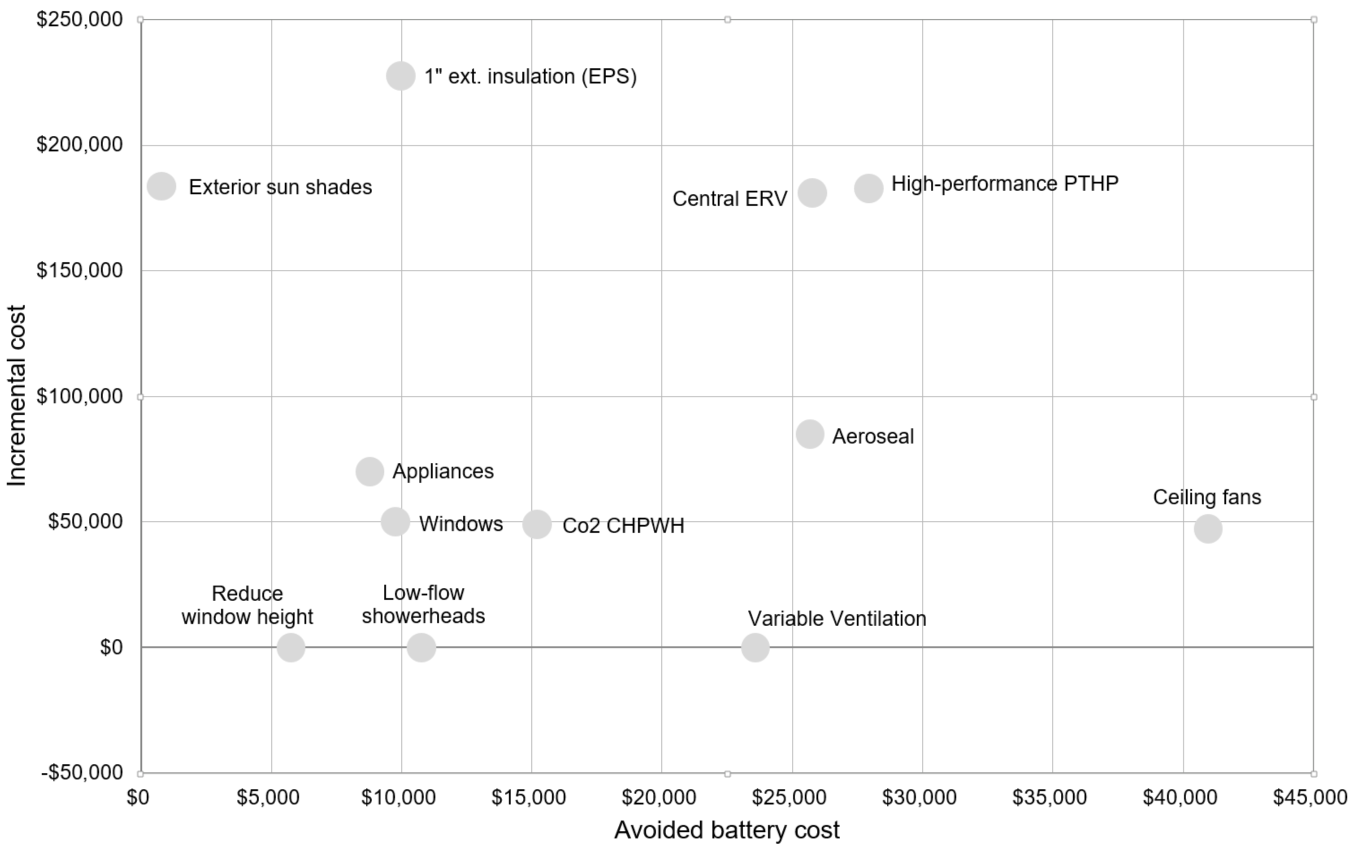
Figure 4: Incremental Cost and Approximate Avoided Battery Cost by Measure



Source: The Association for Energy Affordability

As illustrated in Figure 5, a hydronic heating and cooling system equipped with ample thermal storage effectively minimized heating and cooling demand to nearly zero from 4:00 p.m. to 9:00 p.m. However, it only slightly exceeded the life-cycle emissions reductions achieved by conventional heat pumps and it incurred a significant cost premium, alongside various market and operational challenges, leading to its discontinuation. In the end, it was concluded that modifying standard practices to facilitate the adoption of this technology for peak reduction benefits, particularly during the summer months, was not pragmatically viable.

Figure 5: Incremental Cost and Approximate Avoided Battery Cost by Measure, Excluding Thermal Storage Measures



Source: The Association for Energy Affordability

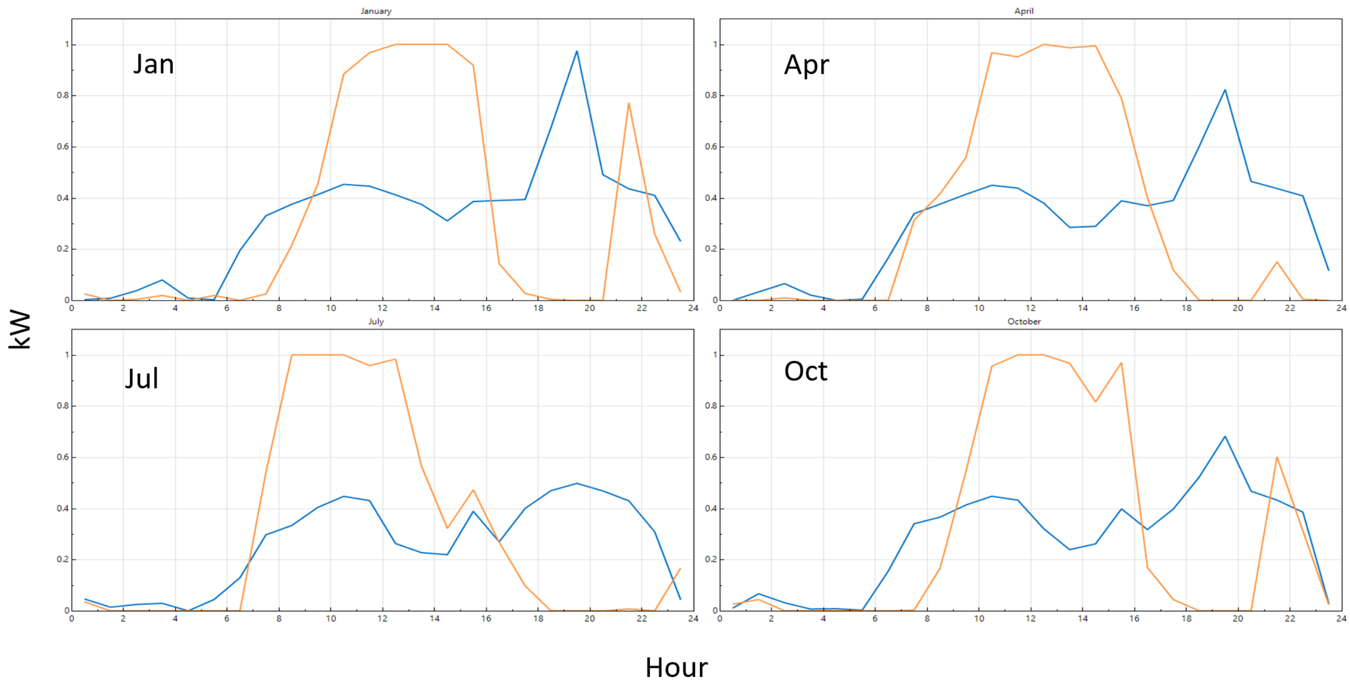
Dynamic Load Management, Grid Interactions, and Resident Engagement

The strategies described in this section are incorporated to shift energy consumption during the daily peak period (4:00 p.m. to 9:00 p.m.).

Thermal Storage Using Controllable Heat Pump Water Heaters

One of the key learnings from this work is that sizing DHW storage and enabling controls to fully shift heat pump water heater operation outside of the daily peak window (4:00 p.m. to 9:00 p.m.) and into the low grid emissions solar generation window is one of the most cost-effective and impactful strategies, but it is not currently common practice. As an example, a DHW shifting outcome that is co-optimized for cost, based on a time of use (TOU) rate, and emissions for Roosevelt Village is shown in Figure 6.

Figure 6: Normalized Average Heat Pump Water Heater Daily Profiles by Season, With Load Shifting (Orange) and Without (Blue)



Source: The Association for Energy Affordability

Dynamic ventilation represents a control strategy permitted by American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 62.2, whereby ventilation rates may be decreased during specific times of the day if they are increased during other periods. In the proposed architectural design, the ventilation rate is elevated by 20 percent above the baseline for all hours, except the period from 4:00 p.m. to 9:00 p.m., during which it is reduced by 50 percent from the baseline. This dynamic ventilation approach remains largely untested in multifamily residential settings and is most effectively and successfully executed through a centralized ventilation system. However, the risk associated with the implementation and testing of this strategy is negligible, as reverting to conventional operation is straightforward.

Smart Thermostats and Consumer Demand Response Platform

After shifting heating, cooling, hot water, and ventilation loads as much as feasible, shifting the remaining major contributor to the afternoon peak — residential electrical loads — is difficult without removing services to residents. Potential peak reduction and grid-responsive behavior is captured through voluntary programs, such as OhmConnect and direct communication from building staff. OhmConnect is an appropriate solution for residential peak load management in affordable housing because it: does not rely on complex interfaces or smart phones (not more than 20 percent of residents are expected to be able to afford one); can adjust to the user's level of comfort or engagement; and is enabled by including a few simple, non-intrusive devices (such as Nest smart thermostats, a smart plug connected to the refrigerator, and a second smart plug to be used on other loads defined by residents) that provide incentives to residents to voluntarily, manually shift electrical loads where feasible.

With these devices enabled, "OhmHour" events would trigger them to automatically adjust down or off, and residents can redeem credits for the curtailment.

Provided the system is explained to residents, participants of the focus groups were positive about OhmConnect's ability to facilitate both automatic and voluntary load management, which would offer utility bill savings with little effort on the part of residents and accommodate each resident's level of interest and capacity to engage in such a program. One resident of Leigh Ave Apartments was already a participant in the program.

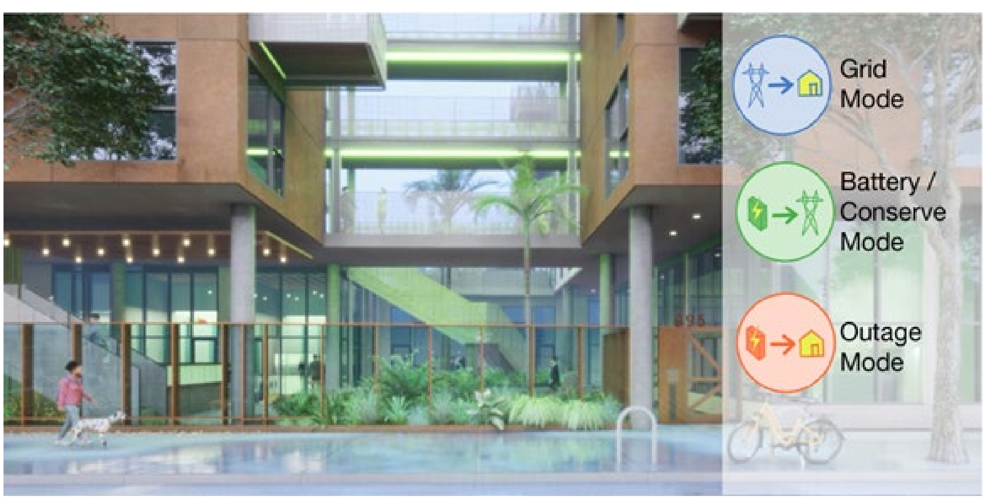
Informational Architectural Lighting

Outside of Ohm events, architectural lighting (Figure 7) was incorporated into the team's design to provide a visual cue for when the building is in battery discharge mode (typically 4:00 p.m. to 9:00 p.m.) and voluntary conservation will lead to shared financial benefits. Decorative LED tape light would change color based on the following modes:

- **Grid mode (blue):** The building is drawing power normally from the grid, and the battery is either charging or charged.
- **Battery/conserve mode (green):** The battery is discharging to the grid (typically during the 4:00 p.m. to 9:00 p.m. peak).
- **Outage mode (orange):** The building is islanding during a power outage with Tier 1 and Tier 2 loads supported.
- **Severe outage (lights off):** The LED tape lights are a Tier 2 load. In a constrained outage condition, "no light" conserves power while indicating that only Tier 1 loads are supported.
- **Bad air quality (purple):** The air quality index is 150 or above.

On-site resident service providers would be a key asset in reinforcing the meaning of this system. This system was attractive in focus groups because it could support general emergency communications, which were a source of concern for residents.

Figure 7: Visualization of Architectural Lighting



Source: The Association for Energy Affordability

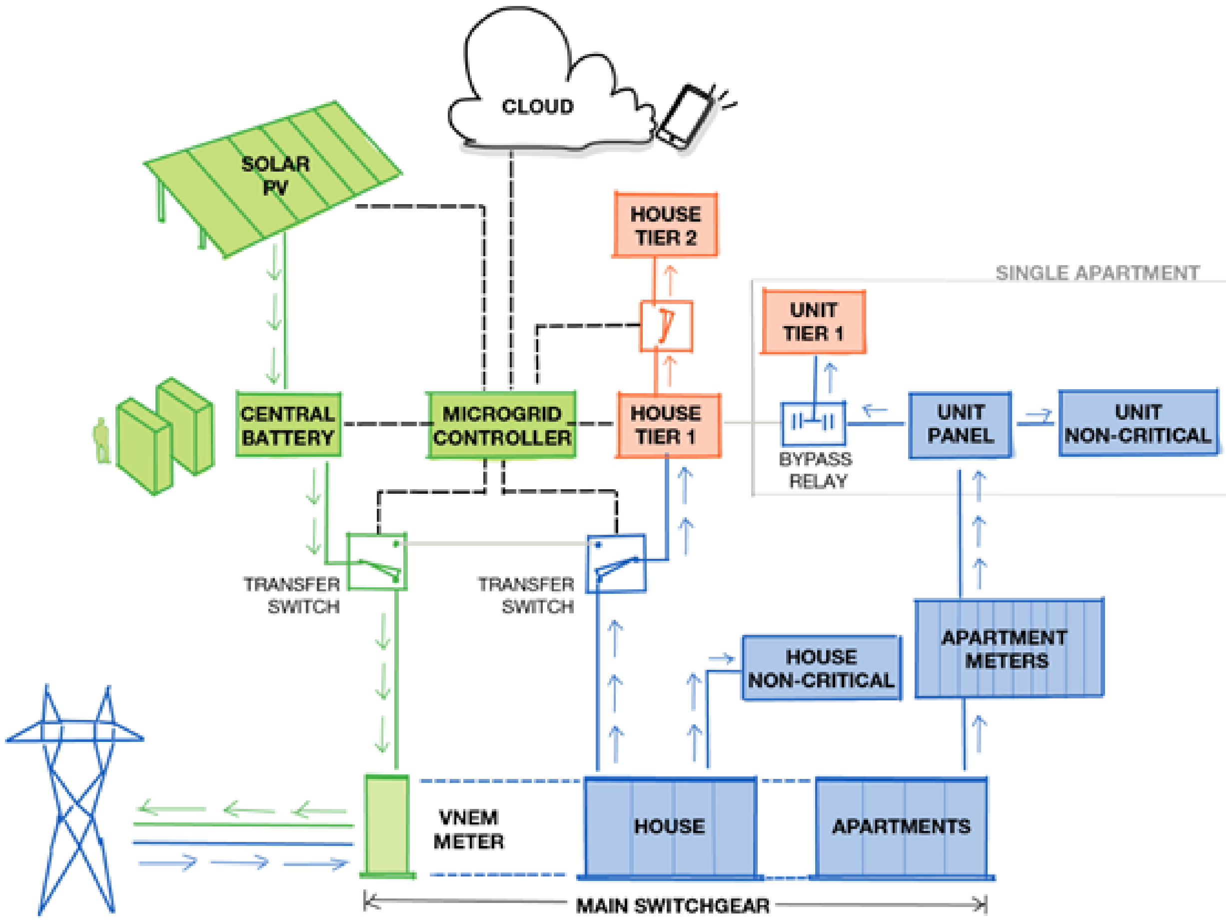
Laundry incentives

The energy model for the building posits that 50 percent of a standard laundry load can be rescheduled outside the hours of 4:00 p.m. to 9:00 p.m. The project team conducted workshops with focus groups to explore various potential strategies, with the most promising being the collaboration with service providers' existing incentive programs to offer rewards to residents who utilize the laundry facilities in the morning. Initial feedback indicates that, while this approach is feasible, it is also delicate, as residents may not share a common interest or benefit in altering their laundry habits. Such pressures and complexities could exacerbate an already difficult living environment. Should this behavior-change strategy be implemented in a real-world project, the post-occupancy evaluation must examine its effectiveness and fairness.

Microgrid Design Strategy

The microgrid features a central configuration comprising a 268-kWh battery and a 171-kilowatt (kW) PV system, which is elevated on a steel framework designed to operate in a virtual net energy meter (VNEM) setup (refer to Figure 8). This VNEM interconnection allows residents to benefit from the savings on utility bills generated by the on-site energy systems. The microgrid controller serves as a central point for managing real-time data and directing energy resources to fulfill operational needs (for instance, load matching — ensuring that there are no grid imports from 4:00 p.m. to 9:00 p.m. for residential demands), isolating from the grid during outages, and engaging in virtual power plant initiatives. The design team opted for a central approach as it facilitated the appropriate sizing of the system in conjunction with daily peak (4:00 p.m. to 9:00 p.m.) reductions achieved through other technologies (particularly thermal storage), while also minimizing materials, costs, and maintenance associated with the physical allocation and management of distributed storage across 74 apartments. Furthermore, a central battery can leverage load diversity among the apartments, thereby decreasing the necessary capacity to merely 2.6 kWh per apartment.

Figure 8: Schematic Diagram of Electrical Design in Normal Operation



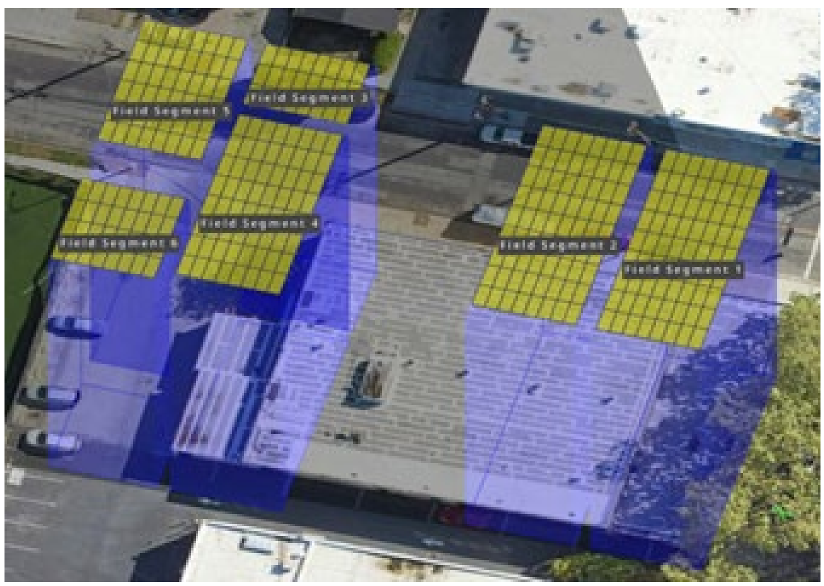
Source: Rocky Mountain Institute

Since the building would serve a senior population for which some critical loads were identified as in-apartment loads, the switchgear and wiring was configured to allow backup power to serve each apartment in addition to the common spaces. During an outage, a series of automatic transfer switches from the VNEM meter to the main switchboard provides immediate power to both in-apartment resident loads and house meter critical loads located on their own panelboards and associated feeders. This proved to still deliver substantial backup power and resiliency benefits at a relatively low cost compared to both central and in-apartment behind-the-meter battery configuration or the utilization of smart sub-panels in each apartment. To place in-unit loads on backup power, the electrical design includes a bypass relay at each apartment electrical panel that switches the power feed from the residential meter to the house meter when the grid goes down. This configuration means that the basic functions of the home — refrigeration, filtered fresh air, power for devices, comfort control, and cold and hot water (until the hot water storage is exhausted), in addition to basic common area safety — can be supported indefinitely by on-site resources for the vast majority of the year, which would be a radical level of resilience for any multifamily building, particularly one providing affordable housing.

After assessing several PV emerging technologies (including façade-integrated PV and bifacial panels), racking systems, and orientations, modeling led the project team to max out rooftop

PV with a monofacial array elevated on structural steel (Figure 9), with a zero-degree tilt and a ground coverage ratio of 0.98 oriented with the long axis in the SW-NE direction. Based on cost, constructability, and a dramatic increase in annual energy production offered by the elevated canopy, this solution emerged as the lowest life cycle cost after accounting for the avoided battery capacity needed to fully shift grid consumption out of the daily 4:00 p.m. to 9:00 p.m. window every day of the year. For comparison, an unelevated 130-kW rooftop array (specifically, a more typical rooftop PV installation) would require more than doubling the battery size to a 593-kWh battery to achieve the same daily shifting outcome. This is likely since, when the building is more PV-constrained and no grid charging is allowed, it is difficult to sufficiently charge the battery enough each day to meet the 4:00 p.m. to 9:00 p.m. residential loads; thus, the battery size must increase. Allowing grid charging makes a big difference in battery size and cost, because it removes this charging constraint but, in the elevated PV scenarios, when PV generation is more sufficient, this dynamic disappears, as the battery can charge sufficiently whether grid charging is allowed.

Figure 9: Helioscope Model of Elevated Monofacial PV Canopy



Source: Helioscope[1]

Electric Vehicle Charging, Vehicle-to-Building Capability

The biggest opportunity to extend critical load support and prevent the need to oversize batteries is to leverage an electric maintenance vehicle capable of vehicle-to-building (V2B) or vehicle-to-grid (V2G) capabilities. The project currently has one bi-directional EV charger serving a maintenance truck, with the other remaining spaces EV-ready for use by on-site property managers and commuting staff. Because this project is in a downtown, transit-rich site, no parking spaces are reserved for residents. But, even at a site with more structured parking, the ability to use electrified residential parking for battery coverage during the 4:00 p.m. to 9:00 p.m. period would be limited by a high degree of uncertainty as to how many and

[1] Due to the proposed Virtual Net Billing Tariff rule, the impacts of a Virtual Net Billing Tariff on the proposed design were also evaluated; see the Cost Benefit Report, Section 4.

when very-low-income residents would have an electric vehicle and as to the reliability of when this resource would be available when it does exist.

The EV charger is a V2B style charger, which enables it to charge under normal power conditions and discharge when grid power is lost. This charger also enables external inputs from the microgrid controller to prioritize charging at low demand and low peak times, as well as to respond to real-time price signals. The intent is that during (rare) multiple-day periods with extremely cloudy weather that coincide with a power outage, staff could charge the truck off-site once a day to replace the missing solar generation and supplement a battery's low state of charge, allowing the site to indefinitely serve Tier 1 loads even under these outlier conditions. As explained in Chapter 3: Results, this approach saves significant upfront cost by circumventing an industry standard to upsize batteries, almost fivefold, to serve the last 1 percent of critical loads that may occur during these rare outage events.

Advanced Construction and Embodied Emissions

To offset the initial cost associated with adding major DER infrastructure to conventional affordable housing, the project team studied opportunities to increase the efficiency of construction. This dovetailed with a whole-building embodied carbon analysis to determine whether there were significant embodied carbon impacts associated with the construction techniques in addition to the team's proposed energy efficiency and energy storage features. Chapter 3: Results goes into further detail about the material optimization and three emerging advanced construction approaches applied to this project.

Embedded Carbon Reduction

Mid-rise podium construction is already fairly optimized for the affordable housing market, and it happens to be, as discovered, the lowest-carbon structural system for dense mid-rise buildings. Utilizing Tally life-cycle assessment carbon calculator, the team evaluated the embodied emissions of a standard design alongside several proposed alternate structural and architectural components. Calculations included superstructure, substructure, facade, DERs, and a generic adder for internal finishes, fixtures, and appliances. Mechanical systems are excluded from the whole-building calculation, but refrigerant, piping, and sheet metal associated with HVAC and DHW systems options are included. A detailed analysis of the LCC and carbon of the proposed and alternative design considered can be found in the Energy and Emissions Report.

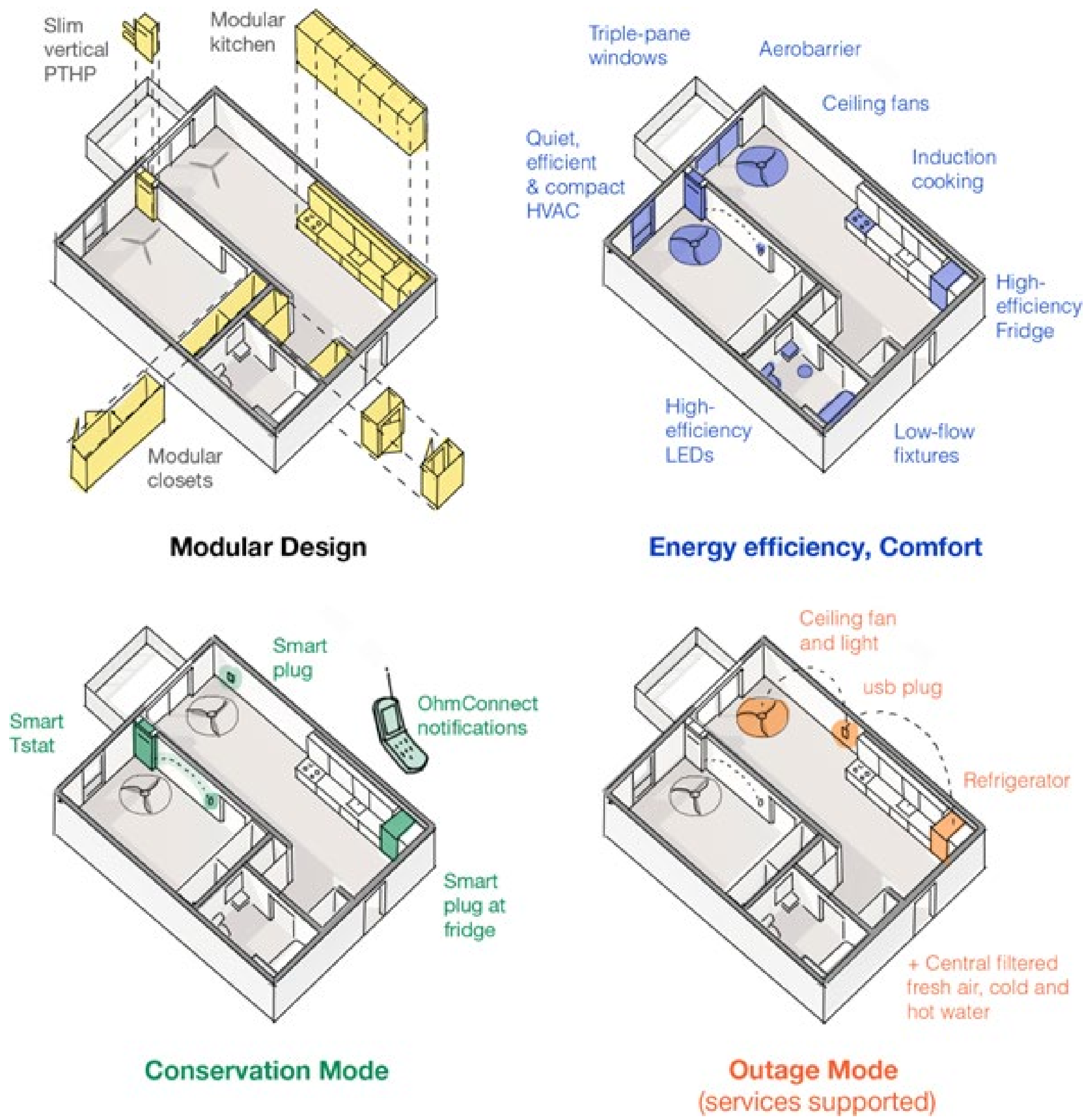
The proposed construction efficiency and embodied reduction measures achieved roughly 20 percent savings over a conventional building. Improved concrete mixes account for the vast majority of this, with optimized wood framing, cladding, and drywall also significantly reducing embodied carbon. Embodied emissions of the added elevated steel PV array, PV panels, and batteries added back roughly 9 percent, resulting in an overall net reduction of 7 percent. See the Zero Emissions Cost Benefit Report (Appendix D) for more details. The added sheet metal of the central energy recovery ventilator resulted in a 0.4 percent increase, while the low-global warming potential (GWP) heat pump saved 0.6 percent. Over 30 years, the proposed HVAC design yields a 30-percent total emissions reduction, contributing substantially to the total lifetime emissions reduction of 36 percent.

Architectural Designs, Aesthetics, and Functionality

Aesthetics and Functionality

Three core principles underpinning the design and evaluation approach are simplicity, legibility, and design integration. Technological solutions that require less material and coordination to achieve an equivalent or a better level of performance are often also the most cost-effective and look better. For example, slimline packaged heat pumps and Kit Switch modular interiors (Figure 10) create standardization and enhance the utility of the apartments. Utilizing heat recovery wherever possible substantially reduces loads while minimizing components, along with the associated space and maintenance needs of these components. Other features, such as the elevated PV canopy and informational lighting, are ways to celebrate and architecturally express the building's lead-by-example vision for the community.

Figure 10: Apartment Design Features

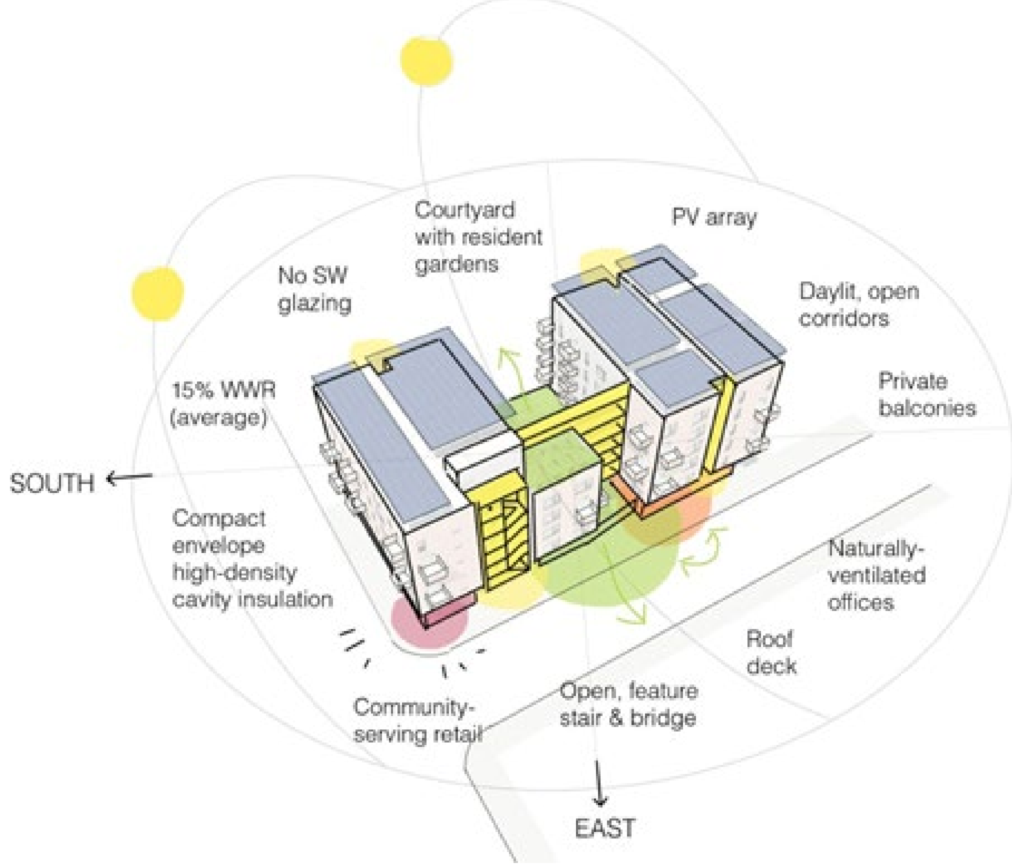


Source: The Association for Energy Affordability

Passive Design

The building massing (Figure 11) is optimally oriented on the site, with two double-loaded bars of apartments facing southeast/northwest, linked by an open-air bridge. This massing eliminates glazing oriented southwest and provides open, unconditioned corridors, reducing energy demand and improving the human experience. Balconies provide critical private open space, aesthetic relief, and shading. All apartments have operable windows and ceiling fans. Ground-floor offices and common amenity spaces have 17-foot ceilings and open onto an exterior lobby and at-grade courtyard, enabling natural ventilation and daylight design in these spaces. Bottom-up window treatments, ceiling fans, accessible windows, simple on/off heating and cooling control, and well-designed lighting controls make it easier for occupants to take advantage of passive design features.

Figure 11: Building Massing Diagram



Source: The Association for Energy Affordability

Market Transformation

Repeatable and Scalable Design

One of the primary goals of this work was to produce a set of generalizable design recommendations for optimizing cost, carbon, grid benefits, and resilience in mid-rise affordable housing in California's major urban centers (for example, the Bay Area and Los Angeles). Based on deep experience with the affordable housing construction industry, the project team pursued a technology strategy that minimized the use of novel or emerging technologies that would have required major industry and market transformation, except for the microgrid and control integration solutions that were most essential. Instead, the focus was on the integration of commercially available and industry-tested products with the aim that this approach would result in a more replicable design in the immediate future.

Informed by detailed LCC and carbon optimizations with input from stakeholders on resilience priorities, the result is a "design recipe" – a loading order of design strategies and investments that achieve the most cost- and carbon-effective solution for meeting the Next EPIC Challenge design requirements. In addition to Roosevelt Village, two other mid-rise affordable housing projects in similar climates were evaluated to validate the team's modelling methods and test the robustness of the design recipe. The resulting blueprint is outlined in Chapter 3: Results.

Knowledge-sharing Activities

A report detailing the team's principles for scaling grid-interactive, resilient housing will be published in the summer of 2025. Throughout 2023 and 2024, the team conducted outreach activities to inform building industry stakeholders about these findings, specifically presenting on panels at events including the ACEEE Summer Study, the United States Green Building Council Smart Building Summit, Living Future, and the Center for the Built Environment Industry Advisory Board Meeting at the University of California, Berkeley.

Scalable Models for Financing

The advanced technology investments of the proposed design add only around 5 percent to the cost of building a mid-rise building; however, this incremental cost was too high for conventionally funded affordable housing projects. To finance the project, the team prioritized searching for vertically integrated, microgrid-as-a-service vendors that design, install, maintain, and often provide financing product options, like lease, loan, or third-party financing (via microgrid-as-a-service agreements), for systems. In contrast to directly buying all the subcomponents of a system, a nonprofit housing developer could enter into power purchase agreements with a vendor without needing to pay upfront or to possess the technical expertise to maintain the system. In combination with the Self-Generation Incentive Program, the Investment Tax Credit, or the Solar on Multifamily Affordable Housing (SOMAH) program, these are often the most effective financing tools to deploy battery storage and solar generation systems at scale.

CHAPTER 3: Results

As shown in Table 1, the proposed project design achieves and exceeds all minimum requirements and targets established by the CEC Next EPIC Challenge.

Table 1: Next EPIC Challenge Minimum Design Requirements Versus Proposed Design

Minimum Design Requirements	Proposed
The building must be all-electric.	**Complies**: The project design does not include any gas equipment, appliances, or infrastructure.
A minimum of 20% of the building's peak load must be available to be temporarily managed or curtailed to respond to grid conditions.	**Exceeds**: The proposed design can shift 35% of the building's (gross) peak load in response to grid conditions, using domestic hot water storage, without curtailing services for residents.
The residential load during the 4:00 p.m. to 9:00 p.m. period must be met through a combination of on-site renewables, storage, and load management.	Exceeds: All of the residential load and part of the nonresidential load are met according to this breakdown by strategy: Energy efficiency: 10% Peak load management: 14% Thermal storage: 32% Battery + PV 38%
All residential end uses must be controllable through the home energy management system and must respond to real-time price signals.	**Complies** (semi-voluntary approach): Occupants will be able to automatically control major in-unit loads with smart plugs and smart thermostats (OhmConnect) and voluntarily control all loads in response to "OhmHour" notifications and informational lighting real-time signals.
Microgrid controllers must be interoperable with DER aggregation platforms, such as virtual power plants.	**Complies**: Only controllers capable of interfacing with California Independent System Operator -approved demand response providers will be installed.
The building must be able to island from the main grid during an outage and to shed discretionary loads for Tier 1 critical and Tier 2 priority loads.	**Complies**: The electrical design enables backup power for in-unit loads, support services, and building access and safety.
The microgrid must be sized for indefinite renewable-driven backup power of Tier 1 critical loads.	**Complies**: The battery is sized to accomplish renewables-driven backup power 98.6% of the year, and an EV truck boosts this coverage to 99.9%.

Minimum Design Requirements	Proposed
20% of all parking spaces must have V2G chargers, with 100% of spaces to be EV-ready.	**Complies**: 1 of 4 spaces has a bidirectional charger to serve the maintenance vehicle and provide Tier 1 outage support.

Source: The Association for Energy Affordability

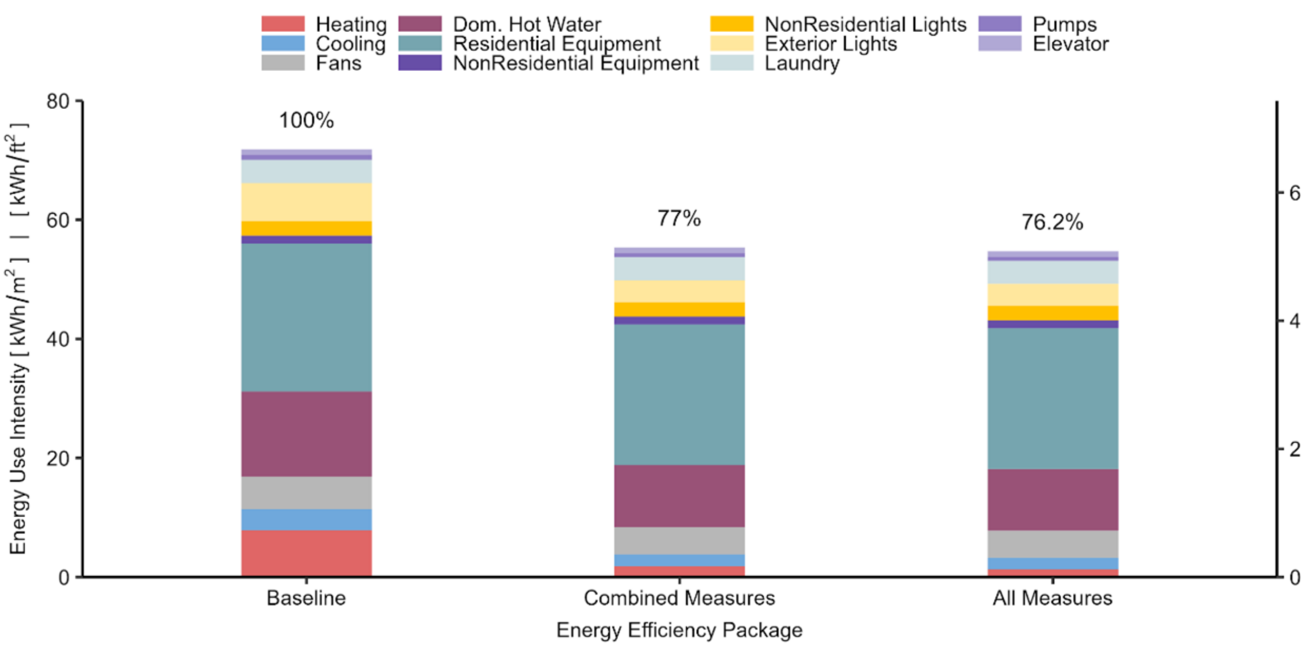
Energy, Emissions, and Cost Performance

The project team evaluated a range of underutilized technologies and control strategies to go beyond a Title 24 code-compliant baseline model, aiming to reduce the building EUI further and shift as much load as possible outside of 4:00 p.m. to 9:00 p.m. using combinations of energy efficiency, thermal storage, and load management measures, and to cover the remainder with solar PV and an electrochemical battery. The following sections provide LCC and emissions information for the proposed design.

Optimizing Load Reduction, Load Management, and DER Measures

Figure 12 shows the proposed energy efficiency design before on-site renewable energy generation or storage exceeds energy reductions beyond the baseline design, a difference of 26 percent annually. The baseline EUI, estimated to be a high-performing 23 kBtu/SF, meets the specifications of a standard-practice Title 24 code-compliant project for this area and is reduced to 17 kBtu/SF.

Figure 12: Energy Use Reduction Between Baseline and Proposed Design

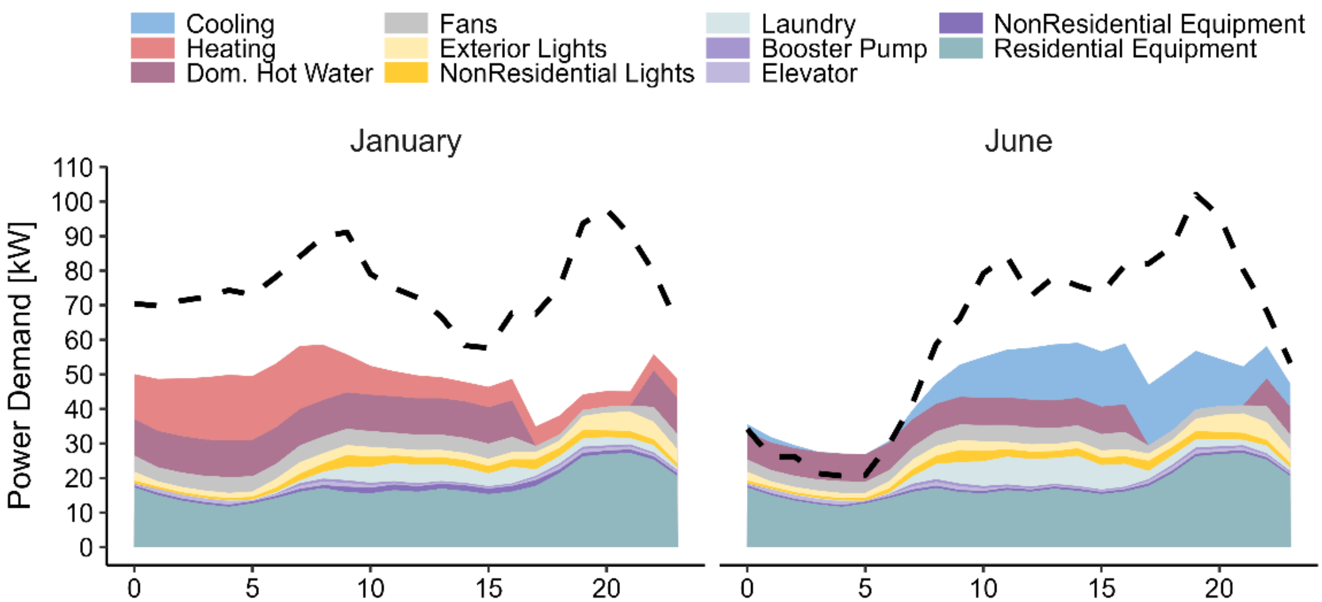


Source: Rocky Mountain Institute

Almost half of the baseline electricity (48 percent) is consumed by tenant meters, with a significant portion (75 percent) of this share used by the refrigerator, range, television, lights, and plug loads. The next significant end-use for the baseline building is domestic hot water, at 20 percent, and other aggregated, nonresidential house loads at about 25 percent, of which lighting accounts for roughly half. The largest reductions in end-use energy consumption in the proposed design are from space heating (77 percent) and cooling (42 percent), outdoor lighting (42 percent), fans (26 percent), and domestic hot water (24 percent) when compared to the baseline end-use energy consumption.

Figure 13 shows how the selected energy efficiency measures reduce peak demand during the 4:00 p.m. to 9:00 p.m. period (shaded) for both summer and winter peaks. Because final design heating and cooling loads were relatively small and the baseline building envelope was already efficient, few envelope and thermal storage strategies targeting these loads are worthwhile in terms of reducing the LCC or emissions. The thermal storage potential of the central water heater is the single most impactful measure, eliminating one-third of the 4:00 p.m. to 9:00 p.m. peak at a modest incremental cost, and several load management strategies offer a worthwhile 14 percent of additional peak load shift.

Figure 13: Daily Power Demand Profiles for Near Peak Heating (Left) and Cooling (Right) Conditions for Adopted Measures in the Proposed Design



The black dashed line indicates power demand in the baseline model.

Source: The Association for Energy Affordability

Overall, these investments resulted in a combination of strategies that left only 38 percent of the annual consumption during the 4:00 p.m. to 9:00 p.m. period remaining for PV and battery systems to cover. As shown in Table 2, this optimization resulted in a total incremental cost for a fully grid-interactive housing project of $2.6 million (without incentives) — or roughly 5 percent of the total construction cost — 80 percent (or $2 million) of which is related to PV, battery, and microgrid design, including the VNEM meter and other electrical infrastructure. Please refer to Appendix C and the Energy and Emissions Report for more details regarding the quality of the team's cost data and a full breakdown of the incremental costs between the standard and the proposed design.

Table 2: Final Measure Impacts on Peak Reduction and Up-front Cost

Strategy	Portion of Annual 4:00 p.m. to 9:00 p.m. Load Served	Approximate Incremental Cost*
Energy efficiency	10%	$550,000
Thermal storage (domestic hot water)	32%	$50,000
Peak load management Dynamic ventilation Light dimming OhmConnect Laundry incentives	14%	~$0
Solar PV array, battery storage including VNEM infrastructure	38%	$1,500,000
Microgrid infrastructure	NA, enables islanding	$500,000
Total Incremental Cost		**~$2,600,000 or 5%**
Total Construction Cost		**~$50,000,000**

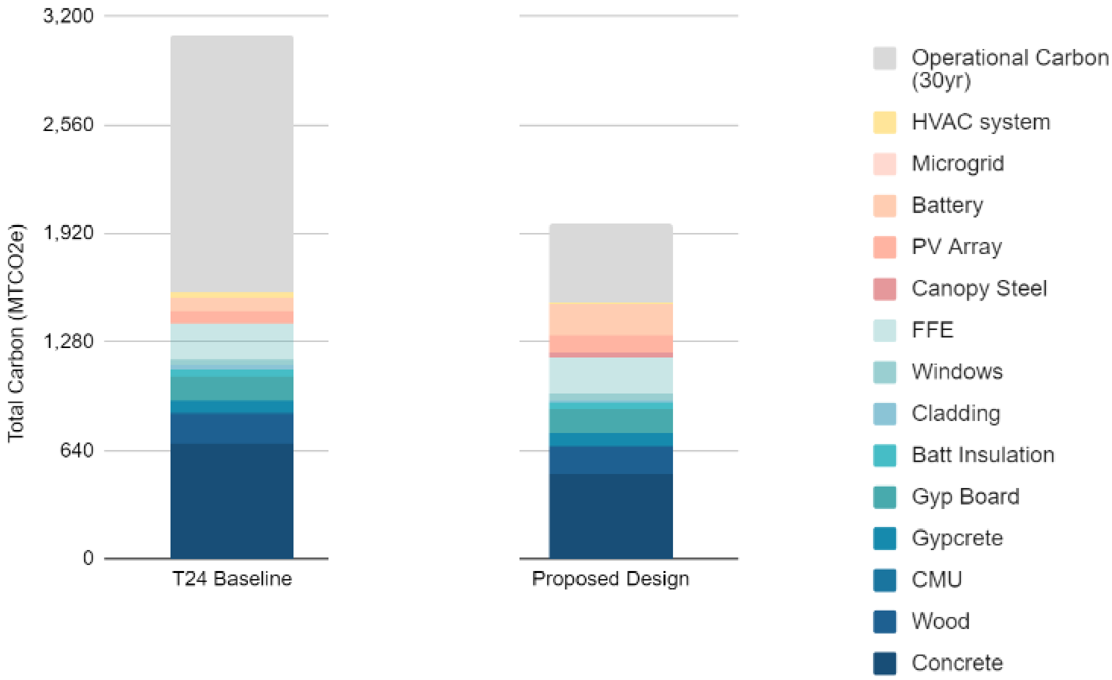
*** Costs are approximate and demonstrative.**

Source: The Association for Energy Affordability

Emissions Reduction

The proposed design achieved nearly a 40-percent reduction of GHG emissions over 30 years, which includes a cradle-to-gate estimate of the embodied emissions reduction using Tally (Figure 14). The proposed HVAC and DHW designs were responsible for a 30-percent of the total emissions reduction, primarily due to operational carbon reduction with the use of thermal storage to shift loads to lower carbon hours with a negligible increase in embodied emissions. For detailed information about embodied emissions reduction due to construction, please refer to the "Advanced Construction and Embodied Emissions" section in Chapter 2: Project Approach.

Figure 14: Lifecycle Carbon Comparison



Embodied and Operational Over 30 Years of Baseline and Proposed Design

Source: The Association for Energy Affordability

Life-cycle Cost and Utility Bill Savings

The LCC and utility bill savings were calculated under both a Net Energy Metering (NEM) 2.0 tariff and a NEM 3.0 Virtual Net Billing Tariff. Critically, affordable housing projects are eligible for NEM 2.0 tariffs, equivalent to projects in the SOMAH program. This was essential in controlling the LCC of the grid-interactive design by maximizing the financial benefit of exports. The LCC was calculated over 30 years with state and federal incentives applied.

The allocation of bill savings to tenant meters in comparison to the house meter is discretionary; however, the team identified a balance point, illustrated in Table 3, where a 63-percent allocation for residents would eliminate annual utility bills for the house while decreasing resident bills by 90 percent. The alternative rates in California for low-income households were found to have a minimal overall effect and did not alter the sizing of the DERs or the relative ranking among scenarios; therefore, they are omitted for the sake of clarity.

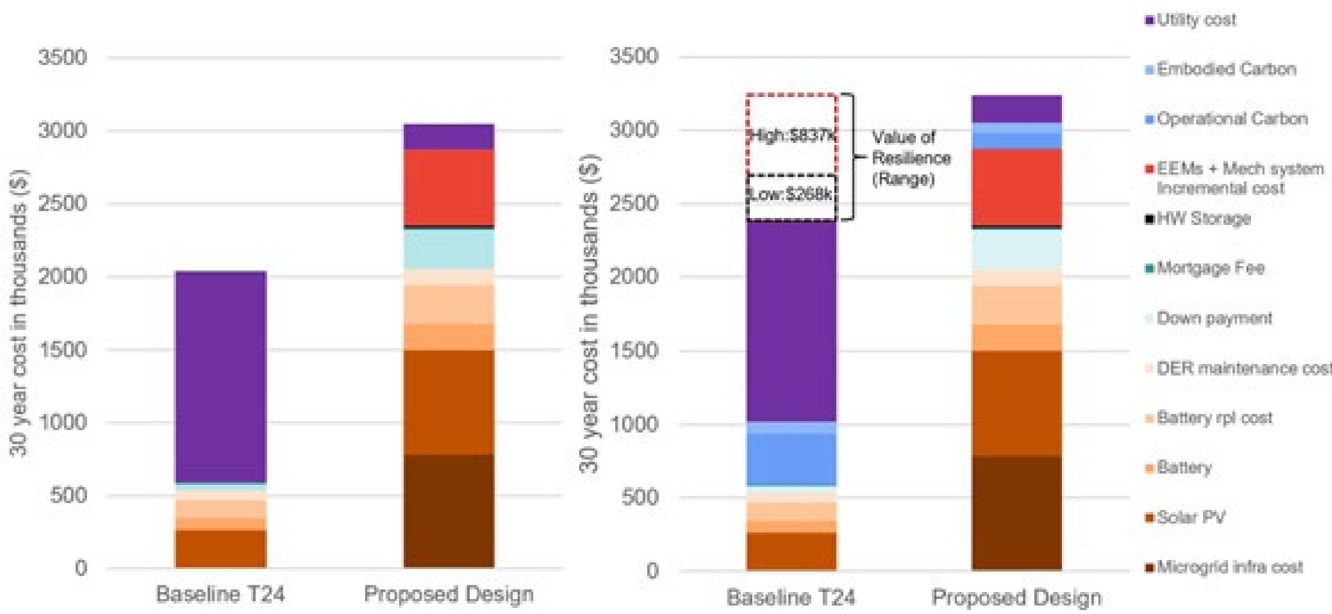
Table 3: Shared Utility Bill Savings

Scenario	Resident Allocation (%)	Resident Annual Bill ($/yr)	House Annual Bill ($/yr)	Average Per-Apt Annual Bill ($/yr)
Proposed Design	63%	$11,170	**$0**	**$150**
T24 Baseline	0%	$85,001	$6,413	$1,103

Source: The Association for Energy Affordability

The net present cost over 30 years for the proposed design, in comparison to a code-minimum standard building lacking grid response, amounts to $1.4 million more than a code-minimum structure ($1.0 million after incentives), as illustrated in Figure 15. This increase in LCC occurs despite achieving an 88-percent savings on total utility bills (shared between the owner and the tenants) due to optimized investments in both DER and non-DER strategies. Although the overall bill savings are lower than they would have been without efficiency investments, they regrettably do not sufficiently offset the substantial incremental costs associated with the enhanced PV and battery systems when compared to current practices.

Figure 15: 30-year Life-cycle Cost Compared to Code-minimum Baselines



***This assumes NEM 2.0 tariffs for a SOMAH/VNEM project with currently available state and federal incentives.**
****The chart on the right includes an estimate of the value of resilience and carbon reduction with the EPA-proposed SCC at $190/ton.**

Source: The Association for Energy Affordability

Social Cost of Carbon and Value of Resilience

An LCC based on operating cost savings alone ignores the societal benefit of emissions reductions and enhanced resilience. To re-balance this equation, the team applied the EPA estimate for the social cost of carbon (SCC) of $190/ton, increasing it to $310/ton by 2050 (2020 dollars) (U.S. EPA 2023), to the embodied (one-time benefit in the year of construction) and operational (over the 30-year analysis period) carbon savings of the design. The team used two recently published methodologies (Sullivan et al. 2015; Lewis 2021) to place a monetary value on the obvious, but difficult to quantify, benefit of resilience, yielding a 30-year net present value of approximately $268,000 to $837,000 for this site. Figure 15 shows the contributions of these factors to the LCC, essentially arriving at cost parity with a code-minimum building.

Resilience

Outcomes From the Stakeholder Process

Based on conversations with staff and existing residents of Leigh Avenue, the nearby similar property, the team developed outage scenarios and then summarized essential and priority services for each scenario. Although the site is close to downtown, with good connectivity and grid reliability, short-term outages of up to several hours are relatively common (1 to 5 per year). In addition, Roosevelt Village would serve formerly homeless seniors, who would tangibly benefit from resilience to power failure. Longer outages of 1 to 3 days are rarer but possible during major storms or earthquakes, and in these scenarios backup power is even more critical.

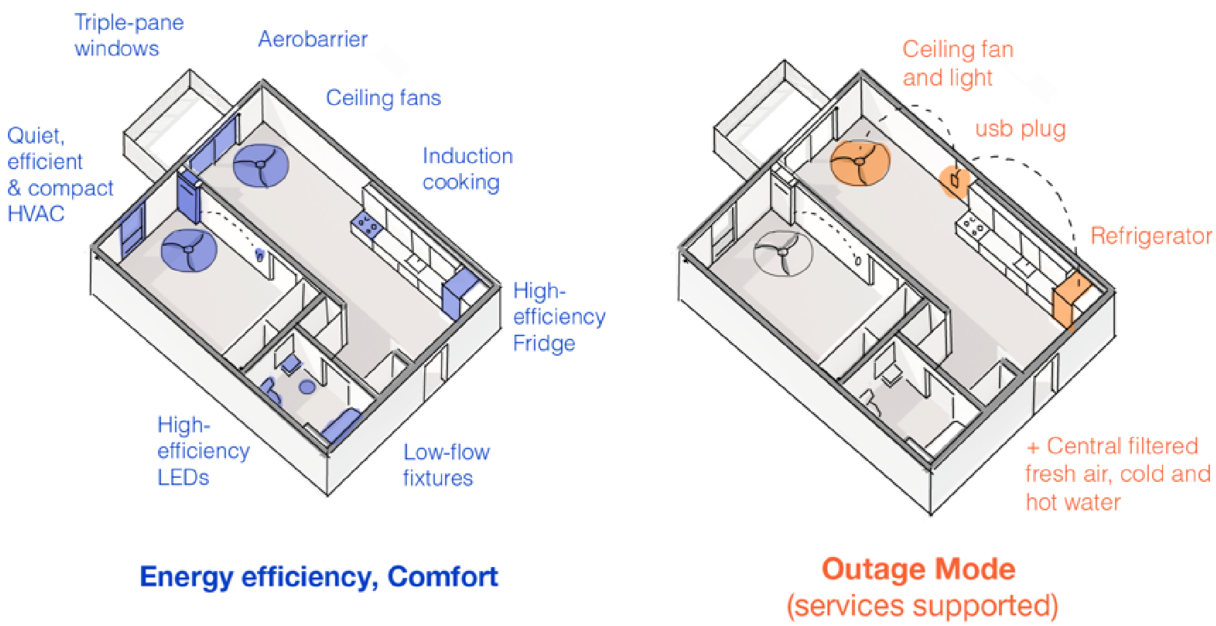
When discussing with residents their priorities during a power outage, the foremost concern was the preservation of refrigeration in their homes, which is essential for safeguarding personal food items and medications. This concern was closely followed by the importance of general safety in shared spaces, particularly regarding building access, corridor illumination, and the functionality of elevators. The maintenance of hot water also emerged as a significant priority during an outage, whereas HVAC systems and apartment lighting were deemed less critical. Staff members expressed heightened concern regarding building access and security systems, the continuity of basic office operations, and effective communication with personnel in the event of an emergency.

Outage Scenarios and Priority Loads

The team analyzed what percentage of priority loads could be covered for 24- and 72-hour outage scenarios throughout a typical year, along with the acceptability of indoor conditions. In parallel, the battery sizing required to run "Tier 1" priority loads indefinitely was evaluated to fulfill the CEC Challenge requirement.

When the battery is sized for the 4:00 p.m. to 9:00 p.m. load shift, a 268-kWh central battery is needed. This capacity is roughly equivalent to one day of Tier 1 loads (265 kWh), which include one elevator, building security and access systems, cold water booster pump and hot water recirculation pump, common area emergency lighting, and the central DOAS, in addition to residential refrigerators, ceiling fan/light, and one USB plug in each apartment. Figure 16 compares end uses available to residents during conditions typical of the in-home resilience supported during an outage.

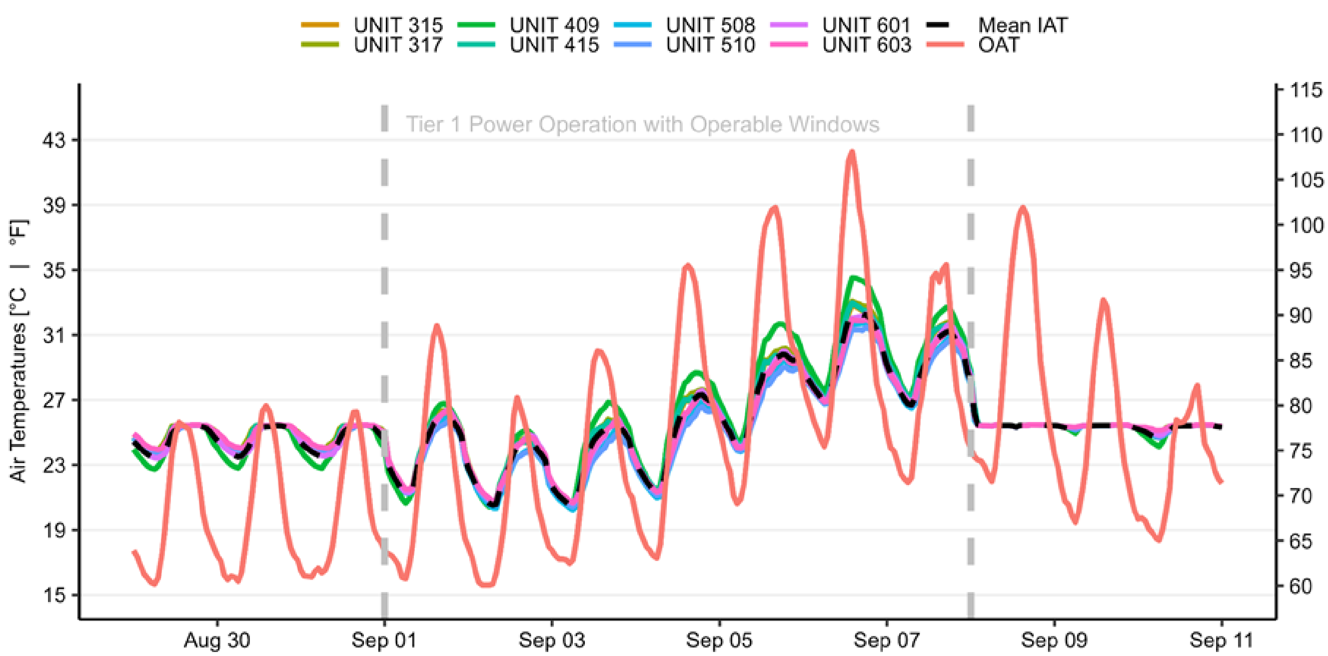
Figure 16: In-home Resilience and Energy Management



Source: The Association for Energy Affordability

With residential HVAC excluded from priority loads, the project team ran an indoor temperature model (Figure 17) that predicts comfortable conditions for up to 72 hours during an outage in peak winter and summer conditions, with ceiling fans, heat recovery ventilation, and operable windows being essential components. The common room HVAC system was assigned to Tier 1 so it could serve as an additional heat stress refuge for residents if a multi-day outage occurs during extreme conditions.

Figure 17: Indoor Conditions During a Typical Heat Wave



Source: Rocky Mountain Institute

Table 4 summarizes the battery sizing necessary to support Tier 1 and Tier 2 loads for different durations, assuming a solar system size of 171 kW. Tier 2 loads include additional functionality in offices and amenity areas and the central domestic hot water heat pumps. Tier 2 loads would come online or be shed according to a specified threshold state of charge for the battery.

Table 4: Percentage of Days of the Year Met With Varying Battery Sizes Necessary for Annual Critical Load Coverage During Backup Power Scenarios

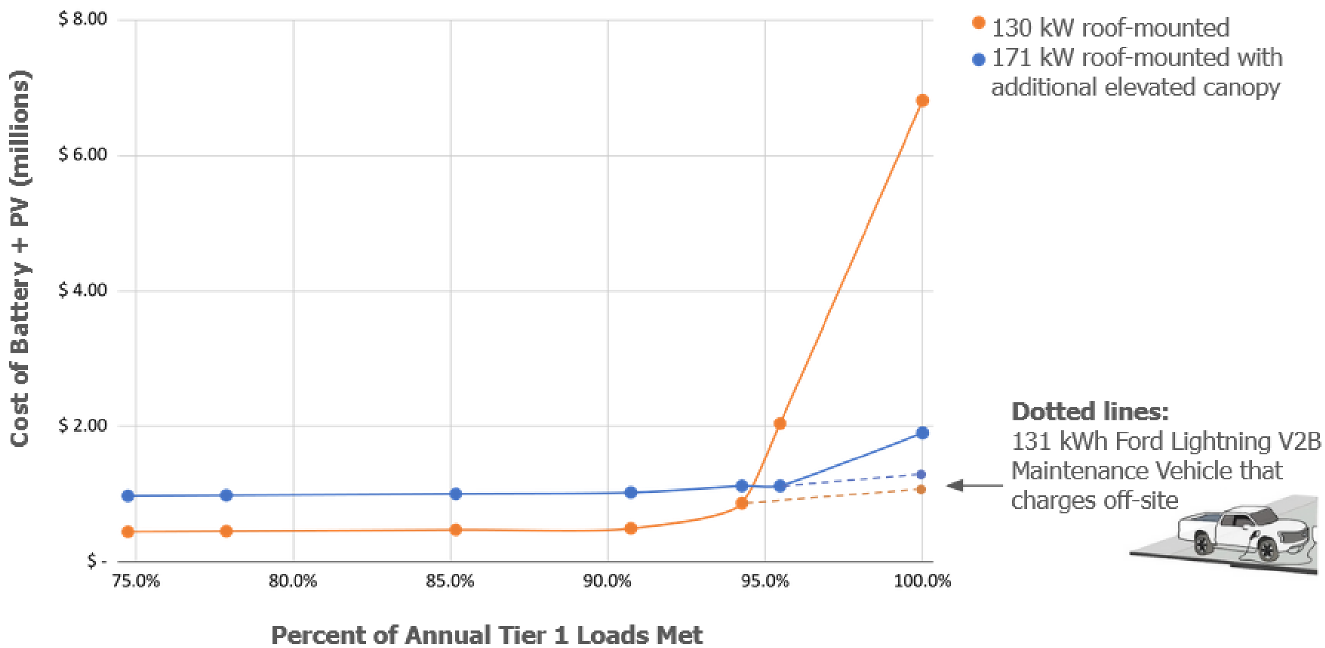
Battery Size*	Daily 4:00 p.m. to 9:00 p.m. Res Load	Indefinite Tier 1 Load	24-hour Outage (Tier 1 & 2)	72-hour Outage (Tier 1 & 2)
No Battery	56%	0%	0%	0%
Medium (268 kWh)	100%	99%	90%	73%
Large (600 kWh)	100%	99.9%	100%	90%
Huge (1,300 kWh)	100%	100%	100%	100%

***Battery sizes assume an elevated canopy PV array of 130 kW and the proposed design efficiency measures.**

Source: The Association for Energy Affordability

Addressing the most extreme annual conditions for backup power, primarily influenced by inadequate PV generation, significantly increases the required battery size. For instance, achieving coverage for the final 1 percent of Tier 1 loads necessitates a battery that is nearly five times larger. Consequently, the expenses associated with battery and PV investments rise substantially to accommodate over 97 percent of the Tier 1 load throughout the year. Further examination, illustrated in Figure 18, indicates that, with a 130-kW rooftop PV system, a 200-kWh battery system costing $0.6 million can fulfill 96.4 percent of the Tier 1 annual load. However, to achieve 100-percent coverage of the Tier 1 annual load, a 3500-kWh battery costing $4.2 million is required, representing an increase of over 17 times to address the remaining 3.6 percent of the annual loads. A novel solution the team identified involves acquiring an all-electric truck to serve as a building maintenance vehicle, equipped with a bi-directional charger that enables V2B functionality. Through V2B, more than 99 percent of the annual critical loads can be supplied with grid power at a significantly lower cost compared to stationary storage, as depicted by the dotted line in Figure 18.

Figure 18: Cost of Resilience



Source: The Association for Energy Affordability

In particularly extreme, and exceptionally rare, outage events, once per day the truck can drive elsewhere to charge and then supply another 131 kWh of battery capacity to the building, essentially eliminating any gaps in indefinite Tier 1 and 24-hour outage coverage.

Advanced Construction

The project team determined that both mass timber and volumetric modular solutions would not pose substantial combined carbon and cost benefits. For more details on why these solutions were not pursued, see the Emerging Technologies Report (Appendix D). Instead, the team turned to other incremental ways to optimize construction and found three promising emerging approaches, as follows.

Wood Framing Optimization: Although whole building cost and carbon analysis did not find cost or emissions reduction potential from mass timber elements, the integrated design process discovered that optimizing framed wall panelization and increasing interior partition framing from 2x4 to 2x6 walls with wider stud framing would reduce framing material by 20 percent, shaving $107,500 from the budget.

Modular Casework: The design involved a partnership with Kit Switch, a start-up modular interiors provider that offers standardized kitchen and bath layouts using a kit-of-parts menu of storage modules, counters, fixtures, and appliances. The components are assembled and mounted on framed panels and arrayed in place, with mechanical, electrical, and plumbing services consolidated at a single point of connection. Although still new, this approach could more reliably streamline project delivery at a lower risk than volumetric modular, resulting in a 30-percent reduction in construction cost for interior components.

Prefabricated Exterior Cladding: The exterior cladding represents an additional focus for enhancing constructability and minimizing embodied emissions. The suggested design utilizes prefabricated metal panels that function as a rainscreen, thereby reducing the labor associated with the installation of various assembly layers. While steel is considered a high-carbon material, when evaluated comprehensively against other cladding systems the life-cycle environmental impact of raw steel is comparatively low, owing to its significant durability and minimal maintenance requirements.

Another potential cladding material that has not yet been commercialized in the United States is DiasenThermactive, which is a cork-based spray-applied exterior insulation finish system (EIFS). This insulated cladding, resembling stucco in its outer appearance, effectively meets all three objectives simultaneously: enhancing energy efficiency, lowering costs, and minimizing the embodied emissions linked to the exterior wall assembly. Future funding initiatives should focus on promoting workforce training and conducting building science analyses related to this material.

Design and Investment Priorities

The project's underlying approach comes down to five key investments that can help mid-rise affordable housing in California's major urban centers, like the Bay Area and Los Angeles, become more resilient, more grid-interactive, and part of the solution to decarbonizing the grid while delivering real benefits to the communities they serve.

1. **Domestic hot water storage and load shifting.** Of all investments, sizing DHW storage and enabling controls to fully shift heat pump water heater operation outside of the daily peak window (4:00 p.m. to 9:00 p.m.), and into the low grid emissions solar generation window, is one of the most cost-effective and impactful strategies, but it is not currently common practice. Even absent the futuristic design requirements, most standard central DHW designs contain sufficient storage to substantially shift central heat pump water heater operation, and this represents a significant opportunity for mid-rise affordable housing. An ideal control strategy would incorporate TOU rates and a real-time carbon emissions signal and would optimize heat pump operation to minimize both costs and carbon. This opportunity becomes even more valuable when considering the California Public Utilities Commission's (CPUC) rollout of dynamic rates in 2027 (CPUC 2024), which would better reflect real-time grid conditions and place a much higher monetary value on load shifting than current TOU rates or emissions weighted by the SCC. A simpler control strategy would raise the DHW tank water temperature setpoint during the day to naturally drive consumption into that window while still ensuring sufficient storage to meet DHW demand. The tradeoffs with this strategy would be mostly during nighttime hours when prices are low but emissions may be high, or during hot summer afternoons when additional daytime load could further stress the grid.
2. **Beyond code energy efficiency.** Designing for radical grid interactivity makes additional efficiency measures beyond Title 24 compliance more cost-effective measures that reduce battery size by producing savings during the daily peak window

(4:00 p.m. to 9:00 p.m.), reduce priority loads, or reduce power consumption during extreme weather conditions. Overall, optimization resulted in proposed efficiency measures that leave only 38 percent of the annual consumption from 4:00 p.m. to 9:00 p.m. for PV and battery systems to cover. The specific set of measures that fall into this category is likely to vary somewhat by project, depending on the unit mix and density, height, and location; however, some measures could be assumed beneficial for all projects, such as ceiling fans, induction cooking, and 1.5 gallons-per-minute showerheads. Other measures, such as energy recovery ventilation and triple-pane windows, could be verified by a simple cost payback analysis during design. Finally, it's unlikely that continuous insulation for wood-framed walls makes up for its high cost and high embodied emissions, at least until emerging carbon-absorbing insulated cladding products become more available. Similarly, other emerging technologies such as phase-change materials integrated into wall systems, or dynamic glazing, would have to be offered at much lower-than-current premiums to be considered.

3. **Max out PV generation.** This may sound like counterintuitive advice given the current California landscape of duck curves and net energy metering roll backs, but PV generation is critical to achieving the design requirements (especially daily shifting out of the 4:00 p.m. to 9:00 p.m. period and resilience goals) and mid-rise buildings are likely to be constrained with a rooftop area sufficient to support the cost-optimal PV system size. There is a design trade-off between PV size and energy storage system size but, given the relative costs of PV panels and batteries, maximized PV generation and minimized battery size will almost certainly be the cheapest option if shifting residential loads out of the evening peak period is the goal. Maximizing PV generation also provides longer resilience during power outages. At Roosevelt Village, it was found to be more cost-effective on a lifecycle cost basis to build a steel rooftop canopy to expand the rooftop system size by 30 percent, essentially raising the $/kW cost fivefold, rather than sizing up the battery. Where available, in addition to the rooftop area, opportunities for ground mount systems (for example, carports) or façade-integrated PV should be explored. Optimal orientation should also be explored — west-facing PV systems may provide more power during the peak window but generate less energy overall. At a site where generation is not constrained, at least some west-facing PV may be preferable, but, at a site with a constrained PV area, maximizing the annual energy output is likely to be the preferred strategy.
4. **Heating and cooling don't need thermal storage.** The combination of beyond-code efficiency measures and mild climates shrinks heating and cooling loads significantly. Additionally, winter heating loads diminish during the daily peak window as internal gains typically ramp up in the evening. And the peak conditions that drive battery sizing are not likely to be coincident with high heating or cooling loads — that is, battery size is mostly driven by days when there is poor PV generation (specifically, cloudy days), and cloudy days are not typically the coldest or hottest days. Finally, there is a large up-front cost difference between in-apartment packaged heat pumps and a 4-pipe central hydronic system with thermal energy storage — even if that same system can provide DHW and thermal storage for load shifting heating and cooling

loads. Thus, the recommendation is to utilize efficient in-apartment packaged equipment and size PV and battery systems to serve the HVAC loads during the daily peak window.

5. **Utilize central shared systems where possible.** Load diversity across apartments and with any commercial space in the building allows central systems (for example, PV, battery, DHW) to be smaller and typically cheaper than the sum of per-apartment systems required to achieve the same objectives, except for HVAC, as described above. This applies to standard business-as-usual buildings too, particularly DHW systems. However, incorporating the daily requirements for the building to satisfy all residential loads during peak hours extends this consideration to include PV and battery systems as well.
6. **Size the battery for remaining peak loads plus any buffer.** If the site is equipped with a battery and PV system designed to shift loads out of peak hours daily, it is probable that it will possess sufficient capacity to provide a degree of significant resilience at the apartment level, alongside essential loads in common areas. Should there be a need for backup power in the apartments, sizing the battery to accommodate the most severe power outage scenarios is likely to substantially increase the necessary battery capacity. Additionally, there may be innovative solutions available, such as bi-directional charging for electric maintenance vehicles, which could assist in bridging these gaps. For locations with less dependable grid connections, a determination must be made regarding whether backup power will be extended to the apartments, common areas, or both. Current regulations mandating individual electric meters for each apartment imply that supplying in-unit backup power necessitates a significantly greater amount of electrical infrastructure (including extra wiring to each apartment, transfer switches, and so on), and the associated costs must be carefully considered with the advantages of improved resilience for the residents.

Validating Design and Investment Priorities at Other Sites

To confirm the proposed design strategies, the team conducted two supplementary analyses: the Harvey West Apartments located in Santa Cruz, California, and the Thorton and Post Apartments situated in Fremont, California. The examination of Harvey West involved an extensive series of energy simulations aimed at validating the effectiveness of a comparable set of energy efficiency measures that exceed code requirements. This analysis substantiated design strategies #2 and #4 mentioned earlier: specifically, that targeted efficiency measures can significantly lower energy demand during peak periods and, once these measures were implemented, the site would experience minimal advantages from thermal storage for space conditioning due to the notably low loads, particularly during peak times.

For the Thorton and Post Apartments, which consist of 128 affordable multifamily housing units within a 5-story mixed-use structure, the project team utilized the results from the energy compliance models to conduct a series of economic optimizations like those executed for Roosevelt Village. The primary objective was to ascertain, considering the cost premium associated with completely offsetting loads from 4:00 p.m. to 9:00 p.m. every day throughout the year, what levels of grid benefits and resilience could be realized with more conventional and economically viable mid-rise affordable housing designs. To assess this, three scenarios were examined at the Thorton property. The first scenario strictly focuses on optimizing costs across all investments in DERs and is termed "Cost Optimized." The second scenario balances cost and carbon while employing the T24 prescriptive battery size on the house meter and is referred to as "T24 Battery." The third scenario aims to optimize for both cost and carbon to achieve a complete offset of residential loads during the daily 4:00 p.m. to 9:00 p.m. period and is labeled "Full 4:00 p.m. to 9:00 p.m. Offset." The outcomes of the techno-economic optimizations for these scenarios are presented in Table 5.

Table 5: Thorton Apartments DER Optimization Scenario Results

Results/Scenario	Baseline	Cost Optimized	T24 Battery	Full 4:00 p.m. to 9:00 p.m. Offset
Solar PV size (kW)	150	280	280	280
Battery size (kWh)	–	–	95	720
HW storage (kWh)	420	225	226	185
HW storage (gallons)	2000	1071	1076	881
DHW HP size (kW)	90	74	74	77
4:00 p.m. to 9:00 p.m. (% of annual loads met)	14.60%	20.50%	37%	100%
Annualized total cost (thousands)	$204.20	$201.80	$208.20	$225.50
30-year lifecycle cost (thousands)	$3,139	$3,102	$3,201	$3,466
Operational carbon (mtco2e/year)	176	129	124	100
24-hour outage (% of year where backup power can be provided)	0%	0%	0%	100%
Tier 1 loads (% of annual loads that can be met with on-site renewables)	0%	0%	77%	100%
Energy Bill	$159,278	$132,268	$123,894	$44,044

Source: The Association for Energy Affordability

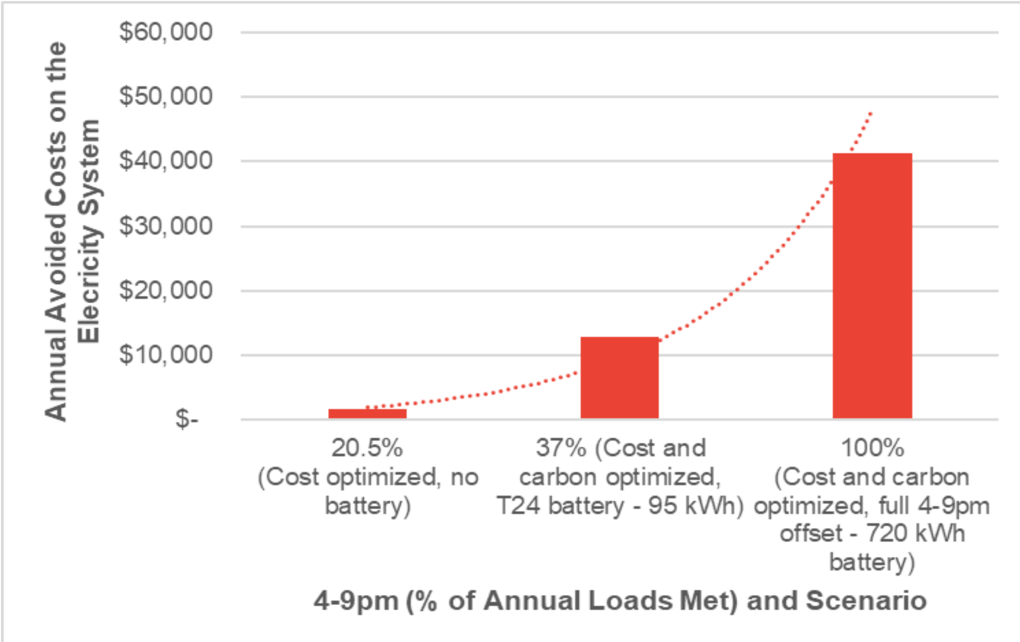
Four conclusions from the Harvey West and Thorton results are relevant to the design recipe discussion above:

1. The most economically viable design priorities, specifically thermal storage and increasing PV capacity, are instrumental in achieving more resilient and affordable

housing. This approach can yield advantages for both the electrical grid and local communities, even if not all Next EPIC Challenge criteria are met. For instance, the implementation of controls for shifting hot water loads, enhancing PV generation, and incorporating a small Title 24 prescriptive battery (as illustrated in the T24 Battery scenario) can significantly benefit the electricity system, offering approximately ten times the value of a cost-optimized design. Additionally, this strategy can ensure backup power for over 75 percent of the year for Tier 1 critical loads.

2. The hot water storage and DHW heat pump size in each of the optimized cases was smaller than in the baseline design. While DHW storage remains a low-hanging fruit for shifting load out of the daily peak window, this analysis suggests that, under current utility rate structures, oversizing these systems provides limited economic benefit. This is highly rate-dependent; in this case, the modeled tariff had a small peak/off-peak price change in winter, minimizing the economic opportunity to shift out of the daily peak window in winter months. However, rate structures are expected to evolve, especially over the given lifespan of a DHW tank. Given the relatively small cost premium for upsizing storage and the CPUC plan to offer dynamic rates starting in 2027, it may be worth incurring that cost today to support future flexibility and better align with emerging pricing signals.
3. The value to the grid of load reduction in the daily peak window varies considerably throughout the year. Figure 19 shows a nonlinear relationship between the annual percentage of loads offset during the 4:00 p.m. to 9:00 p.m. peak window and the annual avoided costs to the electricity system across the three scenarios. This is because there is only a handful of peak load hours where electricity system costs are very high, and there is a relatively low coincidence with those hours for the Cost Optimized and T24 Battery scenarios.
4. Based on economics alone, a battery system may be hard to justify. The lowest cost scenario overall is the Cost Optimized scenario, where the optimization resulted in no battery investment. The GHG emissions difference between the Cost Optimized and the Title 24 Battery scenarios is also small, so it may be difficult to justify along the carbon dimension as well. The economics may change under other utility tariffs (such as those with demand charges) and should be explored. Additionally, without a battery system, there is no backup power benefit of the increased PV system size. In dense urban centers where outages are rare, this is likely a fine tradeoff but, where resilience is a concern, battery systems can add value, as discussed above.

Figure 19: Annual Avoided Costs to the Electric Grid System of Three Scenarios Modeled at Thorton Apartments



Source: The Association for Energy Affordability

Discussion: Priorities for Faster Market Transformation

The primary and arguably the most significant obstacle to the extensive implementation of the Next EPIC Challenge design specifications is the initial cost premium, especially concerning the battery and microgrid infrastructure elements. Following is a discussion regarding potential strategies to reduce lifecycle expenses and accelerate market transformation towards grid-interactive, resilient, and affordable housing in California.

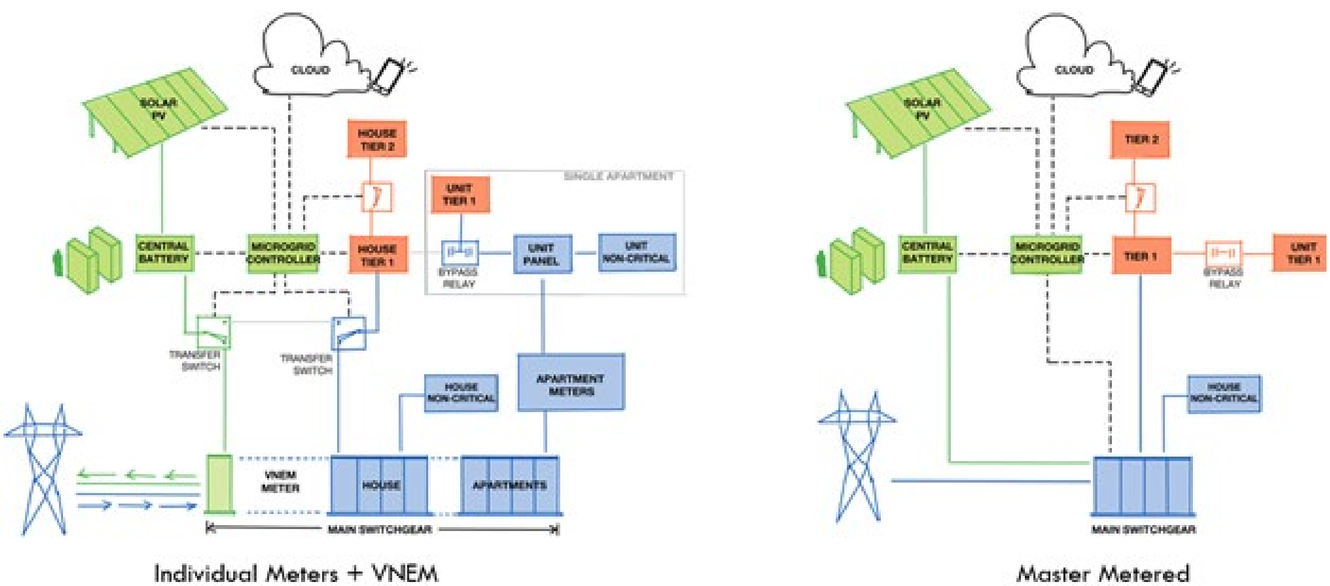
Energy Code Compliance

Proving financial viability for this project relied on guiding principles developed by the project team to reduce demand, shift load, and integrate DERs, before sizing battery components for resilience or rate arbitrage. It is a departure from industry practice, where conventional approaches to battery sizing for backup power prioritize meeting a rare worst-case outage condition occurring less than 3 to 5 percent of the year, with no optimization around other demand reduction technologies. The team's results demonstrate how this drives up costs unnecessarily. Current Title 24 prescriptive requirements mandate battery storage, yet it remains difficult to take source energy credit for thermal storage of central DHW in the current compliance software. This regulatory gap pushes investment towards batteries to meet compliance rather than utilizing potentially more cost-effective technologies with significant demand load shift potential, leaving a knowledge gap in hot water sizing and control that yields economic return for nonprofit housing operators. Providing T24 source energy performance credit for thermal storage could accelerate market transformation but would require coupling with state funding mechanisms to prevent creating an unfunded compliance burden.

Metering Regulation

The CPUC's Rule 18 requires that new multifamily buildings have separate electricity meters for each apartment, effectively outlawing master metered buildings. While there were some very good reasons why this rule was passed, including tenant protections from landlord upcharges on utility rates, it may be time to reconsider technology advancements that can allow for better submetering (for example, smart panels and Wi-Fi-enabled energy monitors), better transparency for tenants about their utility bills, and the desire for buildings to play a critical role in decarbonizing the electric grid. Given that over 38 percent of the incremental first costs for Roosevelt Village were related to electric infrastructure to support virtual net metering and apartment-level backup power, a master metered configuration would represent considerable savings, enough to considerably close the lifecycle cost gap with a business-as-usual Title 24 building under NEM 2.0. Figure 20 shows electrical design schematics for a master meter configuration and an individual apartment meter configuration with virtual net metering that achieve CEC requirements. The master meter building has the additional benefits that, under NEM 3.0, it would be able to self-consume some of the on-site PV generation, which would effectively be valued at the full retail rate, whereas the VNEM configuration would see reduced value for all its PV generation, as it would only be exports.

Figure 20: Individual Apartment Meter Schematic With VNEM and Master Metered Schematic to Provide Daily Peak Window Power to Apartments



Left: Individual apartment meter schematic with VNEM, and in-apartment backup power (currently allowable in California). Right: Master metered schematic to provide daily peak window power to apartments and in-apartment backup power (currently not allowed in California).

Source: The Association for Energy Affordability

Electricity Rates and Market Structures

The three main strategies for a building to recover the additional initial costs, based on the suggested design, include: 1) price arbitrage with fluctuating utility rates over time; 2) compensation via net metering; and 3) opportunities in demand response and wholesale markets. The design framework outlined previously, along with any economic evaluation of a building seeking to implement a comparable design, will be significantly influenced by these three factors.

Time-varying Rates

Currently, most new affordable multifamily construction in California with PV and storage systems, a TOU rate is often required. These TOU rates offer some financial incentives for entirely avoiding peak demand periods. Although the price differential between peak and off-peak electricity usage has increased in recent years, it remains relatively modest, approximately $0.09 per kWh. When applying this price differential to the DHW system at Roosevelt Village, the team anticipated an annual savings of $2,246 on utility bills (Table 6). However, when these savings are distributed among 74 apartments, it translates to only $28 per apartment per year. This amount may not be sufficient to motivate property owners or designers to navigate the complexities involved in establishing the necessary controls to realize these benefits. Furthermore, it is unlikely that these savings alone would justify the additional initial investment required for DHW storage capacity to eliminate daily peak demand periods throughout the entire year.

Table 6: Domestic Hot Water Load Shifting and TOU Value

Annual DHW energy consumption during peak window (4:00 p.m. to 9:00 p.m.) – no shifting (kWh)	Annual DHW energy consumption during peak window with shifting (kWh)	Electricity TOU peak v. off-peak price delta ($/kWh)	Annual savings from shifting ($/yr)
23,638	0	$0.095	$2,246

Source: The Association for Energy Affordability

An alternative to time-of-use rates that may provide more value to customers and better align value with the grid operator could be a real-time price of electricity, inclusive of grid infrastructure costs, carbon emissions, and wholesale energy costs. A real-time rate, similar to the CPUC's Avoided Cost Calculator (CPUC 2022), would more directly address the type of grid interactivity that the proposed design is trying to achieve, however, it would also further complicate building controls in being able to respond to the rate, though it could also simply be scheduled daily to shift out of the same 4:00 p.m. to 9:00 p.m. peak window.

Net Energy Metering

The continuous development of net metering regulations in California significantly affects the cost-effectiveness of the proposed design framework. An analysis of the NEM 3.0 Virtual Net Billing Tariff indicated that utility expenses at Roosevelt Village could rise by more than threefold in comparison to a NEM 2.0 scenario. In the context of NEM 2.0, the value of solar or battery exports during peak hours is approximately $0.4/kWh, which is over four times the arbitrage opportunity previously mentioned. Although VNEM systems associated with affordable housing will be preserved under NEM 2.0, it is vital to uphold this tariff, particularly given that NEM 3.0 could significantly diminish the savings for upcoming decarbonized mixed-use developments and necessitate the creation of new revenue sources to bridge the financial gap.

Demand Response and Wholesale Market Opportunities

One such revenue stream that may continue to grow is participation in demand response or wholesale energy markets. For Roosevelt Village, the project team explored these programs but, currently, almost all wholesale markets in California compensate for energy reductions but not exports. Since the building was not going to use grid power during the peak window every day, there would be no baseline energy use from which a reduction could be measured. One more drawback of the VNEM configuration is that the discharge of battery storage does not reflect a reduction in load on the grid, as it is exported via the VNEM meter; this is another instance where a master-metered configuration could effectively address the issue. A particular wholesale initiative, known as the Emergency Load Reduction Program, provides compensation to buildings for their exports at a rate of $2.0/kWh and can call for up to 60 events annually, each lasting as long as 4 hours. This could potentially yield approximately $30,000 per year in additional revenue for the site, thereby significantly narrowing the lifecycle cost gap.

Individual apartments are also eligible to participate in demand response programs. While the solar, battery, and DHW systems are central, residents could utilize their thermostats, refrigerators, and other plug loads to participate. In the individually metered scenario, these benefits wouldn’t help recoup the up-front costs but would benefit residents.

Balancing Control Sophistication With Accessibility

The Roosevelt Village team aimed to eliminate overly complex systems that, while promising from an automated grid-interactive perspective, introduce maintenance complexity (specifically, requiring a dedicated facilities engineer) or risk invasiveness or inaccessibility to residents.

User-centered Residential Demand Management

Encouraging residents to adopt new personal priorities that govern when and how they cook, clean, wash, and shut off power to devices is also problematic, particularly for a low-income and formerly homeless senior population. Occupant surveys suggested that, while centralized control during grid-outage events (overriding a resident’s thermostat) was likely acceptable to many residents, the population of primarily elderly and formerly homeless was sensitive enough to the concept of overrides for the team to avoid this approach. At the same time, interviews and focus groups demonstrated that formerly homeless seniors often have a relatively high degree of personal resilience and frugality given their experience of living without secure shelter and appreciate the opportunity to save energy and money.

Instead of forcing reductions upon residents, the project captured potential peak reduction and grid-responsive behavior through voluntary programs, such as OhmConnect and direct communication from building staff. OhmConnect does not rely on complex interfaces or smartphones, which not more than 20 percent of residents are expected to be able to afford.

Provided the OhmConnect system is explained to them, participants of the focus group were positive about its ability to facilitate both automatic and voluntary load management, which would offer utility bill savings with little effort on their part and accommodate each resident's level of interest and capacity to engage in such a program. One resident of Leigh Avenue, where the team conducted surveys and focus groups, was already a participant in the program.

Microgrid Technology Suitability and Availability

The integration of grid-interactive controls at this level within a mid-sized mixed-use apartment building is still in its early stages in the construction industry. The search for a microgrid controller capable of delivering all necessary functionalities (such as islanding, load communication, weather forecasting, and so on), along with stable controls integration that is compatible with various battery, PV, electric vehicle supply equipment, and building devices, quickly narrowed the choices to a limited selection of products.

While some suppliers could procure and design individual subcomponents to meet certain design specifications, the inherent uncertainty and risk linked to technology integration prompted the project team to engage in discussions with microgrid-as-a-service providers. These vendors are responsible for design, installation, and maintenance, and they often offer leasing or third-party financing options through microgrid-as-a-service agreements for their systems. Although vertically integrated vendors possess the technical know-how necessary for implementing microgrids, the ability of these technologies to integrate smoothly with commercially available building management systems and other smart devices is restricted, presenting a challenge to achieving reliable operation and user-friendliness.

Moreover, there were even fewer providers willing to take on a small- to medium-sized electrical project (approximately 200 kW), which is larger than the typical capacity for single-family homes (ranging from 13 kW to 50 kW) but smaller than battery energy storage systems designed for commercial clients (around 1 megawatt).

CHAPTER 4: Conclusions

This paper introduces a design framework aimed at achieving the most cost-effective strategy for a grid-responsive, affordable, and mixed-use housing project, which is prevalent in the densely populated urban regions of California. It is important to highlight that other teams participating in the design phase of the Next EPIC Challenge are proposing solutions tailored to housing types more typical of California's suburban and low-density areas. These alternatives differ in several respects from the housing project studied here, having generally higher cooling demands, increased building perimeter to volume ratios, enhanced potential for the deployment and integration of electric vehicles, and more viable and economical on-site renewable energy generation. The approach to grid-responsive affordable housing in California is unlikely to adopt a one-size-fits-all model. Specifically, the risk of outages serves as a crucial site-specific consideration in the discourse surrounding DERs. Nevertheless, it remains feasible to generalize many solutions applicable to both urban mid-rise and suburban low-rise housing contexts.

Key Results

Table 7 shows that the proposed project design achieves and exceeds all minimum requirements and targets established by the CEC Next EPIC Challenge.

Table 7: Next EPIC Challenge: Minimum Design Requirements Versus Proposed Design

Minimum Design Requirement	Proposed Design
The building must be all-electric.	**Complies**: The project design does not include any gas equipment, appliances, or infrastructure.
A minimum of 20% of the building's peak load must be available to be temporarily managed or curtailed to respond to grid conditions.	**Exceeds**: The proposed design can shift 35% of the building's (gross) peak load in response to grid conditions using domestic hot water storage, without curtailing services for residents.
The residential load during the 4:00 p.m. to 9:00 p.m. period must be met through a combination of on-site renewables, storage, and load management.	**Exceeds**: All of the residential load and part of the nonresidential load are met according to this breakdown by strategy: Energy efficiency: 10% Peak load management: 14% Thermal storage: 32% Battery + PV 38%
All residential end uses must be controllable through the home energy management system and must respond to real-time price signals.	**Complies** (semi-voluntary approach): Occupants will be able to automatically control major in-unit loads with smart plugs and smart thermostats (OhmConnect) and voluntarily control all loads in

Minimum Design Requirement	Proposed Design
	response to “OhmHour” notifications and informational lighting real-time signals.
Microgrid controllers must be interoperable with DER aggregation platforms such as virtual power plants.	**Complies**: Only controllers capable of interfacing with California Independent System Operator -approved demand response providers will be installed.
The building must be able to island from the main grid during an outage and be able to shed discretionary loads for Tier 1 critical and Tier 2 priority loads.	**Complies**: The electrical design enables backup power for in-unit loads, support services, and building access and safety.
The microgrid must be sized for indefinite renewable-driven backup power of Tier 1 critical loads.	**Complies**: The battery is sized to accomplish renewables-driven backup power 98.6% of the year, and an EV truck boosts this coverage to 99.9%.
20% of all parking spaces must have V2G chargers, with 100% of spaces to be EV-ready.	**Complies**: 1 of 4 spaces has a bidirectional charger to serve the maintenance vehicle and provide Tier 1 outage support.

Source: The Association for Energy Affordability

Table 7 provides a snapshot of the savings of the proposed design compared to a 2022 California Building Energy Efficiency Standards (Title 24) design, cost-competitive to receive a 4-percent tax credit under the Tax Credit Allocation Committee. The implicit suggestion of the CEC’s challenge is that multifamily buildings are a critical sector for providing grid services, and a focus on affordable housing in particular stands to benefit low-income communities. However, while the societal benefits of decarbonization are clear, the challenging economics of constructing new affordable housing and the sensitivity of nonprofit property owners to new technologies, especially those that don’t align with the priorities of developers and operators, undermine the scalability of this goal.

A central objective of the Roosevelt Village initiative was to extend beyond the fundamental requirements of the Next EPIC Challenge, investigating which investments, or a combination thereof, would most effectively align the needs for affordable housing with those of grid decarbonization while minimizing barriers to market transformation. This objective was largely accomplished, as the team discovered methods to provide benefits to affordable housing tenants through significant reductions in utility bills and enhanced resilience via apartment-level backup power. Nevertheless, it remains true that fully meeting the Next EPIC Challenge requirements yields substantial value for the grid and advantages for residents; however, the associated cost premium remains prohibitively high for widespread implementation within the affordable housing sector. As previously discussed, the team pinpointed strategies to bridge this cost gap. These strategies encompass mechanisms to assign value to resilience, dynamic utility pricing that more accurately reflects time- and location-specific energy costs, and regulatory reforms such as permitting master metering. Nonetheless, the realization of these solutions is unlikely to occur swiftly in the immediate future. This situation prompts a crucial inquiry: Are the Next EPIC Challenge requirements the appropriate standard for affordable housing projects? The team's research indicates that a reduction in full compliance, while still employing the same recommended design strategies, can yield significant outcomes. This approach may be more congruent with the financial challenges confronting affordable housing developers, while still providing value to the grid, lowering costs for residents, and enhancing resilience.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
ACEEE	American Council for an Energy-Efficient Economy
ACH	air changes per hour
AEA	The Association for Energy Affordability
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
BESS	battery energy storage system
CEC	California Energy Commission
CO_2	carbon dioxide
CPUC	California Public Utilities Commission
DERs	distributed energy resources: technologies that support on-site electrical generation, control and storage
DHW	domestic hot water system
DOAS	dedicated outdoor air system
EIFS	exterior insulation and finish systems
EPIC	Electric Program Investment Charge
EUI	energy use intensity
EV	electric vehicle
GHG	greenhouse gas
HRV	heat recovery ventilator
HVAC	heating, ventilation, and air conditioning
kBtu	thousand British thermal unit
kW	kilowatt
kWh	kilowatt-hour
kWh/year	kilowatt-hours/year
LCC	life-cycle costs
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
MERV	Minimum Efficiency Reporting Value - a rating system developed by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) to measure how effectively air filters capture airborne particles.
MT CO_2e	metric tons of carbon dioxide equivalent

Term	Definition
NEM	Net Energy Metering 2.0 or 3.0 - California policy governing how solar customers receive credit for the excess electricity they send back to the grid.
NPV	net present value
OhmHour	An Ohm Hour is an event that triggers smart devices to automatically adjust down or off through the voluntary OhmConnect energy load management program. Residents can them redeem edits for energy use curtailment.
PTHP	packaged terminal heat pump
PV	photovoltaic
R-21	high-density batt insulation
Roosevelt Village	Harmonized Resilience at Roosevelt Village Project
SCC	social cost of carbon
SF	square foot
SHGC	solar heat gain coefficient
SOMAH	Solar on Multifamily Affordable Housing
T24	Title 24: California building code regulating energy efficiency, water efficiency, and safety for residential and commercial buildings
TOU	time of use
V2B	vehicle-to-building or bi-directional charging, enabling EVs to supply electricity into the building
V2G	vehicle-to-grid charging, enabling the export of power back to the power grid from the EV battery
VNEM	virtual net energy metering

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Project Deliverables

The team developed the following project deliverables as part of this grant. These project deliverables, including interim project reports, are available upon request by submitting an email to pubs@energy.ca.gov.

- Project Concept Video (also available on the CEC's YouTube page)
- Community Engagement Plan
- Resilience Planning
- Energy and Emissions Performance Model Report
- Emerging Technologies and Strategies Report (Appendix D)
- Zero-Emission Cost-Benefit Analysis Report
- Conceptual Design and Engineering Drawings for Baseline and Proposed Design (Demo, General, Civil, Landscape, Structural, Mechanical, Plumbing, Joint Trench, Architecture, Electrical)
- Market Transformation Report (draft and final).

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A: Life Cycle Cost Analysis Assumptions

August 2025 | CEC-500-2025-040

APPENDIX A:
Life Cycle Cost Analysis Assumptions

This report performs lifecycle cost analysis using Net Present Value (NPV) as the metric for measuring lifecycle cost. The NPV is calculated based off of the equation below and compares the NPV of the proposed design to that of the standard design. Annual costs include the costs listed in Table A-1 and incorporate assumptions listed in Table A-2.

$$Lifecycle\ Cost = NPV = \sum_{t=0}^{30} \frac{(Cost - Benefit)_t}{(1+r)^t}$$

Table A-1: Cost Categories for Lifecycle Cost Comparisons

Cost Category	Description of What is Included
Solar PV	Solar PV panels, inverters, installation, and steel canopy structure (for elevated PV scenarios)
HW Storage	Hot water storage tanks, installation
Battery	Battery system, inverters, installation
Microgrid Infrastructure Cost	Virtual net energy metering meter and wiring, microgrid controller, backup loads transfer switches and electrical distribution, installation
DER Maintenance Cost	Cleaning, inspection, and maintenance of PV and battery storage systems
Energy Efficiency Measures and Mechanical System Incremental Cost	Incremental costs of efficiency measures and mechanical system described in Section 1
Equipment Replacement Costs	Battery system replacement costs (only system component with a shorter assumed lifetime than 30 years)
Down Payment	10% of total upfront costs per CEC required assumptions
Utility Costs	Utility bill costs for both resident meters and house meters, net of all load shifting, exports, and renewables self-consumption
Mortgage Fee	0.6% of mortgage per CEC required assumptions

Table A-2: Lifecycle Cost Assumptions

Item	Assumption	Explanation
Building lifetime	30 years	Assumed lifetime of buildings according to 2022 Title 24 code cycle.
Inflation rate	3%	Same as the discount rate required below.
Discount rate	3%	Same as the discount rate used in Interagency Working Group on Social Cost of Greenhouse Gases (2022).
Electricity rate escalation	Yearly rate from 2023 to 2052 Refer to Appendix 7.2.7 in California Energy Codes and Standards (2022)	California Energy Codes and Standards (2022), based on assumptions from CPUC 2021 En Banc hearings on utility cost (through 2030) and assumptions within 2022 TDV factors (after 2030).
Financing the residential units		
Down payment	10% of the incremental cost of the proposed design	Taylor et al. (2015) and Denniston et al. (2022)
Mortgage Fee	0.6% of the total mortgage amount	Taylor et al. (2015) and Denniston et al. (2022)
Mortgage interest rate	5% per year	Taylor et al. (2015) and Denniston et al. (2022), based on the average historical interest rate for 30-year mortgage loans
Property tax	Use the property tax rate of the city in which the property is located. Apply a home price escalation rate of 1.6%	
Tax credit		Denniston et al. (2022)
Net Energy Metering (if applicable)	NEM 3.0	

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APPENDIX B: Baseline vs Proposed Design Energy Use Intensity by End-Use and Emission Performance

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APPENDIX B:
Baseline vs Proposed Design Energy Use Intensity by End-Use and Emission Performance

Table B-1: Baseline vs Proposed Design Energy Use Intensity by End-Use and Emission Performance

End-Use	Unregulated? Y/N	Site Energy Use Intensity (kBtu/sf/yr)			GHG Emissions Intensity (kg CO_2/sf/yr)		
		Baseline	Proposed	% Improvement	Baseline	Proposed	% Improvement
Space Heating	N	2.55	0.58	77	0.321	0.074	77
Space Cooling	N	1.14	0.66	42	0.097	0.059	39
Indoor Fans	N	1.65	1.22	26	0.176	0.129	27
Domestic Hot Water	N	4.4	3.34	24	0.443	0.39	12
Residential Receptacles and Indoor Lighting	Y-plugloads and N-Lights	7.99	7.6	5	0.864	0.821	5
NonResidential Receptacles	Y	0.42	0.42	0	0.042	0.042	0
NonResidential Indoor Lights	N	0.78	0.78	0	0.077	0.077	0
Outdoor Lighting	N	2.03	1.17	42	0.222	0.128	42
Laundry Equipment	Y	1.12	1.12	0	0.105	0.098	7
Elevator	N	0.29	0.29	0	0.033	0.033	0
Booster Pump	N	0.19	0.19	0	0.019	0.019	0
TOTAL		22.56	17.37	23%	2.399	1.87	22%

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APPENDIX C: Cost Analysis

August 2025 | CEC-500-2025-040

APPENDIX C:
Cost Analysis

This section provides an analysis of the estimated cost difference between the Proposed Design compared to the Standard Design. The Standard Design refers to the design that achieves minimum requirements for energy savings according to California's 2022 Building Energy Efficiency Standards, effective January 1, 2023. Table C-1 below includes results that report incremental first cost.

Table C-1: Sample Comparison of the Incremental First Costs of Energy Features, Standard Versus Proposed Design

Energy Features	Standard Design	Proposed Design	Incremental First Cost Increase or Savings ($)
Window dimensions	8' H windows	6' H windows	$0
Window type	Standard vinyl double-pane casement/fixed (VPI)	Steel-reinforced vinyl triple-pane casement/fixed (INTUS)	$26,875
Air sealing	Details meeting ACH 2	Aeroseal	$47,000
Refrigerator	ENERGY STAR 17 cu top freezer <450 kWh	ENERGY STAR 15 cu top freezer <350 kWh	-$1,110
Range	Range with electric coil cooktop, front controls	Range with induction cooktop, front controls	$74,000
Ceiling Fans	No ceiling fans	ENERGY STAR, DC motor, 60" ceiling fans in each bedroom	$47,400
Ventilation	Central DOAS with tempered air, MERV 13 filtration	Central heat recovery ventilation, with associated return ductwork and fire smoke dampers, MERV 15 filtration	$180,994
Residential space conditioning	Baseline efficiency PTHP	Wall mounted Ephoca AIO	$182,850
Load shifting DHW	10 Sanden (2) 453 gal DHW tanks	12 Sanden (3) 453 gal DHW tanks	$49,000
High performance water heater	Colmac COP: 3.37 Refrigerant: 134a	QAHV Mitsubishi HPWH COP: 4.11 @ LWT=120 F Refrigerant: CO_2	$0
Water Heating - hot water use reduction	2.0 gpm showerheads	1.5 gpm showerheads	$0

Energy Features	Standard Design	Proposed Design	Incremental First Cost Increase or Savings ($)
DER FEATURES			
Rooftop PV	Baseline Schematic Design PV array (118 kW)	Elevated array (171 kW)	$212,000
Rooftop PV - support	Stanchions	Steel canopy	$593,600
Submetering for microgrid	None	Submetering on all main switchboard and renewable distribution board feeder breakers as well as all unit panels.	$90,100
Electrical distribution infrastructure	Standard	VNEM configuration with automatic transfer switches based VNEM meter bypass for islanding capability.	$636,000
Microgrid controller	None	Microgrid controller integral to the battery energy storage system to make preference-based decisions about the allocation of on-site generated energy to building loads, battery storage or grid export.	$250,000
Battery system	90 kWh	300 kWh	$291,500.00

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APPENDIX D: Emerging Technologies Report – Alternatives Considered

August 2025 | CEC-500-2025-040

APPENDIX D:
Emerging Technologies Report – Alternatives Considered

Figure D-1: Simple Payback by Design Measure

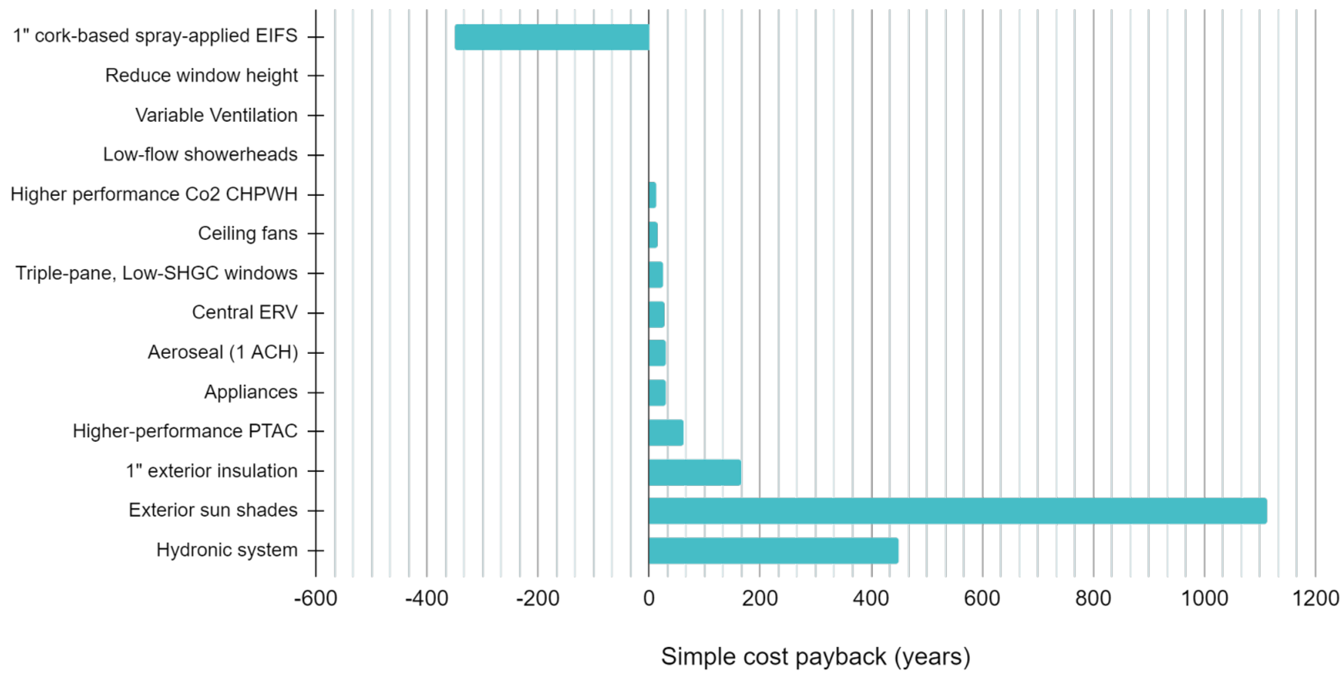
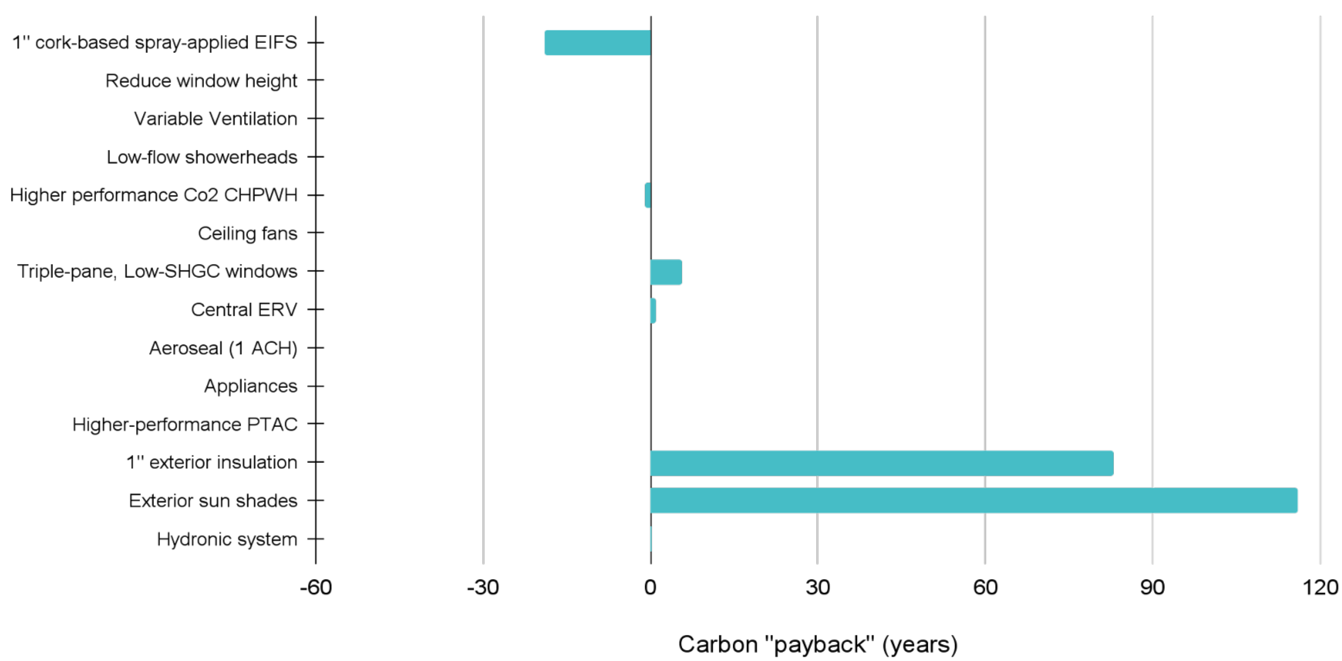


Figure D-2: Carbon "Payback" by Design Measure



With few exceptions, the optimization study ultimately pointed us away from any thermal storage technology that added substantial up-front cost, embodied emissions or novelty, in favor of more basic, easy-to-adopt energy efficiency measures, hot water load shifting, and distributed energy technologies. Although more expensive envelope measures and hydronic heating and cooling improved overall cost and carbon performance, it was not enough to overcome the very high up-front cost and complexity of those measures compared to additional battery capacity, especially when taking into account the already-high fixed costs of the microgrid infrastructure. In the end, even on peak days the 4:00 p.m. to 9:00 p.m. time frame is dominated by residential loads that are un-shiftable without changing fundamental daily routines (cooking, for example) of residents. Therefore, incrementally improving the building's thermal efficiency to draw down heating and cooling loads to near-zero brings diminishing returns that would appear difficult to overcome through market transformation.

Structural and Material Innovations

Building Construction Methods

We propose a series of small, incremental improvements to conventional practice to draw down both cost and embodied emissions, for a construction type (five stories of type III over a concrete podium) that is already highly economical and fairly low-carbon for the current housing market. The goal was to leverage our interdisciplinary team to identify modest but meaningful and reliable offsets for measures added elsewhere in the design.

Proposed Design

Wood framing optimization

We looked to optimize the wood framing and proposed to change interior wood bearing and shear wall 4x wall construction to use 6x framing instead. In a 6x wall, the studs could be spaced at 24" o.c. vs 16" o.c. in the 4x walls, especially at the lower floors where the studs are highly loaded. This modification resulted in a 20% overall reduction in wood material volume, which translated to a 1% reduction in the overall embodied emissions (6620 GWP) and 5% ($107,000) construction cost savings. The downside: a 2% reduction in usable square footage

Lower-carbon concrete and masonry

In our baseline analysis, the concrete accounted for 60% of all of the embodied carbon emissions of the project. Specifying low carbon concrete mixes that are applicable to the project location is a place where large reductions in the overall embodied carbon can be made. Since concrete is local and its properties are subjective to the local aggregates, it is important to work with your local concrete ready-mix supplier to determine which low carbon concrete strategies are available in your market and how to utilize the available low carbon concrete strategies. Overall percentages of reduction will vary from project location to project location.

We have worked with our local ready-mix suppliers to develop high cement replacement concrete mixes using a blend of supplementary cementitious materials (SCMs), specifically fly ash and slag. The use of SCMs can affect cure times and the ability to finish the concrete. Specifying different mixes for different concrete locations within the project can maximize the amount of replacement without affecting constructability. We utilized 70% cement replacement mixes for foundations (footings, grade beams, slab on grade and mat slabs), 50% cement replacement mixes for columns and walls and 30% cement replacement for PT slab. This assumes that our concrete mixes for the walls and columns are cast-in-place. Often walls are requested by the contractor to be placed using shotcrete. If using shotcrete, the percentage of cement replacement is reduced from 50% to 25%. We also specified the use of CarbonCure because it is available in our market. Other strategies to consider are other SMCs, including ground glass and natural pozzolans, and using Type iL cement in lieu of Type II or III.

The use of project specific low-carbon concrete strategies resulted in an 18% reduction in the overall embodied carbon emissions (206,600 GWP) for cast-in-place walls from Pacific Southwest Regional baseline definitions within Tally. If using shotcrete, it is a 15% reduction in the overall embodied carbon emissions (180,000 GWP).

In general, high cement replacement mixes are relatively similar in cost to all-cement mixes. Typically, SCMs cost less than the equivalent amount of cement. Additional costs come from additional chemicals that are needed to maintain workability. Working with your local ready-mix supplier and specifying a reasonable replacement percentage for the usage should minimize the additional costs.

We explored the use of low carbon CMU blocks like Carboclave and Permacon. For a fully grouted CMU wall, products like Carbocave resulted in a 10% reduction from a baseline grouted CMU wall. However, these products were not readily available in our market. Since there was only a small amount of CMU on this project so we chose not to pursue it due to the cost premium. It was noted that the baseline concrete wall mixes have 50% more embodied carbon than the baseline grouted CMU wall. In contrast, the embodied carbon emissions of the high replacement concrete wall mixes implemented on this project (50% cement replacement using fly ash and slag) results in a 25% reduction from the baseline grouted CMU wall.

Modular casework

This project is proposing Kit Switch interiors for apartment kitchens, closets and bath vanity components. Kit Switch is a promising, woman-and-minority-owned small business based in San Francisco. It is part of the Autodesk Research Outsight Network, Net Zero Accelerator, and a Terner Center innovation grant recipient. They deliver modular "kits" from a standardized library of ready-to-install interiors, beginning with the recent commercialization of the Kit-Kitchen. With this product, cooking, fixtures, casework and counter/backsplash components are installed in half of the time and 30% less cost compared to a traditional build-out of interior components, due to improved predictability and resource efficiency, lower labor requirements and turn-key design.

Kit Switch promotes reduction, reuse, repair, and recovery of materials standardizing kits such that they can be reconfigured, removed, easily replaced and recycled. Each modular component includes integrated plumbing/electrical with a shutoff valve, ensuring removal without needing to tear out drywall or building systems. Finally, Kit Switch offers workforce development programs to further the goal of expanding building decarbonization workforce with targeted support for disadvantaged workers.

Alternative Options Considered

Volumetric modular construction

David Baker Architects have formed a large body of both market rate and affordable modular housing work that reaches back roughly 10 years. In that time span, the firm has overseen the completion of over 800 modular units throughout the Bay Area. Volumetric modular construction, if executed properly, promises significant savings both in construction schedule and overall construction costs. Transferring framing and finish work from a job site to a modular factory floor yields benefits such as higher quality and more uniform construction, higher rates of resource use efficiency and material recycling, reduced commute time for employees and a safer work environment. However, modular construction also increases risk by funneling procurement and construction through one vendor who is driven by an assembly-line schedule that is set in advance. In addition, not all factories are set up to maximize material efficiency, and since modules are constructed for transport and assembly, modular often requires significantly more framing material.

A significant barrier to completing projects with volumetric modular construction comes in the form of access to financing. Developers, especially affordable housing developers, who rely largely on public funding, often struggle to meet modular factories' needs for large up front deposits required at or even before the start of on-site construction work. Fortunately, sources of public funding are opening in response to higher demand for modular housing. And tools such as improved integrated project delivery and robotics can significantly improve efficiency. Several recent David Baker Architect

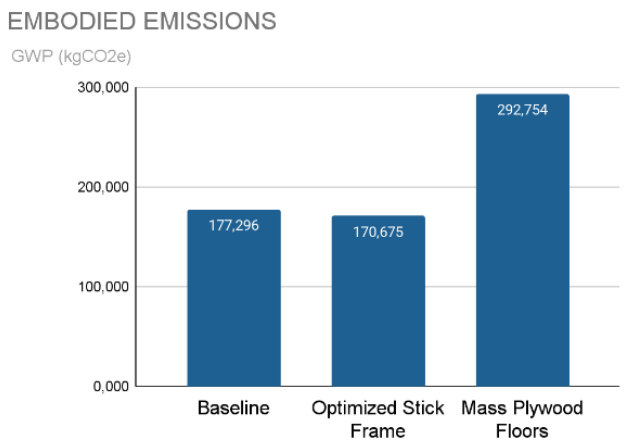
projects including Roosevelt Village, 420 Mendocino Avenue, Page Street Studios and Harvey West Studios were originally designed as a modular project, but the design team and owner determined that the risks outweighed the potential benefits.

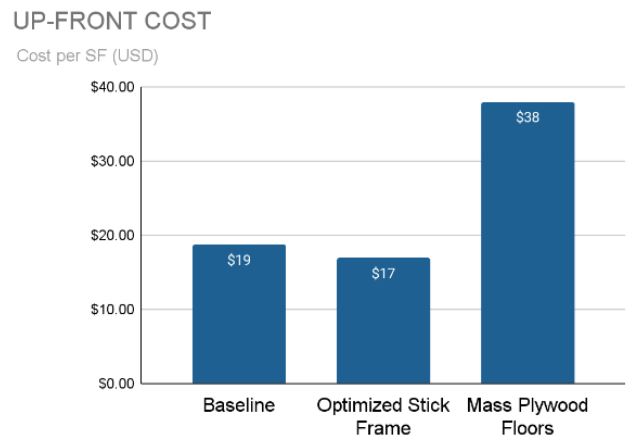
Mass timber construction

We first explored using mass plywood floors in lieu of the traditional stick built plywood over TJI joists, with the promise that it could potentially reduce construction schedule due to speed of mass plywood installation. In particular, this could be helpful at the roof, where there are many additional beams needed to support the rooftop mechanical, electrical, and plumbing, control descent anchors and PV arrays. However, we found that traditional plywood over TJI framing was more efficient than mass plywood, including a 10% increase in whole-building embodied carbon when considering mass plywood for all of the wood floors. In addition, the reduced installation time of the mass plywood was not significant enough to offset the additional unit cost of the mass plywood floors.

We also explored a 6-story and 8-story CLT floor mass timber option instead of the baseline 5 stories of traditional wood stick-framed over a 1 or 3-level concrete podium. The lateral system that was chosen was steel buckling restrained braced frames (BRBFs). The CLT panels are supported on glulam beams, girders, and posts. The walls of the units were framed with non-bearing 2” metal stud construction. The full mass timber option was designed as Type IV-C, and all the wood structural elements were designed to obtain the required fire rating through char. Therefore, the mass timber elements could be fully exposed. The most cost-effective mass timber design requires the structure to extend to grade, with no transfer floor at the podium level. This results in a simpler structure, but also less flexibility in terms of locating circulation cores, mechanical, electrical, and plumbing coordination, and allowing exterior corridors (Figure D-3).

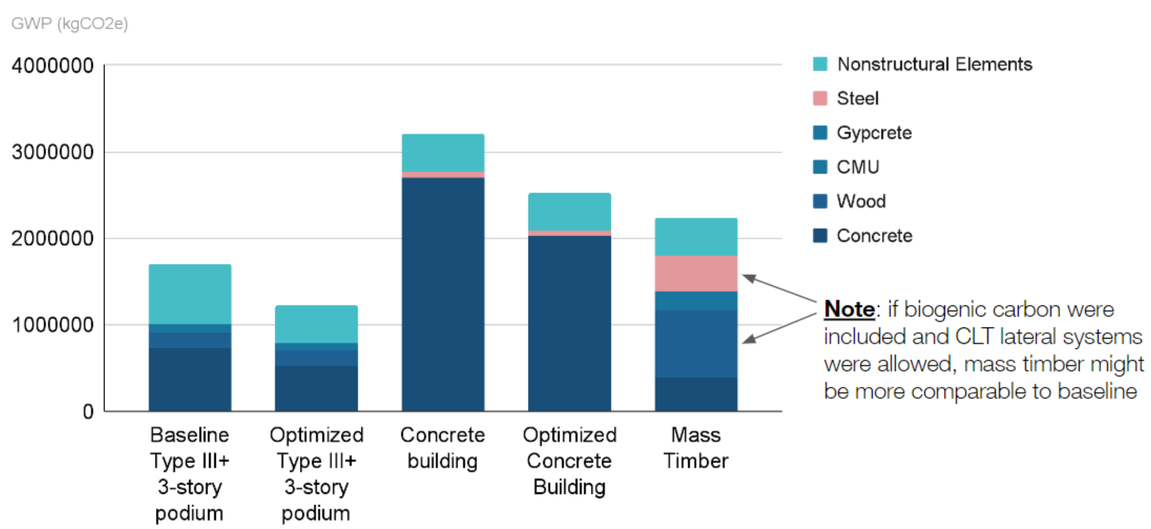
Figure D-3: Performance of Mass Plywood Floors Compared to Stick-frame Options





Our analysis showed that mass timber does not yield an improvement in embodied emissions compared to either the 6- or 8-story podium buildings, resulting in increases of 23% and 30%, respectively. This is because, although the concrete podium is eliminated, the mass timber construction requires a lot more volume of wood material with higher process energy; a steel-braced frame lateral system (instead of a wood shear wall lateral system) and a thicker layer of gypcrete on top of all the floors. The cost is also higher, comparable to concrete construction. Only compared to an 8-story concrete building does the mass timber yields carbon benefits and costs roughly the same, although insurance premiums have been a barrier for nonprofit developers in recent years. Traditional stick-framed construction with optimized concrete design and efficient, panelized wood framing still has the smallest environmental and economic footprint (Figure D-4).

Figure D-4: Embodied Carbon potential for Mass Timber at 8 Stories



Efficiency & Load Reduction Technologies

Building Envelope

Our proposed design includes reduced air infiltration to 1 ACH or below, using Aeroseal, triple-pane windows with a low SHGC, and high-density R-21 fiberglass batt insulation. Windows were also reduced in height from 8 feet to 6 feet, with higher sills. In our energy simulations, all the measures we evaluated beyond best-performing double-pane vinyl windows and R-21 cavity insulation had a marginal load-reduction benefit individually, and almost no meaningful 4:00 p.m. to 9:00 p.m. load reduction on peak "battery design days." But adding continuous insulation or exterior window shades came at a much higher cost; therefore, these were discarded.

There are, however, two promising emerging technologies that would be incorporated into our proposal if we thought they would be available in the next 2-3 years: these are (1) cork-based, spray-applied EIFS insulated cladding; and (2) dynamic glazing for nail-fin vinyl windows. Each of these has the potential to be a cost-neutral alternative to more expensive solutions and also save on embodied emissions and improve environmental quality, as explained below.

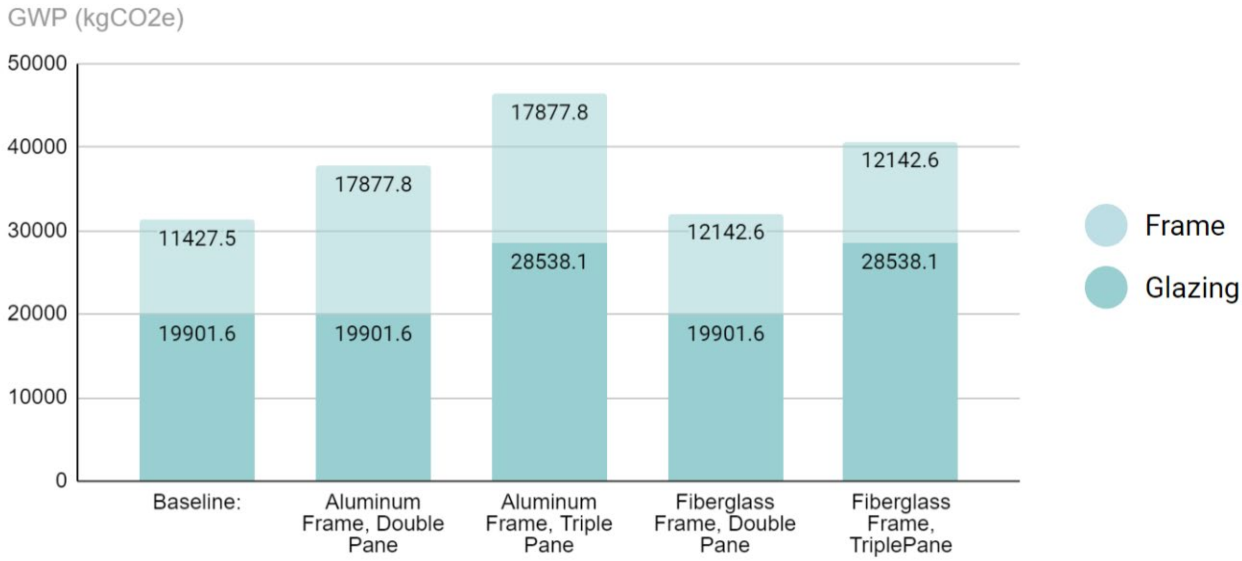
Proposed Design

Highly insulated fenestration

The primary reason for including triple-pane windows in our proposed design is that high-quality products were quoted at a modest incremental cost (within $3/SF) over standard high-performance double-pane vinyl windows, putting the simple payback for this measure at 24 years based on the costs we received. We received quotes for two products, Alpen thin-triple and INTUS triple-pane vinyl windows. Triple-pane windows with low SHGC (0.17-0.19) also had three times as much savings potential compared to other envelope efficiency measures for our project in San Jose.

There are two drawbacks of moving to highly insulated windows with low SHGC: the lower SHGC (below ~0.19) comes with its own incremental cost (another $5/SF), and whole-window visible transmittance drops below 50% all year round. Emerging research points to the benefits of full-spectrum sunlight and view, which should be an important consideration for residential windows. Because multifamily building performance is highly sensitive to orientation- and climate-specific solar gains, and exterior solar control is expensive, and carbon-intensive, the potential to incorporate dynamic glazing into conventional nail-fin vinyl window products emerges as a promising direction for future product development (Figure D-5) (see next section).

Figure D-5: Embodied Carbon Potential by Window Type



Aeroseal

Increasing air tightness of multifamily buildings to 1 ACH or below is a worthwhile measure provided the method is low-cost and reliable. Aeroseal has been demonstrated in multifamily buildings with promising results, provided that efficient construction sequencing can be achieved, given that the window for installing the product is narrow, between drywall and finishes installation, and projects are typically phased. If funded, the grant could support executing Aeroseal on a larger sample of units than has been previously achieved.

Alternative Options Considered

Spray-applied cork EIFS

The exception to the rule that continuous insulation is not cost-effective is an insulating cladding product that achieves both functions in one (Figures D-6 through D-8). Diasen, a manufacturer of cork-based insulating finishes in Italy, offers a spray-applied EIFS, or insulating stucco, called Diathonite Thermactive 0.37, which is a very promising solution in California for adding thermal insulation at a much lower cost than other insulation solutions and at a lower cost even compared to many commonly-used cladding systems.

Figure D-6: Whole-Assembly Global Warming Potential (GWP) Comparison for Typical Cladding Options

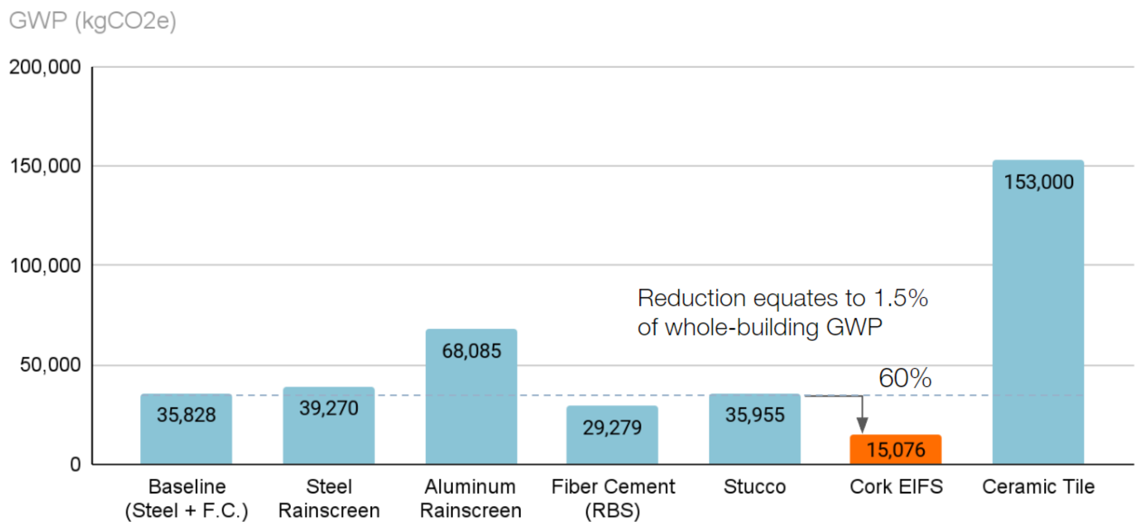


Figure D-7: GWP of Typical Insulation Options and Thicknesses

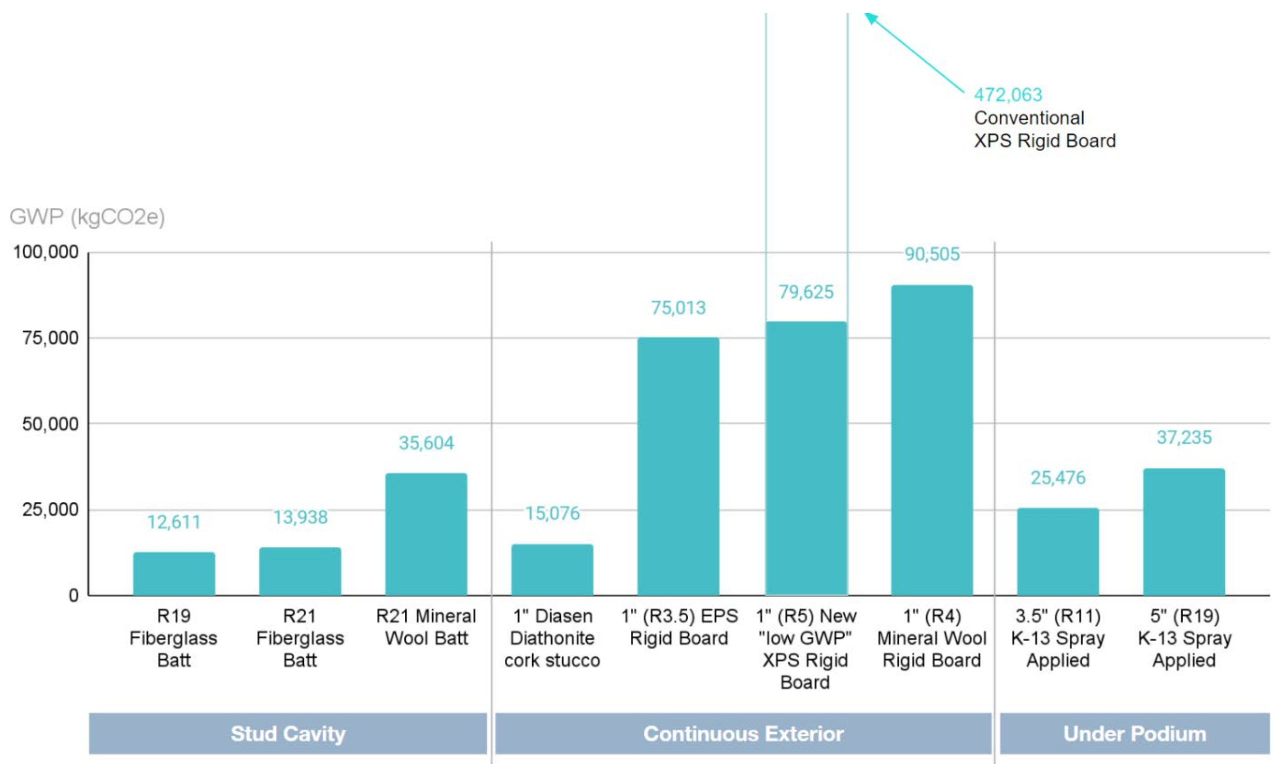
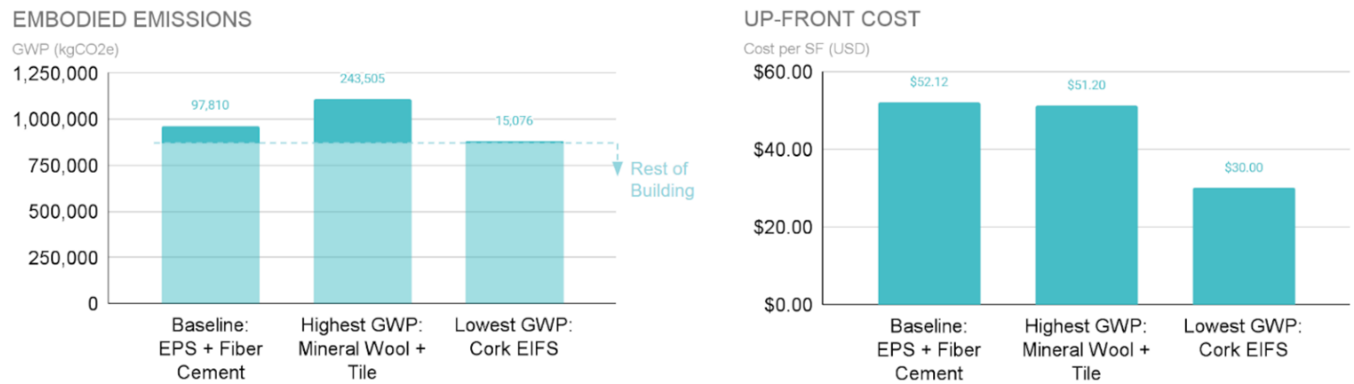


Figure D-8. Worst to Best Exterior-insulated Assembly Comparison Showing the High Carbon and Cost of Exterior Insulation and Cladding Choices Without Innovations Like Spray-applied Cork EIFS



Our baseline design included raw steel rainscreen panels on 40% of the facade and fiber cement panel on the remaining 60%, with an average installed cost of roughly $46/square foot. (Locating a "premium" material on 20 to 40% of the facade is not a given but can be considered typical of urban mid-rise housing projects.) Compared to this cladding mix, 1" of spray-applied EIFS would represent a substantial up-front cost savings while also providing incremental operating cost benefit, including peak load reduction, and drastically reduced embodied emissions. Compared to standard stucco, we assumed a slight incremental cost, although the costs should be comparable once a market is developed, because there is minimal difference between the installation of the Diasen product and a standard stucco.

Cork comes with the added benefit over wood fiber based spray-applied insulating products (such as K-13, not currently developed for exterior applications) of being able to take on and release moisture without risk of deterioration. The downside is that cork will most likely remain a premium market product due to its limited global supply. Achieving thicker applications requires more skill and process (for example, to set guides for a level surface), but is possible without mechanical fasteners up to a thickness of 6". There is currently no supply chain set up for the product in the United States, and we could not get a solid cost estimate from would-be installers; but the team is still actively pursuing potential installers to partner with on this project.

Electrochromic glazing

As explained above, it is difficult to achieve well-tuned control of solar gain in midrise multifamily affordable housing projects in California; and achieving the best imperfect solution (low U and SGHC) comes at a relatively high cost. These buildings have fairly high internal gains and are highly sensitive to added solar gains during cooling periods, but for many times during the year, direct sun is welcome. Sun, view clarity and full spectrum light also come with mental and physical health benefits that should not be de-prioritized when designing equitable housing. Exterior sunshades are commonly assumed to be an appropriate passive design and comfort strategy to achieve seasonally-dynamic solar control in many California climates. However, exterior sunshades showed very little annual or 4:00 p.m. to 9:00 p.m. peak savings benefits in our energy simulations, and come with high first costs and embodied emissions owing to the fact that metal (aluminum or steel) is the only practically feasible material to use.

In contrast, electrochromic glass has a proven track record of achieving well-tuned solar control that balances view clarity; and in 2022, the Inflation reduction act made dynamic glass eligible for federal tax credits, which puts the cost on par with standard double-glazed insulated glazing units (IGUs) and opens the door, potentially, to examine this technology in sectors like multifamily.

This technology is not incorporated into our proposal because no punched-window products currently exist. Two major producers of dynamic glass - Saint Gobain and Sage Glass - do not currently have any partnerships with manufacturers of operable, nail-fin vinyl or aluminum windows, which are ubiquitous in mid-rise multifamily buildings. Window wall, a more cost-competitive envelope solution for apartment buildings above 9 stories, might present a more near-term demonstration opportunity. Beyond the lack of an existing market, the cost and complexity of introducing wired, dynamic controls into housing projects must be carefully examined for long-term operational durability. As a general rule, actively controlled building components should be used with extreme caution because at some point they typically break. Also, it is imperative that residents be well informed about how the dynamic control works. In other permanently supportive housing projects, automatic control of systems has been shown to trigger negative reactions like paranoia.

Panelized continuous insulation

Panelized EIFS, or other types of thermally broken exterior cladding panels with an internal structure, are a possible solution to streamline mid-rise new construction while improving performance; but we determined that they do not add enough of a benefit for the added complexity, cost and high carbon relative to conventional practice. To be worthwhile, the cost of any continuous insulation has to be extremely low, seamless for the industry to adopt, and extremely easy to repair and replace (see spray-applied EIFS above).

Thermal storage-enhancing finishes

Cool paints, as well as paints or wall treatments incorporating phase change materials, are a worthwhile category of emerging technology to enhance thermal performance with little impact on design. On paper, they should have low barriers to adoption and low incremental cost. However, in reality, even a modest incremental cost on a standard product such as paint that is used over a vast square footage, and maintained actively over the building's life, becomes a prohibitive expense; additionally, procurement of specialty alternatives by maintenance personnel over the long term is not a realistic expectation. For a building type that is already fairly high in thermal mass, using specialty products to increase the thermal storage capacity of the structure did not reach the necessary high bar of incremental performance gain to justify its adoption, in our determination.

HVAC

Our proposed HVAC design uses high-efficiency vertical packaged terminal heat pumps (PTHP), coupled with central ventilation using an HRV that is controlled to vary ventilation rates dynamically, contributing to the load shifting capabilities of the project. The HRV also includes a bypass to avoid unwanted heat transfer during mild conditions (free-cooling), as well as reduced pressure drop during these free-cooling periods. These base technologies are supplemented with modern controls (Nest or Ecobee) and a ceiling fanlight on backup power for extending the thermal comfort zone, particularly during outages and peak events.

Our team considered many other strategies and systems to address the goals of this challenge. Ultimately these other solutions were not determined to be the best for our project. We detail many of these considerations and deliberations below.

Proposed Design

Low GWP packaged terminal heat pump (PTHP)

Packaged terminal heat pumps (PTHP) are not new, however the form factor of and refrigerant type used in our chosen product (Ephoca AIO, vertical style) are newly available and fundamentally different from the standard offering in the marketplace. Standard vertical PTHP products have a 24”x24” footprint, taking up valuable floor area. Their form factor, which uses a rectangular wall sleeve, can also be difficult to air-seal properly and results in relatively large louvers on the facade. They also typically use noisy, and inefficient single-speed compressors, along with low efficiency filters (MERV-3) and limited control options.The selected vertical PTHP (Ephoca AIO) has the following advantages over a standard vertical PTHP:

- Is only 12” deep
- Uses R-32 refrigerant
- Uses high-efficiency inverter (variable speed) scroll compressor that is also very quiet
- Small outdoor louver requirements result in lower risk of improper air-sealing and a better facade aesthetic
- They include a MERV-13 filter option for the recirculated air
- They have multiple modern control options, including integration with smart thermostats like Nest and Ecobee

Central heat recovery ventilation with summer bypass and dynamic control

Centralized heat recovery ventilation (HRV) is also not a new technology or approach, though its use in the marketplace is rare. Dynamic ventilation control is a strategy allowed by ASHRAE Standard 62.2, which allows for reducing ventilation during parts of the day as long as you increase ventilation other parts of the day. This strategy is an emerging, largely untried strategy in multifamily residential that is most easily and successfully implemented using a centralized ventilation approach. A centralized HRV approach with summer bypass and dynamic control, which includes both outdoor air supply and exhaust, has the following advantages:

- Centralized filter maintenance that does not require disturbing occupants
- Space for deeper, higher efficiency filters that last longer, are lower pressure drop, and more effective against wildfire particulates

- Tempering of outdoor air with heat recovery instead of compressor-based cooling/heating, which eliminates the associated energy use and refrigerants associated with a central ventilation system using a heat pump for tempering outdoor air. This tempering also helps with building resilience in a power outage or peak event by keeping the outdoor air tempered in such events rather than introducing unconditioned outdoor air.
- The ability to shift the ventilation load to off-peak periods
- The ability to "economize," bringing cool outdoor air when cooler air is desired through bypassing the HRV heat exchanger and associated pressure drop.

Smart thermostat

Smart thermostats are readily available products, but they are uncommonly used in this affordable multifamily residential market, particularly projects that use PTHPs. Modern internet-enabled thermostats allow for intelligent setback based on occupancy, schedule, and external signals (e.g. demand response signal or programs like OhmConnect, see below). This strategy is a key component of HVAC energy curtailment/peak reduction during grid events. Our occupant surveys suggested that while centralized control during events (overriding a resident's thermostat) was likely acceptable to many residents, our population of primarily elderly and formerly homeless was sensitive enough to the concept of overrides for our team to avoid this approach. Instead, by providing an internet-enabled smart thermostat, we were still able to capture potential peak reduction and grid-responsive behavior through voluntary programs, such as OhmConnect and direct communication from building staff.

Ceiling fans

Ceiling fans are hardly a new technology, but their use in affordable multifamily projects is relatively rare because they are considered an easy value-engineering (VE) target. Ceiling fans offer the following advantages for our project:

- They extend the comfort envelope, adding ~6F of cooling effect in warm conditions
- The extension of the comfort envelope allows occupants to keep their cooling setpoints higher and reduce their energy bills, and also provides a measure of cooling resilience during power outages (when connected to backup power).

Alternative Options Considered

VRF

VRF is a common system option for multifamily residential. VRF offers the benefits of low-noise fan coils, heat recovery (though limited in practice), and fewer outdoor condensing units than traditional split systems dedicated to each unit. However, VRF relies on a large network of high-GWP refrigerant that tends to be leakier than single split systems because there are many more joints. VRF systems rely on R-410a and lower GWP alternatives are at least a few years away from availability and are based on A2L type refrigerants that have stricter requirements surrounding allowed refrigerant quantities. These requirements will effectively mean that VRF systems will only be allowed to serve smaller networks, which reduces heat recovery potential and reduces the advantage of fewer outdoor condensing units. VRF systems are also proprietary bundles, meaning once you decide on a manufacturer, you cannot mix and match manufacturers in the future. Thus, the building is locked into that particular VRF manufacturer for the life of the system. For the purposes of our evaluation to achieve the grant goals, VRF was not selected for these primary reasons:

- High quantities of of high GWP refrigerant
- No ability to shift peak load
- High embodied carbon of piping distribution

Ducted split systems

Ducted split systems use the same technology as VRF systems, with refrigerant running between an outdoor unit and indoor unit, except there is only one of each in a split system. This setup is the most common form of conditioning for low-rise and mid-rise multifamily residential, largely due to cost and simplicity. Each individual split system is on the tenant's electrical meter, which is also more straightforward than VRF, which requires a proprietary refrigerant sub-metering system. Split systems share similar refrigerant issues as VRF: they currently use R-410a and there are no viable alternatives available now. Additionally, because each fan coil is home-runned to each condenser unit on the roof, there is additional copper used compared to VRF and the associated embodied carbon. Because each unit has its own condensing unit, the roof can become relatively crowded with these units, which can impact space for photovoltaics as well. For the purposes of our evaluation to achieve the grant goals, split systems were not selected for these primary reasons:

- High quantities of of high GWP refrigerant
- No ability to shift peak load
- High embodied carbon of piping distribution

Water-source heat pumps

While a condenser water based hydronic system (sometimes referred to as 2-pipe hydronic system) is efficient and allows for heat recovery, there is limited ability to peak shift with this type of system and without that ability, the added complexity of going hydronic (controls, pumps, air-to-water heat pumps, etc) is not worth the added cost. These types of buildings do not have on-site building operators, and while all systems will require outside maintenance and repair, hydronic-based systems often require more specialized technician services. Hydronic systems have both the advantage and disadvantage of having a central plant. Central plants generally will result in fewer equipment failures because there is less overall equipment, but such failures are much more critical because they serve the whole building. In contrast, a distributed conditioning system (like PTHP or split systems) will have more failures (many more compressors to fail for example), but each failure will only affect a single residential unit.

Hydronic 4-pipe fan coils

A 4-pipe fan coil system using chilled water and heating hot water is an extremely efficient option that allows for full heat recovery and peak shifting through thermal energy storage of chilled water and hot water. We considered this option in a lot of detail and you can refer to the rest of our report for all of the considerations. This type of system shares the same concerns we had related to any hydronic system, as discussed in the water-source heat pump section above.

Radiant (in-slab or ceiling)

While radiant pairs well with air-to-water heat pumps, is efficient, and allows for peak shifting through thermal mass, it also relies on a complex hydronic central plant and is not an intuitive or fast-reacting thermal comfort control system. This option also shares all of the concerns we had regarding all hydronic system types.

Central control system and load shifting with thermostat setpoint adjustment

Central control of thermostat setpoints can be a strong strategy for peak load reduction in critical grid events, though it requires the expense of the central control system (~$400/unit) and it also requires understanding and buy-in from tenants. Based on the tenant population, we felt that centrally controlling setpoints would not be favorable and prefer to keep that control in hands of tenants with incentives for adjusting setpoints during critical times.

In-unit PCM, e.g. walls, etc.

In-unit phase-change materials (PCM) allow for peak load reduction and shifting. The peak load reduction component also helps with the resilience of the building while conditioning systems are down. In order to maximize the efficacy of this strategy, it would rely on central thermostat control (to precool/preheat the PCM), which exacerbates the issues of central control discussed above given this central control would happen more often and be less intuitive to the residents. While central control is not required to gain some benefit from PCM, the added cost and construction complexity was deemed not worth the limited energy cost reduction and peak load reduction benefits.

Domestic Hot Water

Our proposed domestic hot water (DHW) design uses a central CO_2 heat pump system with storage sized for extended peak shifting. The DHW system also incorporates phase change material. Other DHW strategies were considered, as well as add-on strategies to further reduce DHW energy use. DHW energy use is a significant driver of whole-building energy use.

Proposed Design

CO_2 heat pump water heating plant with phase change storage

Our proposed DHW design is a central system with CO_2 heat pumps and phase change storage/swing tank. A centralized approach allows for central maintenance and better space efficiency in the residential units. The CO_2-based heat pumps offer an extremely low GWP solution for DHW. Critically, a central system allows for easy load shifting of DHW energy use. We partnered with Small Planet Supply on a pilot project to test the use of phase change storage, which allows for a reduction in space required for storage and the ability to reduce the energy input for the swing tank. The swing tank handles the recirculated hot water load.

Our DHW storage system is sized based on the optimization platform Xendee, which is co-optimizing multiple DHW goals:

- minimize carbon emissions
- minimize overall cost
- no reduction in DHW availability during grid outages

Our centralized system is co-located with the building's battery systems to recover heat associated with battery inefficiency.

Alternative Options Considered

Unitized heat pump water heater

A decentralized approach to domestic hot water has the main advantage of eliminating all energy use associated with recirculation losses. By putting the DHW heaters in the units, piping runs are short enough to eliminate the need for recirculation and its associated energy. There is also the advantage that DHW energy use is on the tenant meter instead of the common meter, which provides more direct feedback between consumption and energy costs. While these advantages are large, there are few options in the market for small efficient (heat pump) water heaters. For studios and 1-bedroom apartments, the DHW needs are quite small (25 to 40 gallons). While larger in-unit water heaters allow for better peak shifting capability, there is a tradeoff with unit floor area taken up. Additionally, in-unit water heaters add to the overall maintenance burden, particularly if they use tanks that require anode rods. Most importantly, however, in-unit water heaters make control strategies more challenging than a central system does. While simple peak shifting/reduction can be handled with in-unit heaters by oversizing the storage, there are not other holistic central-control strategies that can be implemented across all in-unit water heaters without both higher cost and potential conflicts with tenants.

Per-unit mini heat exchanger ties to central hydronic HVAC option

This strategy is a hybrid of centralized and decentralized DHW approaches and shares many of the advantages of each. This option is only valid when paired with the hydronic 4-pipe fan coil HVAC option. The strategy involves using heating hot water piped to each unit and using a heat exchanger to heat domestic cold water to make instantaneous hot water. This option shares the primary pro of the unitized heat pump water heater option above, which is to eliminate the DHW recirculation loop. While the DHW recirculation loop is eliminated, there is still recirculation energy associated with this strategy whenever heating hot water is not needed for HVAC needs but is needed for DHW purposes. Because this strategy is tied to the heating hot water system, the benefits of that centralized system (storage, peak shifting/reduction, central control and maintenance) are shared with this option. Because we did not select the hydronic 4-pipe fan coil HVAC option, this option was not selected.

Drain water heat recovery

This strategy uses a copper-tubing heat exchanger around a shower drainpipe to preheat incoming cold water that serves the shower. This reduces the amount of hot water required to achieve the same mixed water temperature. Based on prior experience on other projects, the payback period is quite long for our climate/demographic and there is also a potentially significant embodied carbon tradeoff with all of the additional copper piping required. While we did not quantify this embodied carbon tradeoff, our choice to exclude this strategy is consistent with our criteria that strategies should avoid adding more material unless the benefits are significant.

Wastewater-source heat pump (piranha)

This strategy takes advantage of the wastewater heat recovery to provide very-efficient water-source DHW heating. This strategy is particularly applicable for multifamily residential projects, where DHW load is high, but it does add cost, complexity, and maintenance on top of a similar air-source solution (as in our proposed design). Our proposed design chooses to take advantage of air-source heat recovery with the battery storage system and is thus also very high-efficiency.

Lighting & Appliances

For residential and common area lighting and appliances, the current state of the art does not leave a lot of opportunity for novel technologies, particularly for developments like Roosevelt Village with limited specified equipment (no in-unit laundry or dishwashers). Our design takes advantage of low-hanging fruit load reduction opportunities, resulting in a combined, estimated 5% load reduction compared to typical practice. A discussion of emerging DC products and why they were omitted is also included below.

Proposed Design

Refrigerators with 350 kWh max rated energy use

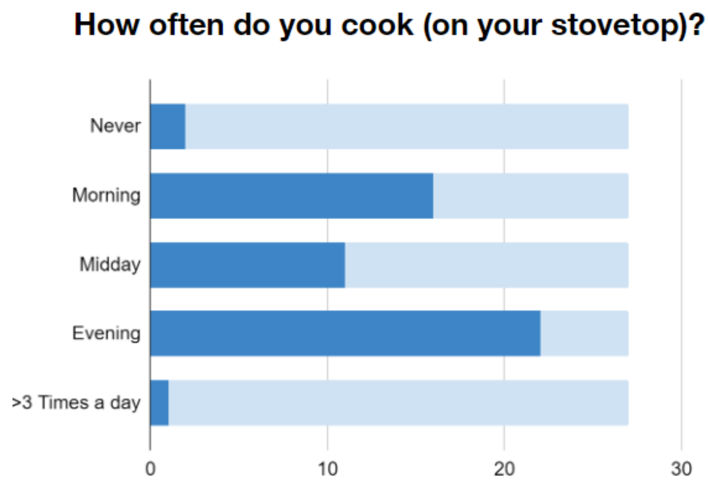
A typical refrigerator specification is a 19 cubic foot top-freezer ENERGY STAR model from a major manufacturer, which range from 365kWh. Including a maximum rated energy use of 350 kWh in the project specifications restricts the project to slightly smaller refrigerators (15-17 cu ft) but is achievable without a major change in service or incremental cost.

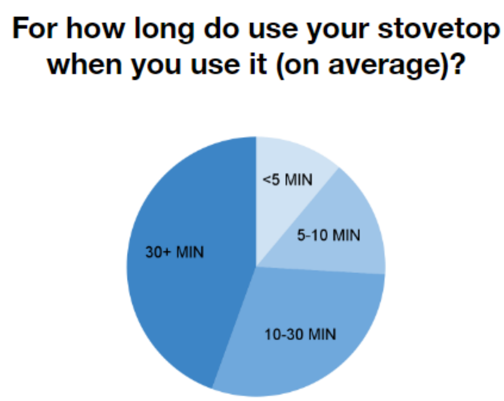
Induction ranges & cooktops

Induction cooktops are an important measure for reducing load in the 4:00 p.m. to 9:00 p.m. window, when the majority of intensive cooking occurs. In the absence of good data by end use for this population, we included questions about cooking habits in our stakeholder outreach, shown in Figure D-9. Despite the value and increasing availability of affordable induction products, there are still significant barriers to adoption in affordable housing, particularly dwelling units with full ranges. Other than nonprofit developers' general reluctance to adopt a new technology, barriers include lack of clear information in the market about compatible cookware that is affordable, along with unknowns about how to manage cookware provided by property management to residents. There are also several remaining maintenance and replacement concerns, such as the lack of reliable induction range products that have a reliably long life, are at a reasonable price point, and meet ADA requirements. The fact that virtually all products are glass-top, which scratch easily, is problematic for most housing providers. We found no commercialized products designed in a way that allows individual burners to be easily replaced. We evaluated several ranges as well as cooktop/electric oven combinations, which mitigate some of the maintenance concerns.

See below under "alternative options" for more comments about induction cooktops with on-board batteries.

Figure D-9: Resident self-reported typical stovetop use (27 resident interviews)





Advanced 100 lumen per watt solid-state lighting

Typical residential lighting fixtures generally have an efficacy of around 80 lumens per watt. Our design incorporates a kitchen fixture that exceeds this efficacy to over 100 lumens/watt and is at a competitive price point to be suitable for affordable housing.

Smart lighting controls network

Smart lighting controls allow for more automatic control of lighting. When networked and provided with an automatic demand response capable controller, a smart lighting control system also allows for grid interactivity. During times of high demand on the grid, daily 4:00 p.m. to 9:00 p.m., and during outage conditions lighting can be automatically dimmed to reduce load. This also allows for participation in demand response aggregation programs which provide financial incentives for reducing load during demand response events.

Alternative Options Considered

DC lighting/networking

A DC lighting system can have an advantage over traditional AC lighting in reducing AC to DC conversions as well as reducing installation costs of running AC wiring. The main hurdle for the residential units is that each apartment would require a dedicated DC panel and would not be cost effective as there is minimal lighting loads for each apartment. It would also be difficult to locate in the 1-bedroom apartments with limited wall space as there would also be an AC panel for the AC loads. For common areas a dedicated DC panel is feasible, but the main hurdle is the fact that DC lighting fixtures have a cost premium vs traditional affordable housing fixture. Another issue is that due to our VNEM setup on our project there is no way to directly tie the PV/Battery DC output to the DC panel to eliminate the AC/DC conversion so the energy savings from that would not be eliminated.

DC induction cooktop with integrated battery

Traditional electric resistance or induction stoves require a 208/240v 40amp circuit, which can often trigger upsizing upstream electrical infrastructure. Battery integrated stoves use a 120v outlet that can be connected to other appliances to "trickle charge" the stove when not being used. When in use, the stove will use available power on the 120v circuit (which is typically sufficient to perform light cooking activities on a single burner) and will supplement that power using the on-board battery when needed. Battery integrated stoves (and other appliances) also provide additional benefits to the user by allowing them to program a time of use schedule to either avoid peak pricing periods or to run when solar PV is being generated. During a power outage the stove can store sufficient power to cook multiple meals, and in the case of Copper's stove, includes a 120v outlet that can be used to charge cell phones or provide power to a refrigerator. There are two companies (as of Q2 '23) that are working to bring these products to market. Copper is currently selling a 30" battery integrated induction range and Impulse Labs is working on bringing a battery integrated induction cooktop to market in the near future. These products are not specified at this time, because our current central battery design provides redundant energy storage capacity to these loads. However, these products will be reconsidered at a future date pending design changes in Task 2 of the Build Phase.

Heat pump commercial dryers

Nonprofit developers lease commercial coin-operated laundry equipment from third party vendors like Speed Queen and WASH. These vendors do not yet offer products with heat pump technology, in part because there is not yet a big market for them. So, we did not pursue this option, although it would be a beneficial market opportunity.

Renewables, Energy Storage & Load Management Technologies

Our approach to this design was to integrate on-site solar PV generation and battery energy storage with load management products that would provide high efficiency, monitoring and controllability. These features enable the following strategies for our design to avoid importing energy from the utility grid from 4:00 p.m. to 9:00 p.m., provide resiliency for Tier 1 (indefinitely) and Tier 2 loads in the event of a utility power outage, and meet other criteria set forth by the solicitation.

- **Peak Shaving:** This refers to the strategy of reducing the amount of energy consumed during periods of peak demand on the grid. Peak shaving strategies aim to reduce demand charges, which are calculated based on the highest 15-minute average energy use recorded during a month. Methods to achieve peak shaving include using stored energy from a battery storage system or temporarily reducing or shutting down certain processes or operations.

- **Load Shifting:** This is a strategy used to decrease energy consumption during high-demand (and often high-cost) times, and move it to lower-demand periods, often in the night when the energy prices are typically lower. This helps balance the grid load and can also be used to take advantage of time-of-use energy rates. Load shifting is achieved through the use of energy storage systems (such as batteries) or by altering energy usage patterns.
- **Resilience:** In the context of power and energy, resiliency refers to the ability of an energy system to recover quickly from power disruptions or interruptions and to maintain continuous operation despite these challenges. For example, a microgrid with on-site power generation like solar PV and energy storage could still supply power to a building during a grid outage, demonstrating high resiliency.

All of these concepts are becoming increasingly important as we shift towards a more decentralized energy system and as the impacts of climate change place increasing stress on the traditional energy infrastructure.

The following sections detail the renewable generation, energy storage & power electronics technologies explored to meet the criteria of the Epic Grant.

Renewable Generation

Proposed Design

Rooftop PV and Elevated PV Canopy

After careful evaluation of various solar PV orientations and racking systems, the team elected to move forward with two PV scenarios based on the annual energy production and annual energy/system size (kWh/kWp) ratio: 1) rooftop east-west racking at a 37.3 degree tilt, and 2) elevated PV canopy with flat panels oriented with the long axis in the SW-NE direction. We assessed a number of solar PV orientations including fixed tilt, east-west racking, north-south racking, elevated rooftop PV canopy, and facade integrated PV systems on the southwest and southeast facade. During the evaluation process, we took into account row spacing, tilt angle, shading from the parapet, and panel orientation which are all important factors in optimizing the PV design. Considering the cost and annual energy production, these two PV systems paired with electrochemical storage and other distributed energy resources were incorporated into the proposed design.

Alternative Options Considered

Façade-integrated PV

The team evaluated options for integrating solar with a rainscreen cladding system and pursued a flexible thin film PV product by Merlin Solar that could be adhered to the metal or fiber cement rainscreen panel. Utilizing this product on the optimally oriented and uninterrupted SW-facing property line wall considerably increased production (to 220 kWh) without adding structure. However, we ultimately made the decision to exclude the SW facade-mounted option due to the possibility of the adjacent lot being developed, which would result in complete shading of these panels in the future, even though no development was imminent; this is in part because we learned that the panels were not easy to remove and re-purpose. Likewise, the SE facade presented challenges as it had limited areas suitable for PV panel installation, and it was heavily shaded by street trees and balconies.

Bifacial PV

We conducted a comprehensive parametric analysis comparing the energy production of bifacial and monofacial PV modules, varying tilt angle, ground coverage ratio (GCR) and orientations. The results show that the maximum AC energy gain from bifacial modules is just 2% higher than the optimal monofacial design with a 0-degree tilt angle and GCR of 0.98. Due to this minimal gain and increased cost, bifacial modules were not chosen.

We found that lowering GCR from the initial value of 0.98 to 0.8, 0.7, and 0.6 resulted in a progressive increase in bifacial AC energy gain, ranging from 2% to a maximum of 17%. However, this gain was accompanied by a notable reduction in both the total PV power output and the AC energy production as shown in the table below. As the GCR increases, the deployment of more PV modules leads to a corresponding rise in AC energy output, but at the cost of diminished bifacial gain. On the other hand, shading loss increases by increasing the tilt angle, subsequently leading to a decrease in overall monofacial AC energy output and bifacial gain. In conclusion, the marginal gains from bifacial modules and associated additional costs make monofacial modules more practical (Table D-1).

Table D-1: Bifacial AC Energy Gain for Different Mono-Facial Design Alternatives

Tilt	Ground coverage ratio	Monofacial		Bifacial	
		DC power_kWp	Annual AC energy_MWh	POA rear-side bifacial gain (%)	Annual AC energy_MWh
37	0.80	144	147	17.14%	172
20	0.70	132	195	18.42%	223
0	0.70	132	217	21.30%	250
0	0.98	172	280	1.47%	286

Icarus solar thermal

The Icarus system is a hybrid solar thermal and PV panel. The hydronic component of the panel improves PV efficiency and provides solar thermal hot water. While this product is a novel and clever combination of technologies, we did not pursue the product in order to minimize overall system complexity. As discussed in the HVAC sections above, hydronic systems add a level of complexity that does not align well with the maintenance abilities of the staff for this type of project. Additionally, it can be challenging to integrate solar thermal hot water with a heat pump domestic hot water system in a way that fully utilizes the solar thermal hot water without impacting the efficiency of the heat pump hot water system.

Energy Storage, Microgrid Control and Grid Interactivity

Proposed Design

Battery Energy Storage System

The Battery Energy Storage System (BESS) holds a vital role in the operation of the building. Numerous factors have been taken into account when designing and implementing the BESS, including its chemistry, architecture, sizing, and specifications.

Lithium iron phosphate (LFP) batteries are emerging as the primary chemistry used for a building level BESS. LFP batteries provide high energy density, though slightly lower energy density than traditional lithium-ion batteries. LFP batteries are also more thermally stable and long-lasting than traditional lithium ion leading to a safer solution for energy storage.

Our building electrical service is 208V, which is a common voltage for mid-rise multifamily buildings, as it meets the voltage requirements of the majority of the loads, particularly the residential apartments. Ideally, we would want a 208V battery storage system to maintain compatibility. It is challenging to find battery manufacturers that offer a native 208V system in the size we need. Most available options are designed for 480V, which requires the use of a large transformer to step down the voltage from 480V to 208V. Unfortunately, this setup leads to power losses and the generation of additional heat. However, we also discovered that the voltage drop losses on the 208V system were actually greater than the 480V to 208V transformer losses. Therefore, we have elected to utilize a 480V PV and BESS system which will minimize losses and provide more flexibility in products, it also is a smaller physical size saving interior building space. We also have the ability to capture the transformer heat losses to support domestic hot water heating where voltage drop losses are not able to be captured.

Our BESS design is centered around a Fortress Power Espire 280 series. Each battery cabinet can provide up to 279kWH, our design will incorporate two battery cabinets for a total of 370kWH of energy storage. The Espire 280 is an AC coupled system with a 125kW output inverter.

Microgrid controller

Fortress Power’s Battery Energy Storage System includes an integral controller with the capability to implement the basic microgrid functions (load shifting, resiliency and peak shaving). However, it has been difficult to understand if all of the project’s microgrid requirements can be satisfied. As we feel it is critical to have a robust microgrid controller we have opted to work with a microgrid specialist such as Swell or Castle Gate to build a custom controller.

The microgrid controller will automatically make decisions about what to do with the available on-site energy. These decisions will include whether to use solar generated energy to charge the BESS or to offset building loads. The controller’s priority is to charge and discharge enough energy to offset the daily 4:00 p.m. to 9:00 p.m. period. If there is excess solar production prior to the 4:00 p.m. to 9:00 p.m. window it will push energy back to the grid through the VNEM meter and provide the building with energy credit offsets.

Interconnection & Electrical Distribution Infrastructure

The on-site generation utility interconnection will be a VNEM configuration. There will be a VNEM meter, separate from the building consumption meters, which will track the energy generated on-site. The utility will allocate the financial benefits from the VNEM metered generation to the individual tenants. This means there is no self-consumption of on-site renewable energy generation.

In order to allow for islanding with the VNEM configuration, a set of automatic transfer switches need to be installed such that when the power grid goes down, the VNEM meter will be bypassed, and the Tier 1 and Tier 2 loads will be served directly by the on-site generation sources. To serve the residential loads each apartment will require two dedicated UL1008 branch circuit transfer devices to transfer power from the apartment panel to the Tier 1 panel.

Required electrical infrastructure to support the microgrid system during normal operation:

- DC coupled distribution to collect PV power into a single feed for connection to the BESS.
- Renewable distribution board in the main electrical room to collect the BESS output feeds from the roof into a single feed to the VNEM main breaker.
- VNEM meter and main breaker (integrated into the main switchboard)

Required electrical infrastructure to support the microgrid system during an outage condition (island operation):

- Two UL1008 automatic transfer switches sized to carry the full load of the BESS to serve Tier 1 and 2 loads directly.
- Tier 1 and 2 panelboard and associated feeders throughout the building to serve critical loads.
- two UL1008 transfer devices (20A rated each) and associated wiring to transfer power from the apartment panel to the Tier 1 panel.

Smart Inverters

The smart inverters will be both grid interactive and grid forming. Grid interactive means that the inverter will not export to the utility grid during a power outage to ensure that the utility company can safely work on the grid equipment. Grid forming allows the inverter to function in islanded mode, disconnected from the utility grid.

OhmConnect

Dynamic residential energy management will be achieved by deploying OhmConnect in each residential unit as well as common and office areas. Through OhmConnect we will enable automatic setpoint adjustments by integrating with Nest smart thermostats; we will also pre-install OhmConnect plugs on all refrigerators and provide residents with an additional OhmConnect plug and orientation for opting in to notifications for bill savings opportunities. Provided the system is explained to them and does not rely on smart phones (since not more than 20% of residents are expected to afford one), participants of our focus group were positive about OhmConnect's ability to facilitate both automatic and voluntary load management, which would offer utility bill savings with little effort on their part and could adjust to each resident's level of interest and capacity to engage in such a program. One resident of Leigh Avenue, where we conducted our survey and focus groups, was already a participant in the program.

Architectural display and data collection platform

In addition to OhmConnect platform to communicate demand response events to residents, a separate messaging platform is essential for communicating the switchover from grid electricity to priority loads during a power outage. Our proposed design includes an architecturally integrated LED signal display that would indicate basic useful information to residents about the operating mode and state of the battery, giving them an opportunity to work dynamically to extend supported loads.

The microgrid controller will be monitoring real-time building energy use from building meters along with active solar generation and battery state of charge/discharge. A system of simple colored signal lights visible from corridors will inform residents and also indicate opportunities for maximizing the service of the microgrid system, particularly during an outage, according to the phases below.

- **Grid mode (blue):** the building is drawing power normally from the grid and the battery is either charging or charged
- **Battery/ conserve mode (green):** the battery is discharging to the grid (typically during the 4:00 p.m. to 9:00 p.m. peak)
- **Outage mode (orange):** The building is islanding during a power outage with Tier 1 and Tier 2 loads supported.
- **Severe outage (lights off):** The LED tape lights are a Tier 2 load. In a constrained outage condition "no light" conserves power while indicating that only Tier 1 loads are supported.
- **Bad air quality (purple):** AQI is 150 or above

Alternative Options Considered

On-site energy allocation equipment (Alume/PowerTree)

Allume and PowerTree allow for allocation of on-site energy sources directly to individual units in a multifamily building, however when an islanding scheme is required there are added complications. When each unit is submetered, each allocator connection also requires a transfer switch or electrically controlled circuit breaker to ensure that no energy will back-flow through the tenant's meter into the rest of the power distribution system. The additional cost quickly adds up negating the benefits of the allocation approach.

Ivy Energy on-site DER accounting software

Ivy Energy provides a solution for multi-tenant buildings with a master meter configuration and on-site renewable generation. Ivy provides the accounting software to allocate the financial benefits of the on-site generation to each of the tenants. Since this project will have utility submeters for each unit, the allocation of the financial benefits to the tenants will be done by the utility company.

SPAN Panel

SPAN Panels are residential load center panelboards that include relays that allow for automatic load control and shedding at the branch circuit level within each apartment. This would allow for shedding of non-Tier 1/2 loads during an islanding scenario. However, given the proposed Tier 1 and 2 configurations with each apartment having transfer devices, shedding of non tier loads at the panel is not required as they will not be energized during an outage. While the SPAN panel does offer controllability and load monitoring within the apartment it did not provide enough benefit to the project to justify the cost.

Building management controls

See discussion of building management controls under HVAC above.

Electric Transportation

The Roosevelt Village project has very little parking and EV charging opportunity. However, due to the practical matter of how soon (and reliably) residents or staff would park personal EVs in a common parking facility at any property serving a similar resident population, we determined the most promising opportunity for a parking facility of any size was probably to focus on integrating 1-2 maintenance vehicles owned and driven by on-site property management and maintenance staff.

Proposed Design

Ford F-150 Lightning

The Ford F-150 Lighting has a 98kWH and 131kWH battery option which could be utilized to support building loads through a vehicle-to-building (V2B) charging station. The idea would be to utilize this feature during an outage condition to support the building for an extended duration.

Remaining barriers

Vehicle to Grid/Building utility programs are still in the pilot phase. Participation in the pilot programs requires information that will not be available until later in the project such as electric vehicle registration.