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CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Colegio Zero Net Energy Village

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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.

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

Self-Help Enterprises and its supporting team have used criteria defined by the California Energy Commission to guide the design approach of Colegio Zero Net Energy Village. In meeting and exceeding these criteria, the team sought to identify and integrate emerging energy technologies that are appropriate for an energy-efficient, grid-interactive, low-carbon affordable housing prototype that can be replicated across communities in California's Central Valley and beyond. The proposed design represents a low-rise affordable multifamily housing prototype that is all-electric, achieves zero net energy between 4:00 p.m. and 9:00 p.m. daily throughout the year, and features a site-wide microgrid and numerous other grid-interactive peak shedding and shifting strategies. The project integrates passive design strategies, paired with highly efficient heat pumps for heating and cooling, energy recovery ventilators for unit ventilation, heat pump water heaters for domestic hot water, and numerous smart building technologies. Additionally, a 2.6-megawatt battery storage system, a 571-kilowatt photovoltaic solar array provides on-site energy generation and storage.

Relative to the previous Self-Help Enterprises template design prototype, the project reduces annual operational energy and carbon by 35 percent and 37 percent, respectively, and it reduces the summer and winter peak energy consumption by 15 to 20 percent and 20 to 50 percent, respectively. Additionally, the project reduces the embodied carbon associated with the structure, envelope, interior finishes, and sitework by 25 percent relative to the template design baseline. The project can island in a grid outage event, providing immediate and indefinite, critical shared services that comprise 10 percent of peak load and immediate, critical in-unit services that comprise 25 percent of peak load for up to 72 hours. Through thorough and systematic evaluation and integration of emerging energy technologies, the Colegio Zero Net Energy Village provides a flexible and scalable prototype for future low-rise multifamily affordable housing developments across the state and beyond.

Keywords: Zero net energy, grid-interactivity, low-carbon, resilience, replicability, affordable housing, energy efficient, multifamily

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Background

Climate change is already having devastating effects in California's Central Valley, and those effects are projected to grow increasingly frequent and severe in the coming decades. Building development, and specifically housing development, plays a key role in the state's mitigation and adaptation responses to climate change. Concurrently, California faces an unprecedented housing crisis, which must be urgently addressed. The state needs solutions that tackle each of these emergencies together, rather than in isolation. Fundamentally, the state needs scalable, low-carbon, climate-resilient affordable housing solutions, and it needs them now.

The housing industry has solutions available today to mitigate carbon emissions and provide resilient shelter against the worst effects of climate change. However, the industry will only be able to transition to a low-carbon status quo if everyone in the industry has access to those strategies and technologies and integrates them at scale. This project seeks to do that.

Project Purpose and Approach

The purpose of this project was to design a zero-emission mixed use development that incorporates multiple advanced energy technologies and strategies, combined with financial feasibility analysis. The design serves as a replicable model for industry stakeholders such as architects, engineers, and building developers to inform future developments. Self-Help Enterprises and its supporting team have used criteria defined by the California Energy Commission to guide the design approach. In meeting and exceeding these criteria, the team has sought to identify and integrate emerging energy technologies that are appropriate for an energy-efficient, grid-interactive, low-carbon affordable housing prototype that can be replicated across communities in the Central Valley and beyond. Table ES-1 shows the design approaches that contribute to the achievement of these requirements.

Table ES-1: Project Approach to Minimum Design Requirements

Requirement	Project Approach / Status
All building end uses must be electrified.	The project design does not include any gas equipment, appliances, or infrastructure. In lieu of gas water heating, the project features heat pump water heaters. Ductless heat pumps replace gas-powered heating and cooling equipment. Electric stoves are included instead of gas ranges.
At least 20 percent of the peak load may be curtailed in response to grid conditions.	The Flair Puck smart thermostat will respond directly to grid conditions (with the option for users to opt out) by loosening heating and cooling setpoints. Laundry, electric vehicle charging, and other non-essential end uses will be shut off during these periods to reduce the peak load by 20 percent.

Requirement	Project Approach / Status
Residential load must be met onsite from 4:00 p.m. to 9:00 p.m.	Various integrated energy conservation measures, such as envelope improvements; external shading; and the heating, ventilation, and air conditioning system, allow for a lower peak load between 4:00 p.m. and 9:00 p.m. as compared to both a Title 24-2022 code-minimum design and to a prototypical design that Self-Help Enterprises has deployed repeatedly across the San Joaquin Valley. After these demand reductions, the project solar and battery system are sized to provide energy for all systems from 4:00 p.m. to 9:00 p.m. under normal operations.
Residential end uses must be controllable through energy management system and responsive to real-time pricing signals.	All end loads that are capable of automatic control shall receive signals from the microgrid for various operating modes depending on the utility grid status. All tenant end loads are ultimately controlled via smart circuit breakers to allow load shedding for islanding purposes. Real-time pricing signals will be relayed to participating tenants where manual tenant end-load reductions are expected from behavioral changes by the tenant.
Microgrid controller(s) must be interoperable with distributed energy resources aggregation platforms.	This requirement can be met either through standard net energy metering and demand response participation directly between customers and the electric utility or via a third party that owns and operates the solar and battery resources and distributes credits to the building occupants. In either case, the microgrid as proposed can be configured to provide the aggregation function chosen to be deployed at the site. Tenants will not need to be integrated into the distributed energy resources aggregation platform as they will not have electric utility bills.
Ability to island from the main grid during an outage and 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).	A site-wide microgrid will be included. The microgrid includes a 2.6-megawatt battery storage system and a 571-kilowatt photovoltaic array. This system allows the site to island from the main grid as needed. In the islanded state, the microgrid provides power to Tier 1 loads indefinitely. This includes fire alarms, allowance for emergency medical equipment equivalent to a medical ventilator, and exterior lighting at the residences. Additionally, Tier 1 includes Wi-Fi, a microwave, a refrigerator, USB4P chargers, and space conditioning at the community center. The system provides power to Tier 2 loads for as long as 96 hours continuously and an average of 75 hours continuously. In addition to the loads listed in Tier 1, Tier 2 adds an additional microwave at the community center, residential USB outlet charging,

Requirement	Project Approach / Status
	residential Wi-Fi, residential refrigerators, and 15 percent of residential interior lighting.
Microgrid must be sized for indefinite renewables-driven backup power of Tier 1 critical loads.	Arup performed a system simulation showing that the project's solar photovoltaic and battery energy storage system sizing can support 10 percent of the peak electrical demand for 24 hours a day and 365 days a year. Gridscape performed a second simulation that verified this result.
A minimum 20 percent of all parking spaces must have grid- and/or building-responsive electric vehicle charging stations.	Forty percent of the parking in the design includes electric vehicle charging stations installed on day one. Each of the installed charging stations will be able to respond to grid signals, as each station will be controlled by an automatic load management system. The automatic load management system reduces the electrical load associated with electric vehicle charging by intelligently sharing power across stations. The system dynamically varies the load in response to grid or building electrical demand. When either the buildings or grid demand is high, the automatic load management system can reduce the charging rate for some stations or turn off charging to select stations to reduce the total charging load.
All remaining parking spaces must be electric vehicle-ready, with a dedicated electrical circuit that can eventually become a charging station.	All remaining parking spaces (60 percent of total) are electric vehicle-ready. Each space is wired for the future installation of Level 2 electric vehicle chargers.

Source: Self-Help Enterprises

In addition to these minimum design requirements, the project has also committed to the following project-specific targets:

- Reduce hourly energy cost and emissions by 10 to 50 percent versus the Self-Help Enterprises template design baseline.
- Ensure functional recovery of critical electrical services after an outage (10 to 25 percent of peak load.)
- Reduce embodied carbon of structure, envelope, interiors, and site concrete by 10 to 20 percent versus template design baseline.
- Reduce unit electricity costs to $28 for three-bedroom units, $15 for two-bedroom units, and $9 for one-bedroom units (calculated from the California Utility Allowance Calculator, version 2022).

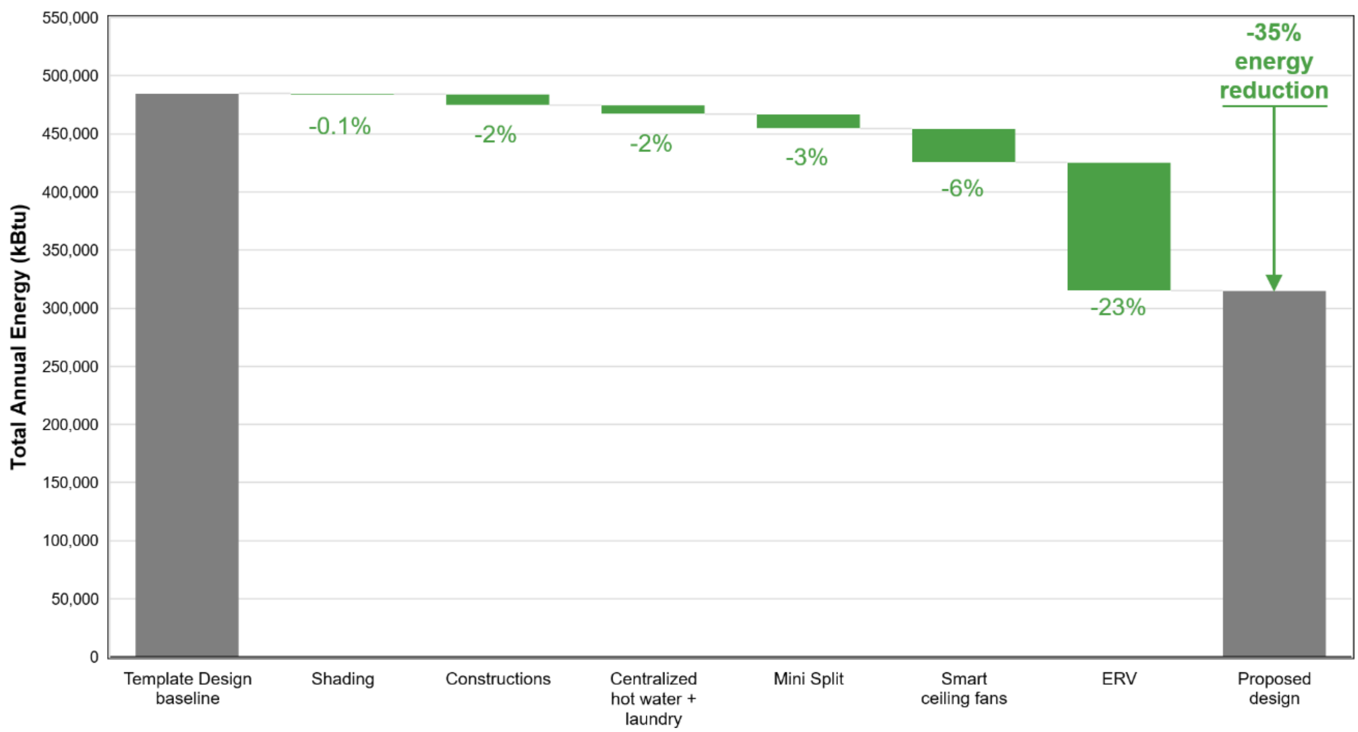
- Provide housing that is at least 25 percent one-bedroom units and 25 percent three-bedroom units.

Key Results

The project completed a design for a zero-emission mixed use development that met or exceeded all minimum design requirements and project-specific goals set in advance of the design process. Key achievements are listed below:

- The project team achieved a 35 percent reduction in annual energy consumption and cut winter peak energy consumption by 30 to 50 percent and summer peak consumption by 15 to 20 percent. Figure ES-1 shows key contributing strategies to these achievements.

Figure ES-1: Key Energy Conservation Measures



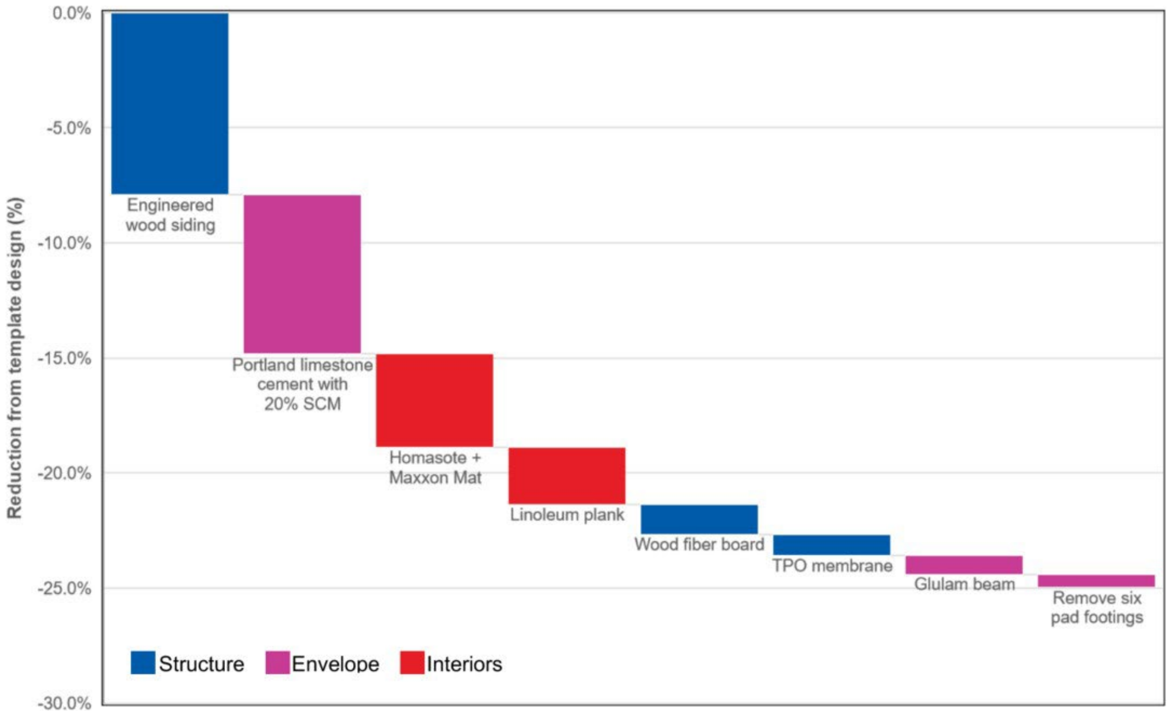
ERV: Energy recovery ventilator

Source: Self-Help Enterprises

- Through a site-wide microgrid, the Colegio Zero Net Energy Village can immediately recover limited functionality in a grid outage. Ten percent of peak load, or Tier 1 load, is immediately and indefinitely restored. Services include site-wide safety features, like exterior lighting and fire alarms, and concentrated services in the community space, including power for medical devices, Wi-Fi, a microwave, USB charging, and space conditioning. Twenty-five percent of peak load, or Tier 2 load, is available for 72 hours. This includes the Tier 1 load plus limited services within each unit, including refrigerators to maintain access to food, Wi-Fi, and 15 percent of unit-level lighting.

- The Colegio Zero Net Energy Village achieves a 25 percent reduction in embedded carbon versus the Self-Help Enterprises template design baseline. The most beneficial embodied carbon-reducing strategies are shown in Figure ES-2.

Figure ES-2: Most beneficial embodied carbon reduction measures



SCM: Supplementary cementitious materials; TPO: Thermoplastic polyolefin

Source: Self-Help Enterprises

Knowledge Transfer and Next Steps

The team for the Colegio Zero Net Energy Village was assembled intentionally. Self-Help Enterprises has convened the same architect, contractor, and sub-consultants and sub-contractors who have collectively built thousands of units across the San Joaquin Valley of California. This approach uses the team's shared history, expertise, and leverage to reimagine the template design in a way that achieves ambitious energy and carbon targets in a replicable way for Self-Help Enterprises and in a way that encourages broad adoption throughout the San Joaquin Valley and beyond. This approach helps to ensure that the project is prototype instead of a one-off.

Beyond the deliberate team structure, the design approach aims for flexible replicability at scale. While localized climate conditions informed the specific design criteria of various energy-efficiency strategies (such as envelope design, shading, mechanical and electrical systems, and so on), the underlying approach to reduce demand, shift load, and integrate distributed energy resources will be a core theme in future decarbonized mixed-use projects. The core strategies that support the demand reduction, load shifting, and distributed energy resources integration approach are either layered (that is, a modular collection of innovative technologies that can be tailored to a given project) or they can be scaled back as needed for a given future project budget. For example, the core heating and cooling systems at the Colegio Zero Net Energy Village are widely available and easily integrated into future designs. The modular layers of emerging technologies build in sophistication and innovation on top of these conventional systems at a relatively low cost. This strategic flexibility allows the project to serve as the proof-of-concept for several emerging approaches and technologies.

CHAPTER 1: Introduction

Self-Help Enterprises (SHE) has partnered with Mogavero Architects (Mogavero), Arup, the Association for Energy Affordability (AEA), and Ashwood Construction (Ashwood) to develop the design for the Colegio Zero Net Energy Village, an innovative, buildable, and scalable solution for resilient, low-carbon affordable housing in California's Central Valley.

The team has combined SHE's expertise in California affordable housing finance and development, Arup and AEA's global/national best practice innovations in emerging technology, and Mogavero and Ashwood's local knowledge and design-build experience to develop the proposed design. As proposed, the development includes 94 affordable rental units, a community center, and commercial office space, as well as outdoor site amenities for residents. The team has developed a replicable, all-electric, zero net energy (ZNE) design, which improves the efficiency and resilience of building operations while minimizing operating costs for the residents. Ultimately, the goal is to create a flexible and scalable prototype for future affordable, low-carbon development.

Six energy and climate goals drive the design: (1) achieve all-electric and ZNE operations; (2) implement grid-interactive technologies; (3) demonstrate drought innovation; (4) design for replicability; (5) ensure climate resilience; and (6) enable growth of the local high-quality, affordable housing capacity. The multi-disciplinary project team has used emerging energy technologies, computationally driven analysis methods, and advanced construction practices to design and build a mixed-use development that is affordable, equitable, emissions-free, and resilient to extreme weather events and climate change impacts while addressing the local community's needs regarding homelessness and housing affordability.

The six energy and climate goals above are specified within the California Energy Commission (CEC) minimum design requirements and project-specific goals. These requirements and goals are listed below:

- Minimum Design Requirements:
  - All building end uses are all-electric.
  - More than 20 percent of the site's peak load can be temporarily managed in response to grid conditions.
  - The site achieves ZNE between the hours of 4:00 p.m. and 9:00 p.m.
  - All residential end uses must be controlled through a home energy management system that responds to real-time pricing signals.
  - Microgrid controllers must be interoperable with distributed energy resource aggregators (for example, virtual power plants).
  - Buildings must be able to island from main grid during an outage and provide immediate, indefinite power to Tier 1 loads (10 percent of peak load; See Table

ES-1) and immediate power to Tier 2 loads (25 percent of peak load; See Table ES-1) for 72 hours.

  - Twenty percent of parking spaces must have building- or grid-interactive electric vehicle (EV) charging systems.
  - Remaining parking must be EV-ready.

- Project-Specific Targets:
  - Reduce hourly energy cost and emissions by 10 to 50 percent versus the template design baseline.
  - Ensure functional recovery of critical electrical services after an outage (10 to 25 percent of peak load.)
  - Reduce embodied carbon of structure, envelope, interiors, and site concrete by 10 to 20 percent versus the template design baseline.
  - Reduce unit electricity costs to $28 for three-bedroom units, $15 for two-bedroom units, and $9 for one-bedroom units (calculated from the California Utility Allowance Calculator, version 2022).[1]
  - Provide housing that is at least 25 percent one-bedroom units and 25 percent three-bedroom units.

Typically, projects can achieve only a fraction of these goals. For example, it is common for market-rate or luxury housing projects to achieve ambitious sustainability goals, and affordable housing projects (by definition) grow affordable housing capacity; however, it is very rare for affordable housing projects to set and achieve a progressive sustainability target, as the technologies required to do so are typically either cost-prohibitive and high-risk or perceived to be. Through thorough and systematic evaluation of existing and emerging technologies and their suitability for affordable housing with respect to capital and operational costs, ease-of-installation, ease-of-use, and ease-of-maintenance, the Colegio ZNE Village achieves all six of the established energy and climate goals listed earlier.

The Colegio ZNE Village is neither theoretical nor a one-off: The project will turn innovative, zero-carbon housing design into a reality. It will only be successful, however, if it is designed and built in a way that allows for flexible replicability on future projects. Design replicability depends on the careful evaluation and validation of the performance and costs of the selected emerging technologies. Once validated, the project can be translated to other design teams, developers, and policy makers to scale the outcomes beyond Self-Help Enterprises' portfolio.

Through its pragmatic innovation, the Colegio ZNE Village offers the State of California an opportunity to truly move the needle toward standardizing decarbonization in affordable rental housing.

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[1] California Energy Commission staff. n.d. "California Utility Allowance Calculator (CUAC)." Available at https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/california-utility-allowance.

CHAPTER 2: Project Approach

Overall Design Approach and Strategies

Baseline Design

The SHE template design baseline is described in detail in Appendix A. Briefly, the baseline design is a three-story, garden-style apartment with a gable roof. The systems and equipment are all-electric (which exceeds energy code), with heating and cooling provided by unitary air-to-air heat pumps, ventilation provided by bathroom exhaust fans, and domestic hot water provided by per-unit, 50-gallon heat pump water heaters. Clothes washing and drying is provided in each unit as well as in a centralized location. Electric resistance ranges are provided to each unit. All unit appliances meet ENERGY STAR criteria, where applicable.

Envelope constructions roughly align with Title 24-2022 Building Energy Efficiency Standard requirements.

Proposed Design Approach

At 95 percent construction documents, the project currently achieves the zero energy/ emissions goals by integrating into the design a host of innovative energy and emission conservation measures (ECMs) and electrification strategies. These strategies were selected with several priorities in mind: (1) end-use energy efficiency; (2) peak load shifting and shedding to support the achievement of the California Energy Commission's (CEC's) Minimum Design Requirements and broader operational carbon and resilience goals; and (3) replicability and scalability to allow broad translation to future affordable housing projects.

The included ECMs have been selected through an iterative, computationally driven genetic optimization process, which enabled the project team to identify the combinations of strategies with the best cost and carbon performance. This process is described in detail in Appendix A.

The team took a layered approach to ensuring that the project integrates emerging energy technologies in a replicable and scalable way. At its core, the approach relies on highly replicable, cost- and carbon-optimal core systems. For example, the design optimizes the massing for passive heating and cooling and solar generation and relies on familiar but highly efficient heating, cooling, and hot water systems. The design then layers on less familiar, carbon-optimal technologies that are still quite replicable and are highly flexible. These include energy recovery ventilators (ERVs), smart thermostats, ceiling fans, equipment with low-carbon refrigerant, and the addition of the microgrid. Last, the design layers on highly innovative, carbon-optimal systems. These include the selection of an ERV with economizer capabilities, demand-responsive thermostats, and smart ceiling fans. The resulting prototype is defined by this flexible and layered approach. The Colegio ZNE Village deploys one combination of systems, whereas other deployments of this prototype can adopt other combinations to meet project needs. This allows for scalability to future projects within the San Joaquin Valley, the state, and beyond.

Build Phase Milestones

There are several build phase milestones, the first of which is procuring the emerging energy technology identified in the design phase. A large component of this technology is the microgrid system. The milestones associated with the microgrid include system design and engineering, integration, and testing, constructing the microgrid, commissioning, and finally operating the microgrid to test and verify performance. The construction team will be installing all other emerging technologies after procurement, and the design team will be assisting with reviewing submittals and responding to Requests for Information. As systems are installed, the next milestone will be to commission systems in each building and carry out the measurement and verification plan.

As construction progresses, the project team will be developing educational materials as well as a Handoff Manual for Asset Management with new technology operating instructions and maintenance recommendations. In addition, there will be a Resident How-to Guide and in-unit signage to help residents become familiar with operating the systems. One of the last major milestones will be to evaluate the project as a whole and complete the final knowledge transfer activities.

Architectural Designs, Aesthetics, and Functionality

Novel Features and Form Factors Impacting Aesthetics and Functionality

Unlike the template design baseline, the Colegio ZNE Village features a single-slope roof. The differences between the template design baseline and the proposed project are shown in Figure 1 and Figure 2. The single-slope roof provides deep overhangs on the south side and allows daylighting clerestories (that is, a windowed outside wall that rises above an adjoining roof) appropriately only on the north side.

Figure 1: Template design has gable roof and clerestories facing in two directions.

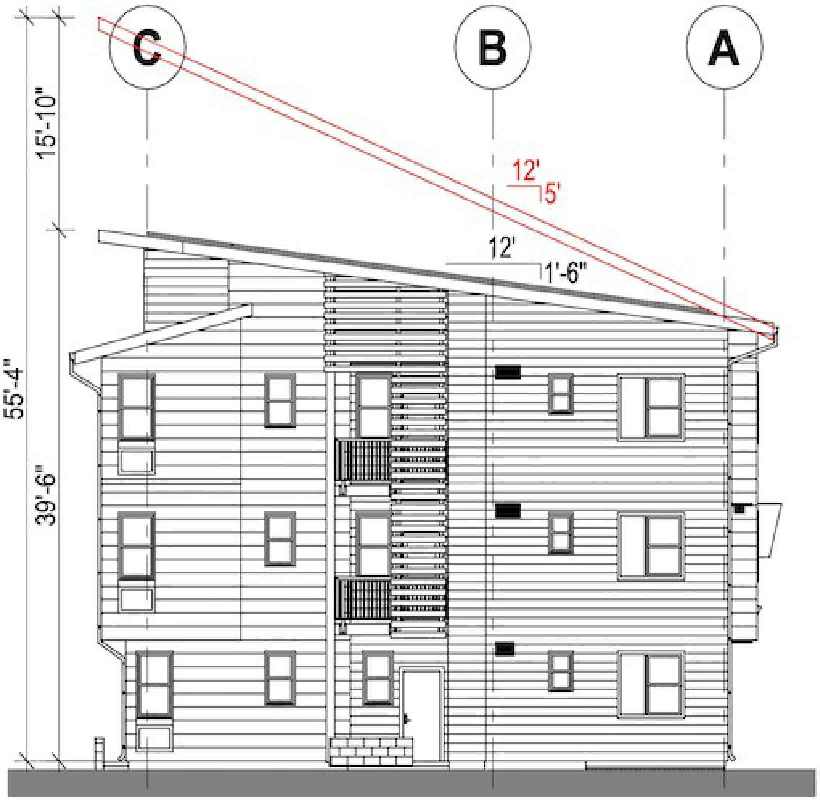
Source: Self-Help Enterprises

Figure 2: Proposed design has single-slope roof, which doubles solar area while serving the same number of units and square footage

Source: Self-Help Enterprises

The single-slope roof greatly increases the area available for solar energy generation. The roof slope strikes a balance between optimal solar performance and economic cost. The project team chose a lower-than-optimal slope for solar to maintain a reasonably sized attic and to avoid increased economic and carbon costs. This decision came with a three to four percent efficiency loss but overall allowed the solar area to exceed that of the template design by 35 percent. The studied roof pitches are shown in Figure 3.

Figure 3: Balancing solar optimization with economic/material cost for roof pitch



Source: Self-Help Enterprises

Passive Design

The south-facing, single-slope roof enables north-facing clerestory windows, which provide daylight in the third-story units. This reduces the need for electrical lighting and enhances the tenant experience. All window head heights are raised to the highest point that is structurally feasible, which brings daylight farther into the spaces. A 3.5-foot roof overhang shades all third-floor, south-facing windows. Overhangs are provided on all first- and second-floor windows on the south side, whereas both overhangs and vertical fins shade west-facing windows.

The exterior walls include a layer of continuous insulation, which reduces thermal bridging (that is, the movement of heat across materials that have a higher thermal conductivity than the materials around them) and infiltration. The team specifically chose bio-based wood fiber insulation for its greater breathability and lower embodied carbon impacts.

Design Strategies for Integrating Conventional and Emerging Energy Technologies

End-Use Energy Efficiency

As proposed, the Colegio ZNE Village design includes the following emerging energy technologies in or serving the residential units:

- **Energy recovery ventilators with free cooling mode:** Each unit includes an ERV to continuously supply fresh, filtered air to the space. The ERV also exchanges heat between exhaust and supply air streams, which reduces the energy required to condition ventilation air. Additionally, the selected system includes an economizer mode. When outdoor conditions allow, the system will bring the maximum amount of filtered outdoor air to the unit, thereby reducing the mechanical system loads. Finally, the ERV allows for a tighter building envelope, which minimizes the outdoor air entering the space via leakage or infiltration.
- **Smart ceiling fans:** Each unit includes smart ceiling fans in the living room and bedroom spaces. These fans improve occupant thermal comfort, air distribution, and perceived air quality. Additionally, the fans include temperature and motion sensors that vary the fan speed for optimal cooling and turn off the fan when occupants are not present.
- **Flair Puck Smart Thermostats:** The Flair Puck is a smart thermostat that is compatible with the selected mini-split heat pumps. Using these programmable thermostats, occupants can "set and forget" scheduled set points that align with their expected daily schedules. Tenants who have smartphones and are interested in deeper engagement can use an app to adjust home/away modes and setpoints remotely. A platform is also available for SHE to monitor all heating, ventilation, and air conditioning (HVAC)-related energy use, thermostats, and setpoints.
- **Centralized heat pump water heaters (HPWHs) with thermal storage and carbon dioxide refrigerant:** The project includes per-building centralized HPWHs to enable load shifting through thermal storage. The HPWHs also use a low-carbon, carbon dioxide refrigerant.
- **Variable Refrigerant Flow HVAC system with heat recovery:** A variable refrigerant flow system was chosen for the community space instead of ductless mini-split heat pumps. Since the community center has spaces with different expected occupancies and end uses, it is likely that simultaneous heating and cooling will occur. When it does, a variable refrigerant flow system allows for heat recovery between different zones.

Demand Response, Grid Interaction, and Resident Engagement

Many of the previously described emerging energy technologies will be used to enable dynamic energy management for demand response. These demand-side reduction strategies, coupled with a site-wide microgrid with distributed energy resources (DERs), allow for site-wide dynamic energy management and enable grid interactivity and load shifting, shaping, and shedding flexibility. Dynamic energy management strategies are listed below:

- **Thermal storage tanks** are provided with the HPWHs to allow hot water to be sourced from the storage point to reduce electrical loads during peak times.
- **Flair Puck smart thermostats** include automatic demand response capabilities and have received Occupant-Controlled Smart Thermostat certification from the CEC. Upon receiving a demand response signal from the grid, the thermostat will automatically adjust the current setpoint by a predetermined amount. Customization is available to establish demand response to custom signals from the project microgrid, in addition to the signals from the grid.
- **Electric vehicle (EV) charging with automatic load management system** automatically and dynamically varies the EV charging load in response to grid or building electrical demand. When either the buildings or grid demand is high, the automatic load management system (ALMS) can reduce the charging rate for some stations or turn off charging to some stations to reduce the total charging load.
- **The site-wide microgrid** enables dynamic management and controls of energy generation systems and islanding capabilities to decouple from the electricity grid. These systems add resilience during power outages as well as carbon-free energy during times of carbon-intensive grid energy production.
- **Pricing incentives:** Residents will be enabled to actively participate in load management using a time-of-use pricing structure for clothes washing and drying and through response to and participation in occupant energy monitoring and reduction programs. For example, SHE plans to provide feedback and guidance to occupants whose energy use exceeds the site average. SHE will additionally develop signage, in-person learning sessions, recurring feedback on usage, or even financial incentives to encourage occupants to minimize resident consumption where possible.

Microgrid Design Strategy

The project team considered both site-wide and building-by-building microgrid configurations. Due to the technical and economic efficiencies and savings, the team pursued a site-wide microgrid using a master meter approach. The site-wide microgrid includes a 2.6-megawatt (MW) battery storage system and a 571-kilowatt (kW) photovoltaic (PV) array, which were sized to achieve the CEC's minimum design requirements of ZNE between 4:00 p.m. and 9:00 p.m. and islanding functionality targets.

The microgrid enables dynamic management and controls of energy generation systems and islanding capabilities to decouple from the electricity grid. These systems add resilience during power outages as well as carbon-free energy during times of carbon-intensive grid energy production. Load systems that contain their own dedicated main controller, such as lighting and domestic water heating, are expected to take operating mode commands from the microgrid and deploy pre-programmed operating parameters depending on the signal received. Electrically operated motorized circuit breakers, found at both the site and tenant levels, round up the load-shedding capabilities necessary for islanding functions.

This configuration enables interoperability with DER aggregation platforms, which can be achieved either through standard net energy metering (NEM) and demand response participation directly between customers and the electric utility or via a third party that owns and operates the solar and battery resources and distributes credits to the building occupants. Tenants will not need to be integrated into the DER aggregation platform, as electricity costs will be included as part of rent.

EV Charging Strategy

Forty percent of the parking in the design includes EV charging stations installed on day one. All remaining parking spaces (60 percent of total) are EV-ready. Each space is wired for the future installation of Level 2 EV chargers. Each of the installed charging stations will be able to respond to grid signals, as each station will be controlled by an ALMS.

The ALMS reduces the electrical load associated with EV charging by intelligently sharing power across stations. The system dynamically varies the load in response to grid or building electrical demand. When either the buildings or grid demand is high, the ALMS can reduce the charging rate for some stations or turn off charging to select stations to reduce the total charging load.

Advanced Construction Planning and Practices

The team included a variety of perspectives in the design process, including input the construction and cost estimation teams. Ashwood Construction, a trusted general contractor that is embedded in the multifamily building culture in the San Joaquin Valley (SJV), was a critical partner in the design process who helped ensure that the final product is something that can be built and operated. There was also extensive coordination between architectural and structural plans to align walls where possible for better gravity and shear load transfer to limit additional footing, rebar, hold down, and beam specifications where possible.

The project used building information modeling, computational design methods, and energy and embodied carbon modeling from the beginning to replicate, test, and optimize the design for predetermined project performance metrics. By working with building information modeling and energy and cost models from the beginning of design, the team optimized energy use and carbon emissions in relation to building geometry, daylighting, shading, materials, and mechanical systems.

Construction time and cost savings

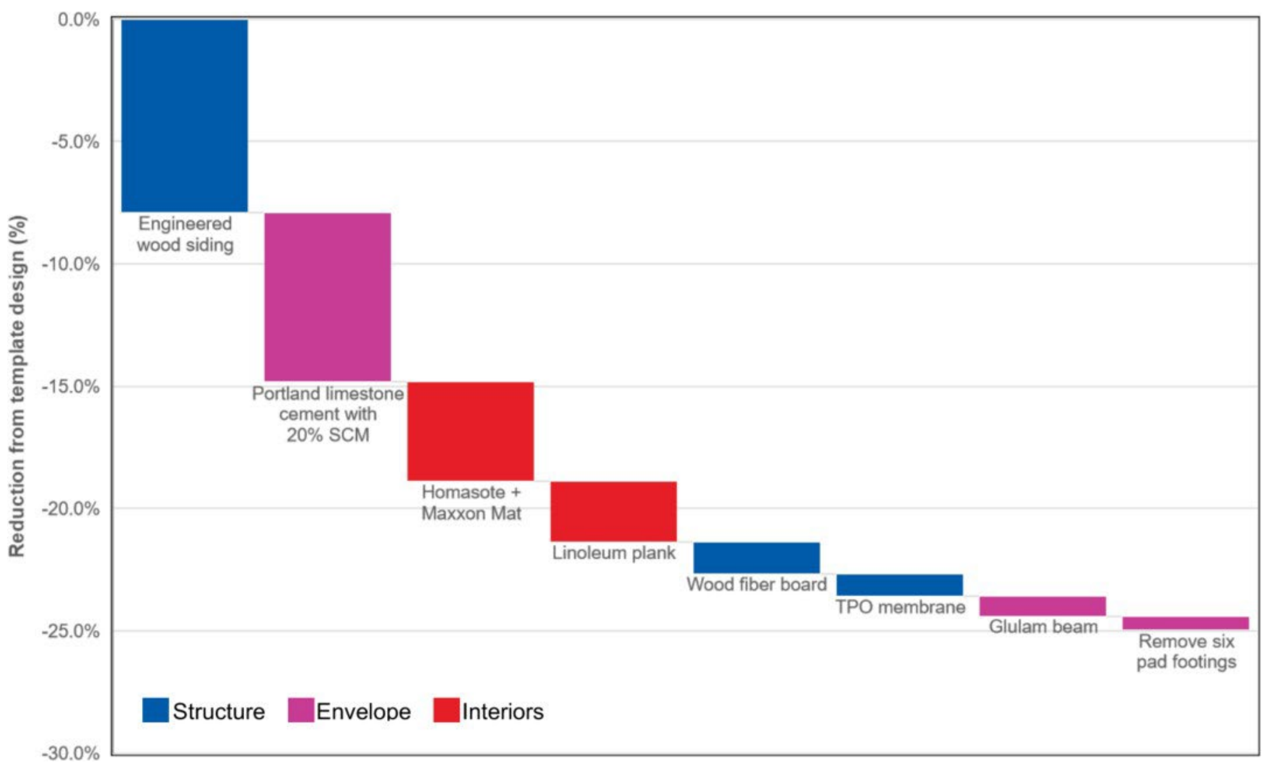
The Electric Program Investment Charge grant allowed the team the time and expertise to identify where systems can be reinvented to achieve new goals for higher performance, better integration, more efficiency, and ultimately less cost. Several examples of these reinventions are given in the list below:

1. Homasote was selected in lieu of gypcrete for the buildings' subfloor. In addition to reducing the embodied carbon associated with the subfloors, the Homasote install is faster with no curing time or associated moisture concerns.
2. The project uses a master meter approach, which makes a community microgrid possible and simplifies the electrical line up on the buildings by omitting individual meters for units.
3. The roof design includes a single slope, which was originally created for optimal solar energy generation, but it is a simpler construction that is less costly than the gabled roofs in the original design.
4. Thermally stabilized wood siding was selected for having a favorable embodied carbon profile, being also lighter and less brittle material than fiber cement, and not constituting a significant incremental first cost.

Embedded Carbon Reductions

The Colegio ZNE Village achieves a 25-percent reduction in embedded carbon versus the SHE template design baseline. The most beneficial carbon-reducing strategies are shown in Figure 4 and described in greater detail below.

Figure 4: Most beneficial embodied carbon reduction measures



SCM: Supplementary cementitious materials; TPO: Thermoplastic polyolefin

Source: Self-Help Enterprises

- Thermally stabilized wood siding replaces fiber cement siding and provides a more than seven-percent reduction in embodied carbon. This material is additionally cheaper to procure and easier to install than the previously specified fiber cement board.
- Concrete at the slabs and footings, as well as the site paving (that is, parking spaces, drive aisles, sidewalks) use low-carbon Portland limestone cement concrete, which additionally includes 30-percent supplementary cementitious material. This strategy reduces embodied carbon by more than seven percent.
- Linoleum tile replaces luxury vinyl plank flooring at all units. This biobased alternative saves more than four percent in embodied carbon and comes with a relatively small added first cost.
- The envelope features a layer of continuous, bio-based rigid insulation. Rather than significantly increase the envelope embodied carbon through the selection of mineral wool board or foam, the team selected a wood fiber-based product for its carbon sequestration benefit.
- The structural design was revised and fine-tuned to omit the use of steel beams at all locations and to reduce the use of steel columns. Parking stalls were intentionally shifted and coordinated to reduce beam spans to omit the use of steel beams throughout the whole project.
- At the site level, the project uses lime-stabilized earthen blocks in lieu of grouted concrete masonry units for the code-required sound wall that surrounds the project.
- Additionally, the project replaces much of the site paving with permeable pavers, which reduces embedded carbon, improves stormwater management, and reduces the urban heat island effect at the site.

Market Transformation

Promoting Broader Adoption of Best Practices

SHE has developed an economies-of-scale approach to affordable housing production in the SJV. SHE assembled a design and construction team to design a product that can be constructed in eight counties throughout the SJV. In the first phase of production, the 20-unit-per-acre product has been used in 14 rental housing communities totaling 812 units over a five-year period. SHE intends to similarly scale the prototype developed at the Colegio ZNE Village. With the integrated emerging technologies in the design, SHE will build and test the product, and conduct another round of improvements post-construction. SHE has used this approach to perfect the mixed-use product in early applications and scale it to broad production. Through the team’s presence in state and federal member organizations and housing policy institutes, this model can be replicated statewide and even nationally.

From Bespoke Development to a Repeatable and Scalable Model

The Colegio ZNE Village has been strategically designed with flexible replicability in mind to enable broad scalability. While localized climate conditions informed the specific design criteria of various energy efficiency strategies (such as envelope design, shading, mechanical and electrical systems, and so on), the underlying approach to reduce demand, shift load, and integrate DER will be a core theme in future decarbonized mixed-use projects. The core strategies that support the demand reduction, load shifting, and DER integration approach are either layered (that is, a modular collection of innovative technologies that can be tailored to a given project) or they can be scaled back as need for a given future project budget. For example, the core heating and cooling systems at the Colegio ZNE Village are widely available and easily integrated into future designs. The modular layers of emerging technologies, such as the Flair Puck smart thermostat and Haiku smart ceiling fan, build in sophistication and innovation on top of these conventional systems at a relatively low cost. This strategic flexibility allows the project to serve as the proof-of-concept for several emerging approaches and technologies.

Replicable Financing Models

The proposed financing model does not require any ongoing grant funding and is designed to be positive cash flow for a minimum of 20 years. SHE applied for Multifamily Housing Program funds in July 2023. The affordable housing financing includes a combination of deferred funding programs from the state, such as the Multifamily Housing Program, which provides a fully deferred 55-year loan with only a 0.42 percent monitoring fee required. Financing also includes the use of low-income housing tax credits, which is equity from an investor and does not require on-going debt service payments. There may be a small permanent loan from a conventional lender, which requires monthly debt service payments, but the loan will be sized to allow for at least a 1.15 debt service coverage ratio. All the operating costs of the technology will be included in the annual operating budget, including deposits to the maintenance reserve accounts to allow for ongoing maintenance and upkeep of all technologies.

This model allows the incorporation of the capital cost of decarbonization techniques and creates a cash flow structure that allows for the use and maintenance of that technology in the long term. This is a model that can be replicated for other types of mixed-use developments around the state and could also take advantage of new markets tax credits in place of the low-income housing tax credits if the project does not include housing.

Creating a Plug-and-Play Environment

There are two main principles that ensure that the Colegio ZNE Village can be replicated using a plug-and-play approach. The first is to ensure the correct team is in place. For this effort, SHE is not proposing to dramatically change its typical team. Rather, SHE has assembled a familiar, local team that has shown it can deliver a high-quality housing project on-budget and to the expected standard. That team has then been augmented with the specific expertise required to achieve the technology goals of this effort.

The second principle is that the team will analyze all technologies and approaches through a financing and affordable housing lens, which will involve comparing how these approaches compete for affordable housing funding. The team will ensure that the final package can be presented and explained as a viable approach because of its blend of cutting-edge technology, operational costs savings, and adaptability to meet the needs of future projects.

Managing the Risk of Adopting New Technologies

The design process of the project has balanced the need and desire for innovative technologies with the need for reliability and safety of building systems. The team has struck this balance using several strategies: (1) applying tried and true technologies in novel ways to affordable housing. For example, SHE typically uses HPWHs but has done so on a per-unit basis. By switching to centralized HPWHs, the team has ensured performance and reliability while adding efficiency and peak shifting benefits; (2) examining previous installations of new technologies and discussing the processes and outcomes of those projects with the project team and manufacturer. For example, the team had extensive discussions with project teams involved with the installation of ERVs in multifamily residential projects.; and (3) leveraging existing relationships with technology manufacturers and developers to honestly and transparently discuss benefits, risks, and case studies in which the product/technology was used. Across these approaches, the team carefully weighed performance, capital and operational cost, maintenance, and equity to arrive at the most suitable and reliable solutions.

Given that buildability and replicability are central goals of this project, ensuring performance, safety, and reliability is essential to its success. The approach described above ensures not only that innovative, next-generation technologies are deployed successfully on the site, but it also increases the likelihood of subsequent installations on future projects.

Community Engagement

The team has gathered valuable input from community members through a variety of outreach efforts, including community meetings, surveys, and design charrettes. This input has guided the development of the project.

The feedback received highlighted the importance of creating affordable housing options that are accessible to all members of the community, including those with low incomes, disabilities, and families with children. It also emphasized the need for sustainable design features that promote energy efficiency and reduce the carbon footprint of the project. The team has taken this feedback seriously and has incorporated it into the project design, ensuring that the development meets the needs of the community.

Minimizing Gentrification and Aligning with Community Needs

SHE addresses gentrification by developing 100-percent affordable rental communities. SHE only provides housing solutions for low-income families at or below 80 percent of area median income (AMI), and most of the units in the Colegio ZNE Village will serve very low-income households ranging from 30-50 percent AMI. The project site is in one of the more affluent areas of the community and is a direct mitigation for gentrification. To ensure the units remain affordable in the long-term, the project will include a 55-year deed restriction, which requires the units to remain affordable at or below 80 percent AMI for the next 55 years.

Positive Impact

The proposed project site for the Colegio ZNE Village was intentionally located immediately adjacent to commercial development and just north of a large shopping center with retail, restaurants, and other commercial amenities. The proximity to these commercial amenities provides access to job opportunities and basic daily needs without requiring personal cars. The site is also located on two City of Visalia bus routes, which have a 15-minute headway and are the most frequent routes in the City of Visalia. The site is also located immediately west of a large park space, which will allow access to expanded outdoor recreation and open space.

Workforce Development

The Colegio ZNE Village is expected to have a positive impact on workforce development and local job creation. The project involves the construction of affordable housing units, which will require a variety of skilled and unskilled workers to complete. This means that there will be job opportunities created for construction workers, architects, engineers, and other professionals who are involved in the construction process.

In addition to the direct job creation that will result from the construction of affordable housing units, there will also be indirect job creation. As more affordable housing becomes available, it will attract businesses and investors to the area. This, in turn, will create job opportunities in a variety of industries, such as retail, hospitality, and healthcare.

Overall, Colegio ZNE Village is expected to have a significant impact on the local economy by creating job opportunities and promoting economic growth.

CHAPTER 3: Results

Design Challenges

Per-Building Versus Site-wide Microgrid

The team considered both a per-building approach and a site-wide approach in configuring the microgrid. This decision involved weighing tradeoffs between technical and economic efficiency and regulatory constraints that prevent direct tenant billing. The team opted for a site-wide microgrid, despite the loss of direct tenant billing, due to the technical and economic advantages. This approach will require the development of more intentional and proactive resident engagement around energy use, as residents will not be held financially accountable for excessive use. To mitigate the associated risk, the project includes unit-level energy metering, interactive energy monitoring systems, and plans to include a robust resident education/engagement program. Additionally, the team is optimistic that the regulatory challenge preventing direct tenant billing will be resolved soon, as more projects face this challenge.

Balancing Controls Sophistication with Accessibility

In considering controls strategies, the team had to weigh sophistication, innovation, and performance against the realities of installation, tenant accessibility, and maintainability. While several controls strategies were promising from an energy management perspective (for example, building automation systems, window sensors tied to HVAC operation, and so on), these were ruled out due to their complexity. Installation of these systems would require a dedicated and highly sophisticated facilities engineer, which would be both infeasible within SHE's current operating budget and difficult to procure in the Central Valley. Furthermore, the complexity of these systems risks inaccessibility to residents. Grid-interactive energy components will be automated where possible, and the microgrid vendor will be responsible for microgrid maintenance, eliminating this responsibility from the on-site facilities engineer.

Battery Technology Selection

The project team compared several chemical battery technologies against the industry standard lithium-ion system. The project features lithium iron phosphate batteries, as this system is considerably safer and has a longer lifecycle than lithium-ion batteries. Lithium iron phosphate batteries also have a wider optimal operating temperature range than the lithium-ion system. All that said, this choice came with tradeoffs. The lithium iron phosphate system has a higher first cost and a larger footprint relative to the lithium-ion system. Future projects may not be able to afford the higher first cost or be able to allocate the space associated with this approach.

Vehicle-to-X

While the project team carefully vetted the benefits and tradeoffs of vehicle-to-building and vehicle-to-grid technologies, they were not deemed suitable for this project. The team reached this conclusion through two key determinations: (1) the period when the vehicle battery discharge would be most valuable (that is, between 4:00 p.m. and 9:00 p.m.) overlaps with the period when the vehicles would likely provide the highest utility to occupants; and (2) the frequent and consistent cycling of the vehicle batteries would shorten their lifetimes, thereby requiring frequent and costly replacements.

Energy and Emissions Performance

The proposed design exceeds all minimum design requirements set forth by the CEC. Additionally, the project exceeds the minimum project-specific targets that were established for the Colegio ZNE Village. The following sections describe the operational energy and carbon performance of the project from both an annual and an hourly perspective.

Annual Results

Table 1 below describes the proposed design performance on an absolute basis and relative to the SHE template design baseline. Each number represents the performance before on-site renewable energy generation and storage.

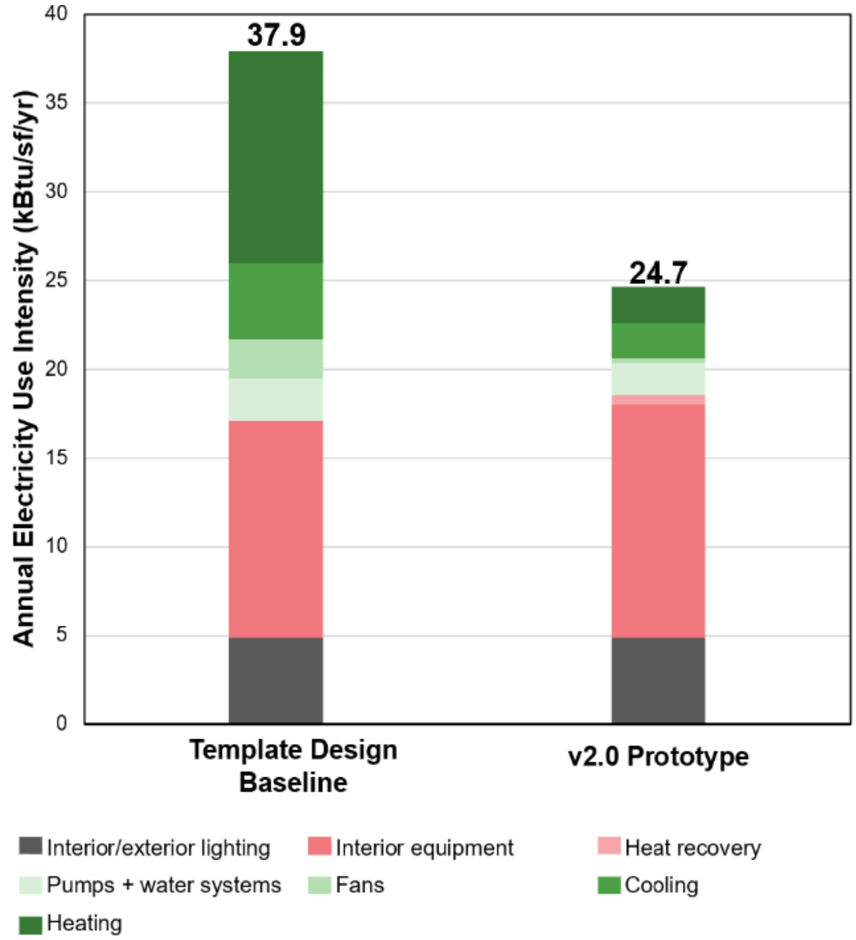
Table 1: Proposed Design Operational Energy and Carbon Performance

Metric	Performance *(Percent Improvement)*
Energy Use Intensity (1000 British thermal units per square foot per year)	24.7 *(35 percent)*
Carbon Emissions Intensity (kilograms of carbon dioxide equivalent per conditioned square feet of building area per year)	1.4 *(37 percent)*

Source: Self-Help Enterprises

Heating, cooling, ventilation, and domestic hot water systems comprise more than 50 percent of the template design baseline energy use intensity. The proposed design was able to reduce the annual electricity consumption associated with these end uses by more than 60 percent, which is shown in the bar chart in Figure 5 below.

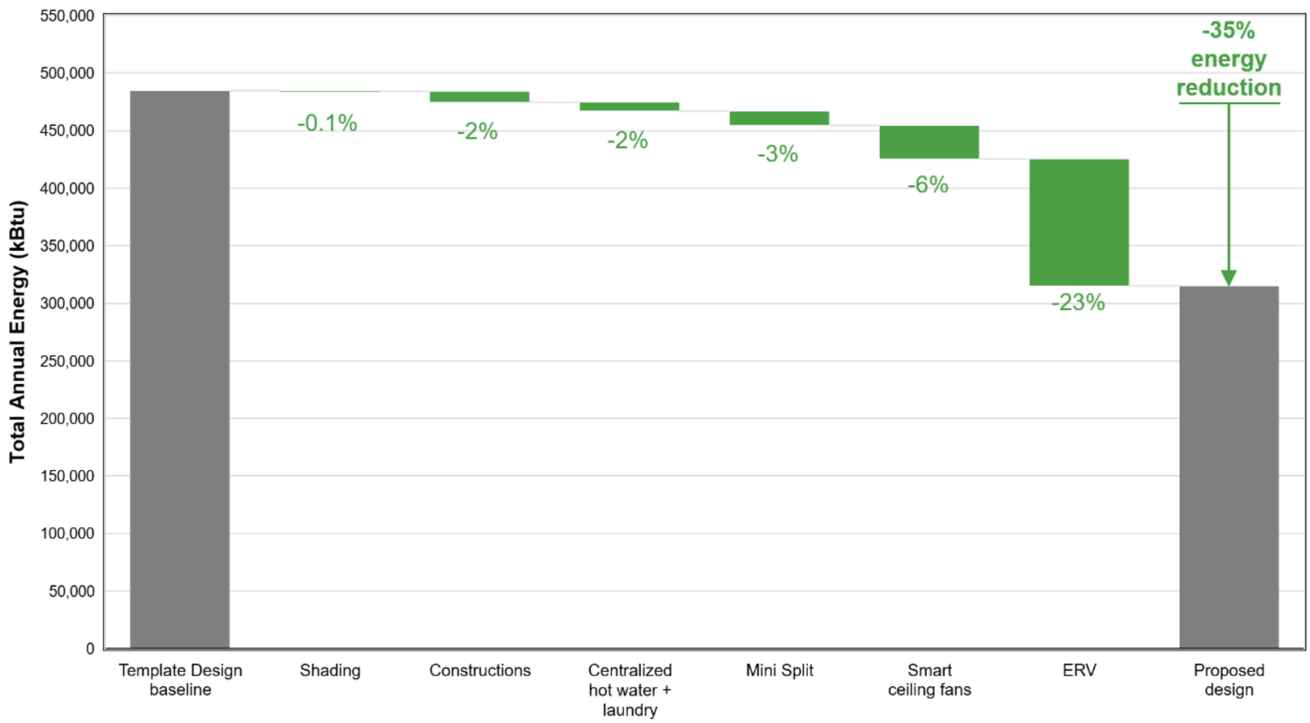
Figure 5: Annual Electricity Use Intensity for the Template Design Baseline and the Proposed Design (v2.0 Prototype)



Source: Self-Help Enterprises

Figure 6 below shows how different advanced technologies and strategies contribute to the observed energy consumption / carbon emissions savings.

Figure 6: Contributions of Key Energy Conservation Measures



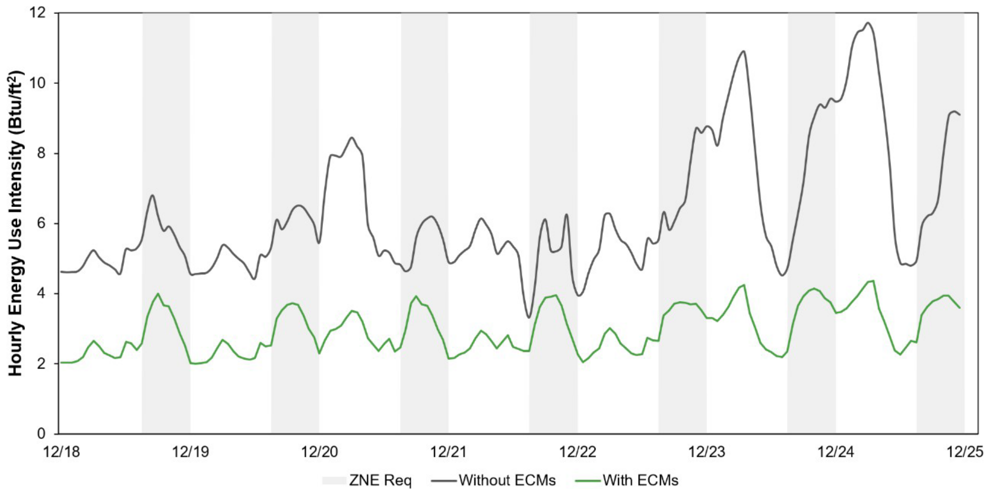
Source: Self-Help Enterprises

As the figure shows, the additions of the ERVs and smart ceiling fans have the largest impacts on the total annual energy use and resulting carbon emissions. Though shading has a relatively small impact, it improves visual and thermal comfort.

Hourly Results

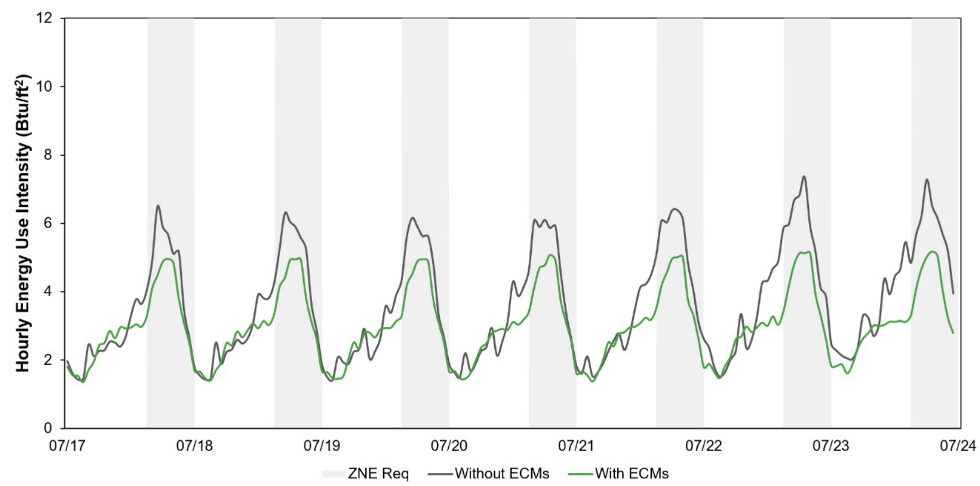
To meet the CEC requirements, the site must reach ZNE between the hours of 4:00 p.m. and 9:00 p.m. The graphs in Figure 7 and Figure 8 below show how the selected ECMs included in the proposed design reduce the peak electricity demand during these hours for both the summer and winter peaks. The graphs represent energy use intensities before on-site renewable energy generation/storage, with shaded areas representing 4:00 p.m. and 9:00 p.m.

Figure 7: Hourly Energy Use Intensity: Winter Design Peak



Source: Self-Help Enterprises

Figure 8: Hourly Energy Use Intensity: Summer Design Peak

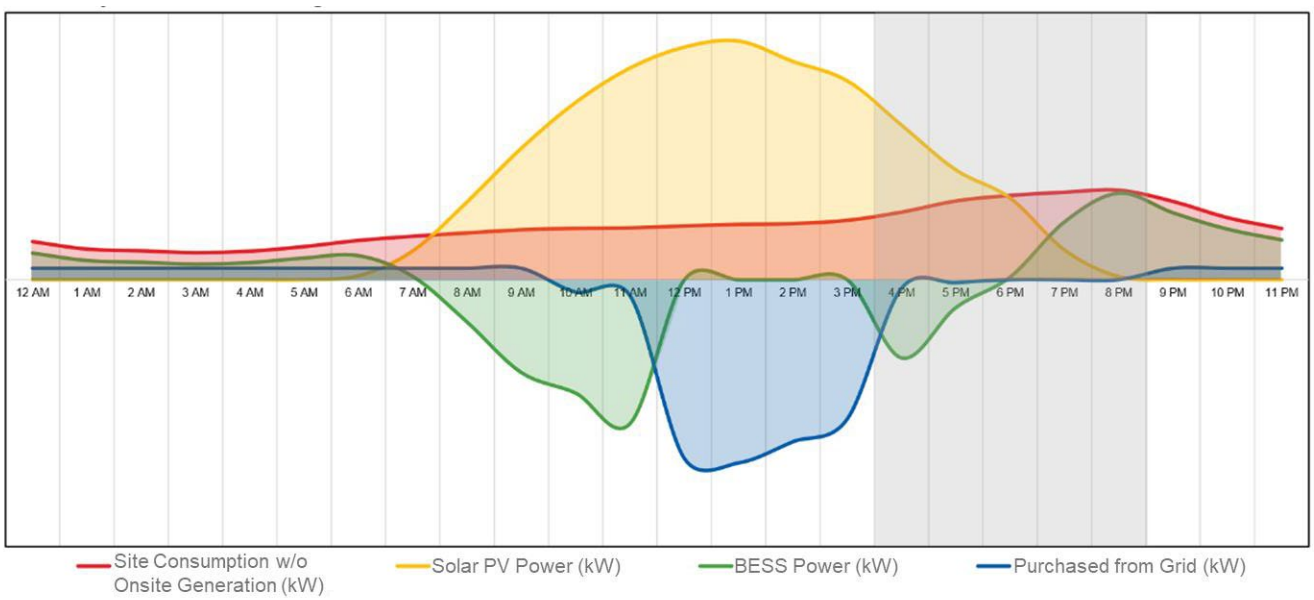


Source: Self-Help Enterprises

Both the heat recovery of the ERVs and the efficiency of the mini-split heat pumps reduce the total load during peak hours, especially during the winter. This allows for smaller battery energy storage systems (BESSs) required to provide energy between 4:00 p.m. and 9:00 p.m.

Unlike the previous figures, Figure 9 accounts for on-site energy generation and storage and the impact of load shifting. The graph shows the hourly site consumption, generation, and storage on a summer design day. The gray region indicates when zero site consumption is allowed per the CEC minimum design requirements.

Figure 9: Hourly Consumption, Generation, and Storage on Summer Design Day



Source: Self-Help Enterprises

As the graph shows, the project achieves ZNE between 4:00 p.m. and 9:00 p.m. Though consumption is highest during this period (shown in red), the battery is sized to provide sufficient energy to offset this consumption (shown in green). The graph also shows that the purchase from the grid (shown in blue) is minimal and only occurs between 9:00 p.m. and 9:00 a.m. (off-peak).

Costs and Benefits Performance

The analysis estimated the cost difference between the zero-emission build-out relative to standard design, construction, and operations. "Standard" refers to a code-minimum project that complies with California's 2022 Building Energy Efficiency Standards (Title 24, Part 6), effective January 1, 2023. Cost is reported in three categories for the residential units within the broader mixed-use development: incremental first cost, lifecycle cost from the owner's perspective, and lifecycle cost from a societal perspective. This last cost category accounts for the benefits of carbon emissions avoidance, which results from advanced building design and operation.

Lifecycle Cost Assessment Methods and Assumptions

Lifecycle Cost Assessment methods and assumptions are fully described in Appendix B.

Incremental First Costs

This section estimates the incremental first costs of the standard and proposed building and explains the goals and challenges that the project experienced and that informed the final design. The reported costs shown include materials, labor, and installation.

Building Features + Construction Methods

Table 2 shows the incremental first costs associated with the novel building features and construction methods included in the proposed design that deviate from the standard design.

Table 2: Incremental First Cost: Building Features + Construction Methods

Features	Standard Design and Cost	Proposed Design and Cost	Incremental First Cost Increase (+) or Savings (-)
Increased cavity insulation	2x6 R-14 16″ on-center	2x6 R-21 16″ on-center	+ $20,514
Continuous exterior insulation	None installed	1.5″ bio-based rigid insulation	+ $1,200,000
Exterior door and window glazing	U-0.58	U-0.3	+ $553,900
Roof	Asphalt shingle	Thermoplastic polyolefin cool roof	+ $55,474
Structural and site concrete	Replace 20 percent cement	Replace more than 20 percent cement	+ $279,000
Site soundwall	Fully grouted concrete masonry units	Lime-stabilized earth block	+ $222,407
Cladding	Fiber cement board	Thermally stabilized wood	- $470,466
Total incremental cost increase (+) or savings (-) for project			+ $1,860,829
Incremental cost per residential unit ($/sf)			+ $19,800

Source: Self-Help Enterprises

The list of building features and construction methods in Table 2 includes strategies that both reduce operational energy use/carbon emissions and reduce the embodied carbon of the project. The included strategies were thoroughly evaluated for their operational and embodied carbon performance as well as their cost performance. The team started this process in schematic design using a genetic algorithm[2] to test thousands of combinations of ECMs and identify the cost- and carbon-optimal packages of ECMs.

Through that analysis, the team elected to increase the energy performance of the envelope in several ways:

- **Exterior opaque walls:** The team switched to a cavity insulation with a higher R-value[3] and added an additional layer of continuous exterior insulation. The incremental cost associated with the higher R-value cavity wall is small. The additional

[2] Genetic algorithms mimic the evolutionary selection process observed in nature, combining outcomes that represent "success" and rejecting solutions deemed "weaker."

[3] R-value is the rating system used to grade insulation products or the insulating properties of a material. A high R-value means a product or building is well-insulated.

continuous insulation is expensive, in part because the team has selected a carbon-sequestering material, as it was critical to maintain or reduce embodied carbon, even while adding additional materials to the project.

- **Cladding:** The team switched to a thermally stabilized wood siding from a fiber cement board cladding system. This both reduces embodied carbon and cost.
- **Window and door glazing:** The genetic optimization showed that decreasing the U-value[4] of the project's glazing is advantageous despite its high incremental cost. The team also felt that window and door glazing is relatively simple to replace on projects with tighter budgets.
- **Roof:** The genetic optimization process also suggested that a thermoplastic polyolefin cool roof would be advantageous, due to the relatively minor incremental first cost, the energy use reductions, and the urban heat island effect mitigation the cool roof would provide.

In addition to the envelope strategies described above, the project includes several non-envelope measures that reduce the embodied carbon of the project, including low-carbon cement for structure and site paving, as well as the use of earth block construction in lieu of fully grouted concrete masonry units. Some of these materials come at a higher first cost, but they have remained in the project due to the goal to develop a project with low whole-life carbon emissions.

Energy Features

Table 3 below shows the incremental first costs associated with the novel energy features included in the proposed design that deviate from the standard design.

Table 3: Incremental First Costs of Energy Features

Features	Standard Design and Cost	Proposed Design and Cost	Incremental First Cost Increase (+) or Savings (-)
Unit heating and cooling	Unitary air-to-air heat pump	Ductless mini-split heat pumps	+ $282,000
Unit ventilation	Bathroom exhaust fan (80 cubic feet per minute)	Zehnder energy recovery ventilator	+ $416,796
Unit thermostat	Standard thermostat	Flair Puck smart thermostat	+ $8,554
Ceiling fan	Standard fan with integrated light	Haiku smart ceiling fan	+ $75,000
Domestic hot water	Centralized gas hot water heater	Centralized HPWH with swing tank	+ $34,962

[4] U-value is the rating system used to grade the thermal transmittance of window and door units. A low U-value means a window or door is well-insulated.

Features	Standard Design and Cost	Proposed Design and Cost	Incremental First Cost Increase (+) or Savings (-)
Rooftop solar PV array	176 kW array	571 kW array	+ $1,467,625
Battery energy storage system and control/monitoring system	None required per 2022 code	2.6 MW lithium iron phosphate	+ $1,855,028
EV charging infrastructure	2022 code-minimum (10 percent EV-ready; 5 percent EV-capable)	20 Level 2 chargers, 75 Level 2 ready	+ $337,500
Total Incremental Cost Increase (+) or Savings (-) for project			+ $2,836,290
Incremental cost per residential unit ($/sf)			+ $30,200

Source: Self-Help Enterprises

The list of energy features in Table 3 includes strategies that reduce annual energy and carbon emissions but also, perhaps more critically, enable the peak shedding and shifting and demand flexibility that are critical to both site and grid resilience.

As with the features and methods described in the previous section, the team identified viable ECMs in schematic design using a genetic algorithm to test thousands of combinations of ECMs and identify the cost- and carbon-optimal packages of energy conservation measures. This process yielded several key features:

- **Ductless mini-split heat pumps:** The team switched from a unitary air-to-air heat pumps to ductless mini-split heat pumps. The incremental cost of the switch is relatively small, but there is an energy/carbon benefit.
- **Centralized heat pump water heating with thermal storage:** Similarly, this approach comes with a relatively modest incremental cost but has a significant contribution to annual and peak reductions. Like the ductless mini-split heat pumps, this approach uses tried-and-true technology, but it does so in a novel way by centralizing and building in the capacity for load shifting with thermal storage.

In addition to the above features, the team introduced several additional ECMs that did not emerge from the genetic optimization process.

For example, the Flair Puck thermostats, which include several advanced energy features, including automatic demand response capabilities, were not included in the genetic optimization but have become critical to the project, as they contribute to the achievement of several CEC goals and come with a relatively small added cost.

The Zehnder ERVs are quite expensive, but they are included because: (1) they precondition ventilation air with a heat exchange process, thereby reducing energy/carbon associated with conditioning supply air; (2) they provide a continuous supply of filtered fresh air to occupants, which is especially critical in the Central Valley; and (3) this particular unit includes an economizer mode, which provides "free cooling" when the indoor setpoint is higher than the outdoor air temperature. Future projects can still get the heat recovery and indoor air quality benefits of ERVs, even if they are working with a tight budget, by selecting a less expensive system.

The microgrid, solar PV array, and battery storage system are the highest cost items in the project. They are also critical to the achievement of several CEC goals, including ZNE from 4:00 p.m. to 9:00 p.m., islanding capabilities, and the ability to curtail 20 percent of the peak load. Because these elements are so fundamental to the achievement of the CEC goals, the team elected to proceed with them despite the high cost. That said, several iterations were developed to try and reduce the first costs associated with these items. The team tried to minimize demand load to reduce the associated solar/storage needs; the team also evaluated different microgrid layouts, including both a site-centralized or distributed approach. The team selected the site-centralized option in part because it had a lower first cost.

Lifecycle Cost Analysis: Owner's Perspective

Lifecycle cost was calculated assuming the perspective of the property owner/operator (SHE), given the ownership and utility model for the property. The project is intended to be master-metered, which allows for all energy savings and capital cost and benefit from ongoing savings to accrue to the owner. Resident rents are fixed to meet the low-incoming housing requirement, and electricity costs are capped at $30/month in the standard case and included in monthly rent in the proposed case.

Currently, the lifecycle costs for the proposed design exceed the baseline life cycle costs by $56,202 per unit. This is due to a combination of high capital costs driven both by the embodied carbon measures that contribute no operational savings and the fact that the property currently is a net exporter of electricity until such time as additional zero emissions vehicles may utilize fully the charging energy available. Table 4 below demonstrates these findings.

Lifecycle Cost Analysis: Societal Perspective

When the societal cost of carbon is included in the lifecycle cost analysis, the proposed development provides a lifecycle value per unit of $22,746, which include societal carbon cost savings associated with embodied and operational carbon. This is summarized in Table 4.

Table 4: Summary of Lifecycle Cost Analysis

	Incremental First Cost ($/Unit)		Lifecycle Cost ($/Unit)		Societal Lifecycle Cost ($/Unit)*	
	Standard	**Proposed**	**Standard**	**Proposed**	**Standard**	**Proposed**
SHE Costs	$72,917	$141,109	$129,082	$185,285	$196,968	$174,222

*Societal lifecycle cost includes both the lifecycle cost and the cost savings associated with avoided carbon emissions.
Source: Self-Help Enterprises

Technology Transfer Plan

Throughout the Colegio ZNE Village design phase, there were several activities aimed at introducing the research and increasing awareness of it to a broader audience. The project team engaged in public outreach efforts, including presentations, panel discussions, design charettes, and current neighborhood resident engagement, to communicate the importance of the research and encourage participation in the project. Through these efforts, the project team was able to raise awareness of the research and engage with a diverse range of stakeholders to drive the success of the project. Through a build phase for this project, the SHE team would continue to ensure technological learnings from the project are captured and disseminated to a range of professionals that would be responsible for future deployments of this technology or similar technologies.

CHAPTER 4: Conclusion

The Colegio ZNE Village development provides 94 affordable rental units, a community center, and commercial office space, as well as outdoor site amenities for residents. The team has developed a replicable, all-electric, ZNE design which improves the energy efficiency and resilience of building operations while minimizing operating costs for the residents. The proposed design serves as a flexible and scalable prototype for future affordable, low-carbon development.

Through thorough and systematic evaluation of existing and emerging technologies and their suitability for affordable housing with respect to capital and operational costs, ease-of-installation, ease-of-use, and ease-of-maintenance, the Colegio ZNE Village achieves and, in many cases, exceeds its design requirements and targets. The pragmatic innovation inherent to the thorough and systematic approach allows this achievement to be translated to future projects.

Key Results

The project achieves or exceeds all the minimum requirements and targets established prior to the start of the design process. Several of these are highlighted below.

The project achieves:

- All-electric design.
- Zero net energy every day between 4:00 p.m. and 9:00 p.m.
- Islanding capability, which provides immediate and indefinite functionality for ten percent of peak load (Tier 1 loads) and immediate and 72-hour functionality for 25 percent of peak load (Tier 2 loads).
- A 35-percent reduction and a 37-percent reduction in operational energy and carbon, respectively, versus the template design baseline.
- A 25-percent reduction in embodied carbon emissions versus the template design baseline.
- Monthly resident electricity bills that are at or below the targeted rates.

Lessons Learned

The team learned several key lessons over the course of developing the proposed Colegio ZNE Village design:

1. The current regulatory landscape does not favor a master-meter approach for a site-wide microgrid. Due to regulatory constraints, SHE is not permitted to directly bill tenants through this microgrid configuration, which poses a significant financial risk

and a missed opportunity for energy use accountability. The project team is hopeful that the limiting regulations will change in the future as more projects are forced to confront this challenge.

2. There are many innovative controls strategies that are appealing from an energy management perspective but unrealistic from a maintenance, cost-effectiveness, and tenant engagement perspective. The selected controls strategies need to balance these competing priorities.
3. Lithium iron phosphate batteries are favorable from safety, durability, and operational perspectives. That said, they come at a higher first cost and require a larger footprint for the modules than conventional lithium-ion systems. These tradeoffs must be part of the decision to move toward lithium iron phosphate systems.
4. The team carefully evaluated the feasibility and benefits of vehicle-to-grid and vehicle-to-building systems. They were ultimately deemed unsuitable for the project due to the overlap between the period when vehicles would likely provide the highest use to residents and the period when the battery discharge would be most valuable (that is, between 4:00 p.m. and 9:00 p.m.). The team was also concerned that the frequent and consistent cycling of the vehicle batteries would shorten their lifetimes, thereby requiring frequent and costly replacements.

Market Opportunities

The Colegio ZNE Village demonstrates that affordable housing projects can achieve ambitious carbon and sustainability targets through the thoughtful and flexible integration of known and emerging energy technologies. This approach can be translated to future affordable housing development opportunities.

The approach relies on flexible integration of increasingly innovative layers of technology on top of highly replicable, cost- and carbon-optimal core systems. For example, the massing of the Colegio ZNE Village project is optimized for passive heating and cooling and solar generation, and the project relies on familiar but highly efficient heating, cooling, and hot water systems. From here, the design layers less familiar carbon-optimal technologies that are still quite replicable and are highly flexible. For example, the project includes ERVs, smart thermostats, ceiling fans, equipment with low-carbon refrigerant, and the addition of the microgrid. Finally, the project design layers on highly innovative, carbon-optimal systems. For example, the team selected an ERV with economizer capabilities, demand responsive thermostats, and smart ceiling fans.

This layered approach is highly flexible. The Colegio ZNE Village deploys one combination of systems, whereas other deployments of this prototype can adopt other combinations to meet project needs. This allows for scalability to future projects within the San Joaquin Valley, the state, and beyond.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
°C	degree Celsius
°F	degree Fahrenheit
AEA	Association for Energy Affordability
ALMS	automatic load management system
AMI	area median income
BESS	Battery Energy Storage System
CAMx	California and Mexico region
CEC	California Energy Commission
CPUC	California Public Utilities Commission
CUAC	California Utility Allowance Calculator
DERs	distributed energy resources
ECM	emission conservation measure
ERV	energy recovery ventilator
EV	electric vehicle
EVSE	Electric Vehicle Supply Equipment
HPWH	heat pump water heater
HVAC	heating, ventilation, and air conditioning
IDFs	Input Data Files
LCCA	Lifecycle Cost Analysis
NEM	net energy metering
NPV	net present value
PV	photovoltaic
SCE	Southern California Edison
SCM	supplementary cementitious materials
SHE	Self-Help Enterprises
SJV	San Joaquin Valley
TDV	time dependent valuation
TMY	Typical Meteorological Year
USD	US dollar
WBLCA	Whole Building Life Cycle Assessment
ZNE	zero net energy

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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.

- Charrette Report
- Design Review Summary Report
- Program Document
- Planning Entitlement Drawing Design Package
- Schematic Design Drawing Set
- Design Development Drawing Set
- Design Development Written Specifications
- Construction Document Drawing Set
- Written Construction Specifications
- Existing Template Design Operational Energy and Carbon Emissions Memo
- Existing Template Design Embodied Carbon Whole Building Life Cycle Assessment (WBLCA) Memo
- Schematic Design Operational Energy and Carbon Emissions Memo
- Schematic Design WBLCA Memo
- Design Development Operational Energy and Carbon Emissions Memo
- Design Development WBLCA Memo
- Construction Documents Operational Energy and Carbon Emissions Memo
- Construction Documents WBLCA Memo
- Schematic Design Renewable Energy Generation and Storage Narrative
- Markups of Design Development Set
- Markups of Renewable Energy, Battery Energy Storage System (BESS), and Electric Vehicle Supply Equipment (EVSE) Systems Interconnection Drawings and Equipment Specifications
- Future Climate and Infrastructure Resilience Narrative
- Schematic Design Resilience Assessment Report
- Design Development Resilience Assessment Report
- Construction Documents Resilience Assessment Report
- Schematic Design Project Cost Estimate and Lifecycle Cost Analysis (LCCA) Memo
- Design Development Project Cost Estimate and LCCA Memo
- Construction Documents Project Cost Estimate and LCCA

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Appendix A: Energy Modeling Detailed Methods and Assumptions

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APPENDIX A: Energy Modeling Detailed Methods and Assumptions

Reference Files

The template design baseline model relies on the permit set for Building 300 at Santa Fe Commons in Tulare, California as the template for this baseline energy model. The proposed design model relies on the 95 percent construction documents set for the Colegio ZNE Village. The team used the input data files (IDFs) shown in Table A-1 as references in building these energy models.

Table A-1: IDF Reference Files

File Name	Source
US+MF+CZ3B+hp+slab+IECC_2021.idf	Pacific Northwest National Laboratory prototype building model
SingleFamilyHouse_HP_Slab.idf	EnergyPlus example input file
WaterHeaterHeatPumpWrappedCondenser.idf	EnergyPlus example input file

Source: Self-Help Enterprises

Modeling Software

Model geometry was drawn in Sketchup Pro 2022. The OpenStudio 1.4.0 extension for SketchUp was used to assign envelope constructions and occupancy schedules. The IDF file was then imported into EnergyPlus v22.2.0, where the rest of the model was built.

Model Geometry

The building was modeled as 11 units with a shared attic. The model has a total building area of 12,518 ft^2, and a net conditioned building area of 8,994 ft^2. Further divisions within each unit were not created in EnergyPlus at this time; however, the number of bedrooms and bathrooms were noted to inform internal loads. Shared external spaces, such as the external stairwell, were also not modeled. Balconies were modeled for shading of the units below.

Climate Data

The baseline design energy model described in this report is based on outside air conditions as defined by the Typical Meteorological Year TMYx weather file for Visalia, California. TMYx is an updated iteration of Typical Meteorological Year (TMY) data, covering the period of 2006-2021. While TMY3 data (1976-2005) is typically used for this type of analysis, the team used the TMYx data to account for recent changes in climate. Table A-2 summarizes the data used.

Table A-2: Climate Data

Weather File	USA_CA_Visalia.Muni.AP.723896_TMYx
Location	Visalia, California
Latitude	36° 19.02′ N
Longitude	119° 24.00′ W
Elevation	295.29 ft
Summer Design Day	100.22 degrees Fahrenheit (°F) DB (37.9 degrees Celsius [°C]) / 71.78ºF (22.1°C) WB (0.4 percent cooling design condition)
Winter Design Day	29.84°F DB/29.84°F (–1.2°C) WB (99.6 percent heating design condition)

Source: Self-Help Enterprises

Envelope

Table A-3 summarizes the envelope inputs for both the template design baseline and the proposed design models.

Table A-3: Template Design Baseline and Proposed Design Envelope Properties

Component	Template Design Baseline	Proposed Design
Roof	U-0.0499 + U-0.0194 at ceiling below attic R-19 batt insulation between wood trusses placed 24″ on- center. R-49 batt insulation in ceiling below attic.	Same as template design baseline
Exterior Wall	U-0.0453 2x6 stud wall (16″ on-center) with R-21 batt insulation in the wall cavity	U-0.0322 2x6 stud wall (16″ on-center) with R-23 batt insulation and 1″ continuous bio-based insulation.
Slab on Grade Floor	U-1.09	Same as template design baseline
Exterior Glazing	U-0.3/SHGC-0.23/VT-0.5 Double-pane, vinyl-clad windows	U-0.3/SHGC-0.25/VT-0.52 Double-pane, Fibrex-clad windows
Exterior Shading	None	Window overhangs and vertical shades on south and west facades.

Source: Self-Help Enterprises

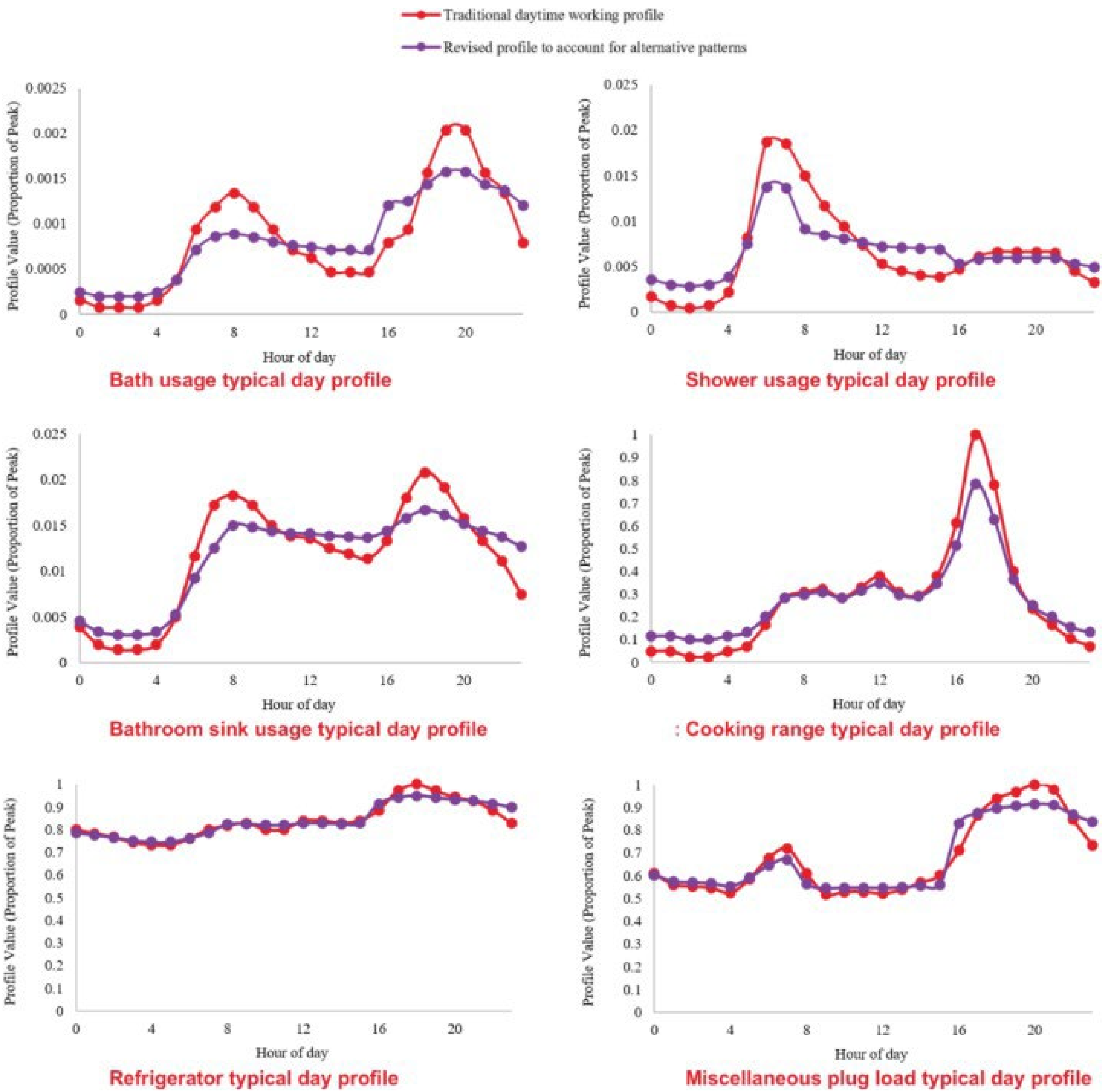
Infiltration was assumed to be constant and continuous at 0.387 air changes per hour at standard temperature and pressure across both the baseline and proposed models. This input corresponds to measured airtightness from blower door tests in a recent study of 274 low-rise residential buildings in the United States.

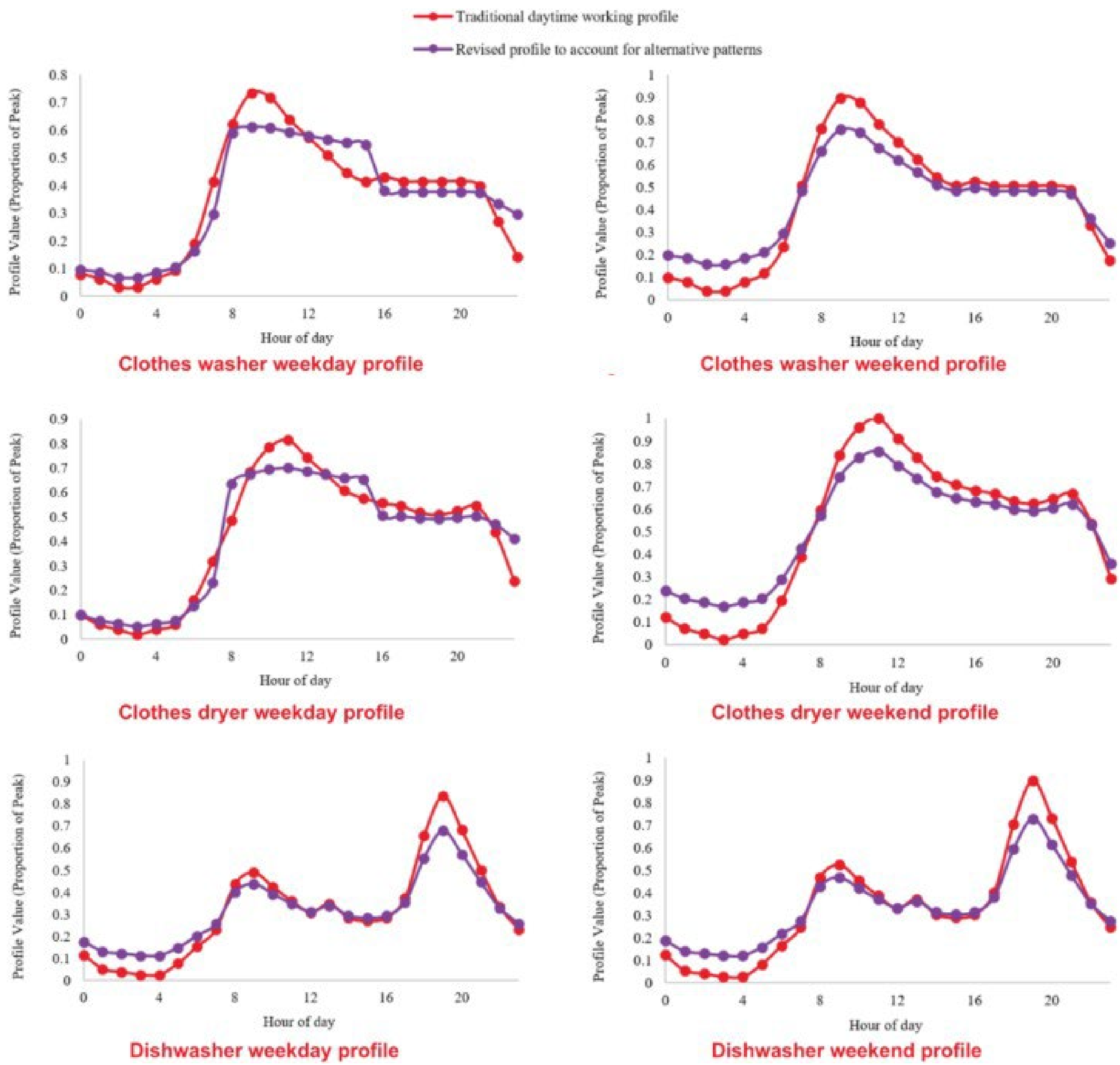
Internal Gains

Schedules

The schedules for this equipment use the Pacific Northwest National Laboratory residential model profile as the starting point and the project team adjusted it to consider variation in resident employment and in-unit activity schedules. These are shown in Figure A-1 below.

Figure A-1: Typical and Adjusted Equipment Profiles





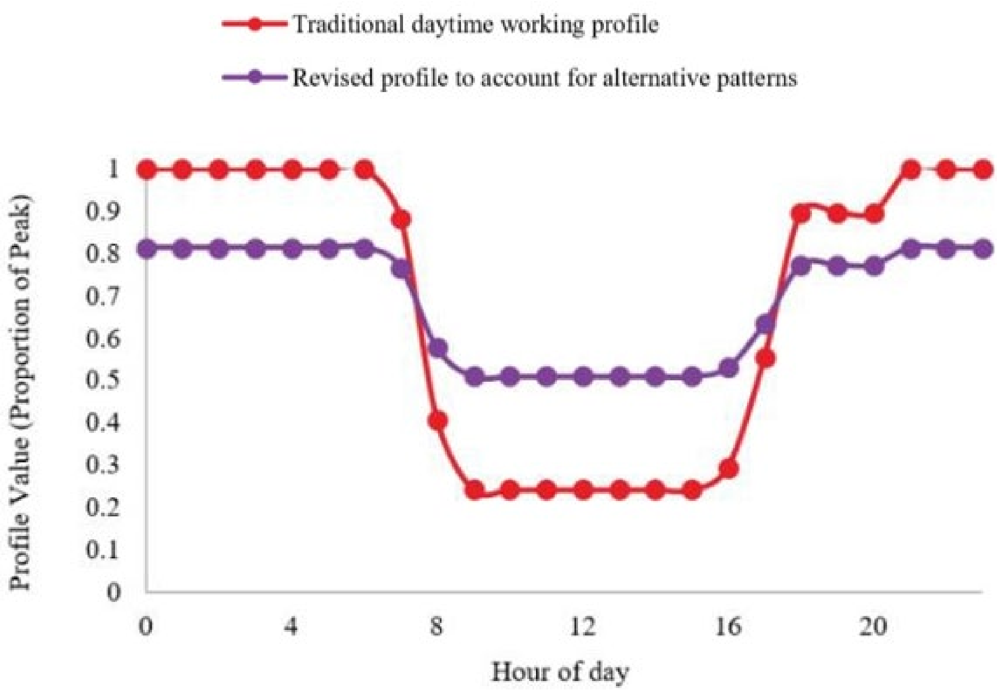
Source: Self-Help Enterprises

People

Two people were assumed to occupy each bedroom within each residential unit. Each person is modeled following the occupancy schedule shown in Figure A-2 below.

This schedule used the Pacific Northwest National Laboratory residential model profile as the starting point (red) and the project team adjusted it to consider variation in resident employment and in-unit activity schedules (purple) (assuming 20 percent of occupants adhere to atypical employment schedules).

Figure A-2: Typical and Adjusted Occupancy Schedules



Source: Self-Help Enterprises

Electric Equipment

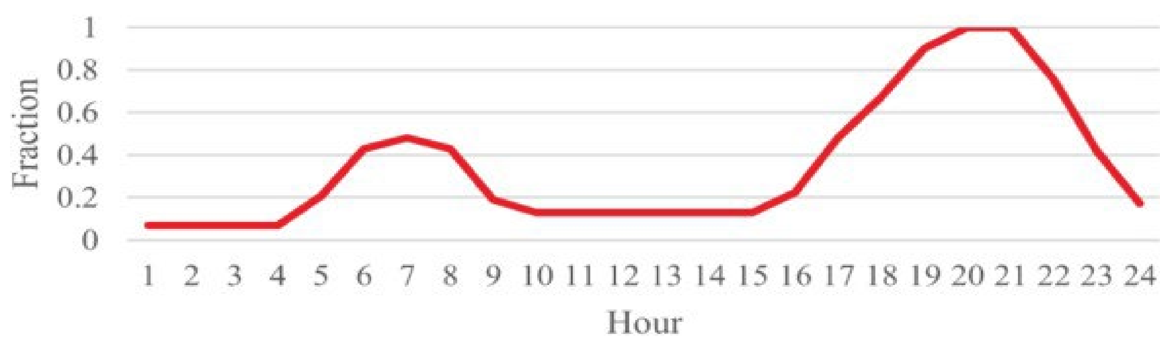
ENERGY-STAR-rated equipment is standard across Self-Help Enterprises (SHE) projects. Therefore, the analysis assumes ENERGY STAR-rated wattages for each appliance in the residential units. Assumed wattages are available from the ENERGY STAR database.

In the template design baseline, clothes washers and dryers are assumed to be one-per-unit, while in the proposed design, the team assumes two washer/dryers per floor of each building.

Interior Lights

A lighting power density of 0.55 W/ft^2 was applied to each residential unit, following the daily profile shown in Figure A-3 below.

Figure A-3: Lighting Schedule



Source: Self-Help Enterprises

Systems

HVAC

A unitary air-to-air heat pump was built into each residential unit of the template design baseline energy model following the mechanical system shown in the Santa Fe Commons drawings. This was added using the HVAC Template feature, which allows for the specification of simple HVAC systems with automatically generated nodes. In this model, the team used the *HVACTemplate:System:UnitaryHeatPump:AirToAir* EnergyPlus object. The fields in Table A-4 were specified for the template design baseline, following the mechanical schedules in the Santa Fe Commons permit set.

Table A-4: Heat Pump Inputs

	One-Bedroom Unit	Two-Bedroom Unit	Three-Bedroom Unit
Cooling Coil Gross Rated Coefficient of Performance (converted from Energy Efficiency Ratio)	3.66	3.66	3.75
Heat Pump Heating Coil Rated Coefficient of Performance (converted from Heating Seasonal Performance Factor)	2.4	2.49	2.49
Supplemental Heating Coil Type	Electric	Electric	Electric

Source: Self-Help Enterprises

The proposed design replaces the unitary air-to-air heat pumps with ductless mini-split heat pumps.

In both the template design baseline and the proposed model, the team assumes that the ventilation added per residential unit was equal to the ventilation requirements provided in the 2022 California Building Energy Efficiency Standards Equation 160.2-B.

Water Heating

For the template design baseline, each residential unit includes a 50-gallon HPWH per the plumbing drawings of the Santa Fe Commons permit set. Since more detailed information was not available in this set, a Coefficient of Performance of 3 was assumed for the heat pump. For each unit, the clothes washer, dishwasher, sinks, showers, and baths were connected to the hot water loop.

For the proposed design, per-unit HPWHs are replaced by per-building centralized HPWHs with a storage tank and swing tank.

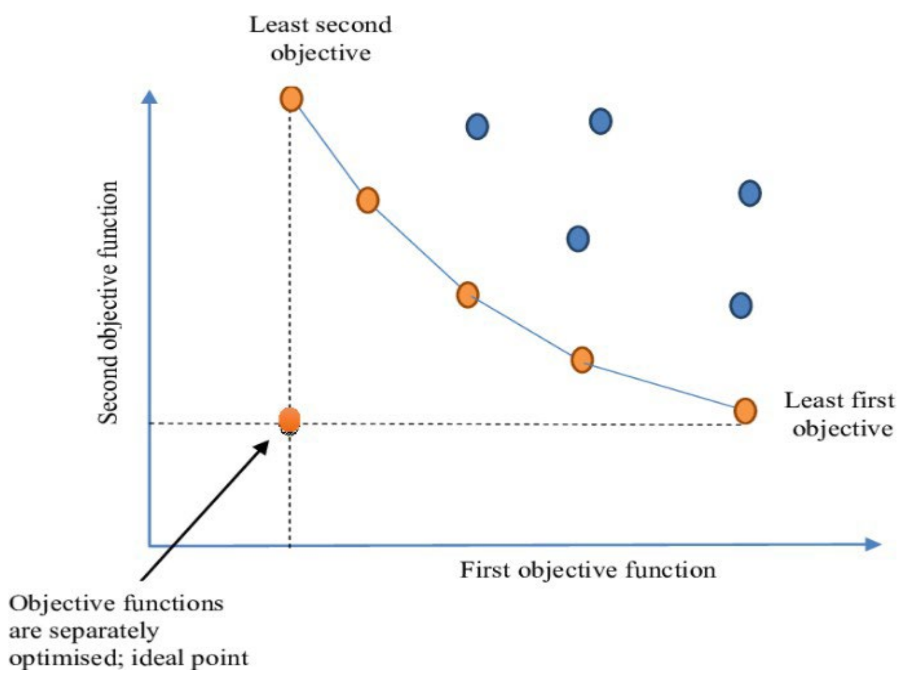
Genetic Algorithm

The team employed a genetic algorithm to pursue optimized combinations of design parameters that minimize capital cost, energy consumption, emissions, and operational cost. Genetic algorithms mimic the evolutionary selection process observed in nature, combining outcomes that represent "success" and rejecting solutions deemed "weaker." The algorithm also introduces random mutations to assess which otherwise unforeseen solutions may help further optimization. Such a workflow allows examination of a solution space that is far wider than could normally be studied through conventional modeling workflows and distilling a vast population of design packages into a human-comprehensible smaller set of solutions to be carried forward for subsequent study.

After a baseline EnergyPlus model was developed, each measure was correlated with a revision—either adding or removing additional EnergyPlus objects or editing values in existing objects. The algorithm then grouped measures into combinations, performing the requisite edits to the baseline EnergyPlus file as needed, before sending the model to a remote server for rapid simulation.

Model results were collected and compared with the goal of optimizing for two output parameters: capital cost and operational carbon. The team scrutinized the model output data and isolated a two-dimensional Pareto front, which represents the set of solutions that yield the most optimal results for the two chosen output parameters. Figure A-4 shows the curve of a Pareto front where solutions are optimized against two objectives. Any of the points shown in orange can be considered a "best" solution, as there are no other solutions that perform better than the orange points in both dimensions.

Figure A-4: Genetic Algorithm Pareto Front



Source: Alinezhad, Alireza, Abolfazi Kazemi, and Mojgan Khorasani (2019).

Genetic Algorithm Optimization Parameters

While there are several parameters of interest, the Genetic Algorithm process currently limits users to a two-dimensional optimization. Operational carbon and capital cost were identified as the two most important parameters to optimize against. Other parameters were tracked so they could be evaluated, but these were not optimized against. Table A-5 lists parameters generated for each ECM bundle.

Table A-5: ECM Bundle Parameters

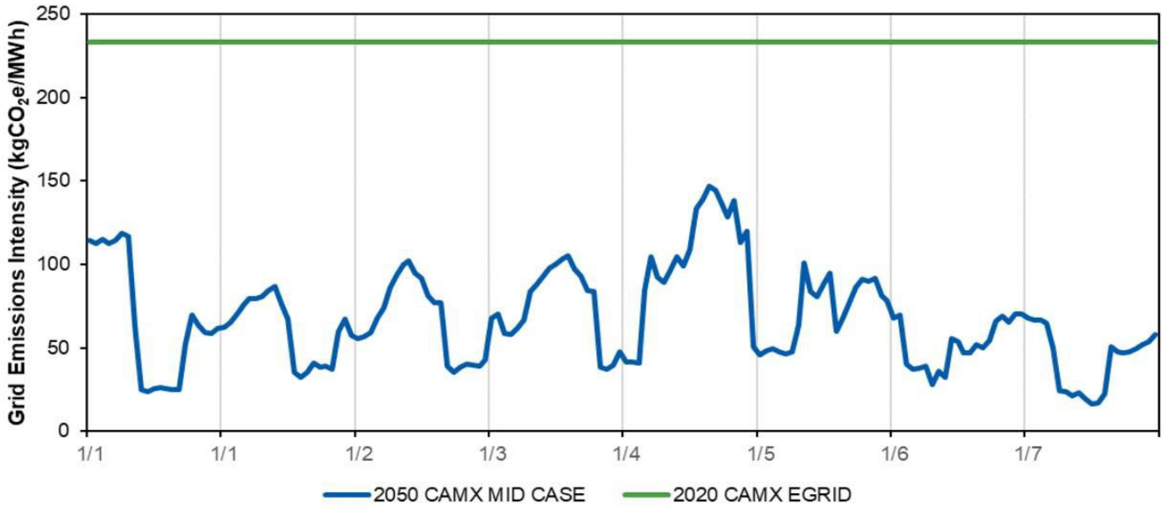
	Parameter	Description
Optimized	Operational Carbon ($kgCO_2e$)	Annual operational carbon emissions, calculated with the annual energy usage and the 2022 grid emissions factors for the California and Mexico region (CAMx)
Optimized	Operational Cost (USD)	Sum of cost scores applied to each individual ECM in a bundle. Cost scores are rough order of magnitude estimates that represent the cost delta between the ECM and the template design baseline system.
Tracked	Total Annual Energy (MBtu)	Annual site energy use
Tracked	TDV Energy (MBtu)	Time dependent valuation (TDV) is a metric that adjusts energy use depending on the impact of that use during a given hour of the year. CZ13 TDV (residential 30-year) values are used.
Tracked	2050 Operational Carbon ($kgCO_2e$)	Annual operational carbon emissions, calculated with the annual energy usage and the 2050 "Mid-case" emissions factors for CAMx
Tracked	Operational Cost (USD)	Calculated based on current Southern California Edison GS- TOU-D rate schedules
Tracked	Embodied Carbon ($kgCO_2e$)	Sum of embodied scores applied to each individual ECM in a bundle. Embodied carbon scores are qualitative and ranked on a scale of one to five, where one represents high savings, three represents no change from the baseline, and five represents high added embodied carbon.
Tracked	Replicability	Average of replicability scores applied to each ECM in a bundle. Replicability scores are qualitative and ranked on a scale from one to five. One represents ECMs that are hard to replicate on future projects, and five represents ECMs that are easy to replicate on future projects.

Source: Self-Help Enterprises

Carbon Data

Carbon emissions data were taken from the National Renewable Energy Lab Cambium dataset. While eGrid data from the Environmental Protection Agency are frequently used for emissions studies, the Cambium dataset accounts for grid emissions fluctuations in time and the impacts of grid emissions policy in the future and is therefore more accurate. This improved accuracy is shown in Figure A-5. Both eGrid and Cambium subdivide the contiguous United States into the same set of generation and emissions assessment regions (Generation and Emission Assessment regions). This study has pulled from the California and Mexico region (CAMx), which includes Visalia.

Figure A-5: Hourly Grid Carbon Intensity (January Week) eGrid versus Cambium



Source: Self-Help Enterprises

There are several datasets available for the CAMx region that attempt to account for future changes in California's grid emissions profile as more renewable energy is added (among other changes). This study relies on the "Mid-case" for both 2022 and 2050. The "Mid-case" assumes existing policies as of June 2021 with no additional carbon-related policy for the power sector before 2050. This study also pulls the carbon dioxide equivalent data from Cambium, which considers methane and nitrous oxide in addition to carbon dioxide.

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix B: Life Cycle Cost Assessment Methods and Assumptions

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APPENDIX B:
Life Cycle Cost Assessment Methods and Assumptions

Energy Conservation Measures and Embodied Carbon Reduction Strategies

The Energy and Emissions Workbook documents the modeling work undertaken in EnergyPlus and EnergyPro to capture the performance of the set of ECMs included in the design. That set of ECMs has also been evaluated for this analysis and includes:

- Ductless mini-split air-to-air heat pump,
- ERV with economizer mode (per unit),
- Centralized hot water and laundry facilities,
- Smart thermostat,
- Smart ceiling fans,
- ERVs with economizer mode,
- Solar panels on the roof connected to batteries, and
- Bio-based continuous exterior insulation.

In addition to accounting for the ECMs listed above, this analysis also accounts for embodied carbon reductions achieved through material selection, including:

- Low-carbon concrete (including slabs, footings, and site concrete),
- Lime-stabilized earth block wall, and
- Thermally stabilized wood siding.

Energy and Cost Estimation

These ECMs and strategies are included in the basis of design documentation for 50 percent Construction Documents from which Ashwood Construction estimated construction pricing for the buildings that comprise the project. Solar and battery storage costs were provided by Gridscape and included an estimate of the Investment Tax Credit available to the project under the Inflation Reduction Act. This includes an estimated 40 percent savings for solar panel costs and 30 percent savings for battery energy storage costs.

Hourly energy modeling results for a single residential building generated operational energy costs, which were multiplied to represent the nine total buildings on the site. Sensitivity analysis previously conducted on the varying orientations across the site indicated that this is a reasonable approximation, with energy consumption varying less than five percent annually due to orientation. Operational costs for the residential units and central systems assume electricity is provided by Southern California Edison under the GS-2-TOU D rate structure, which features the rates in Table B-1.

Table B-1: Electricity Rate Structure

	Weekdays		Weekends	
	4:00 p.m.–9:00 p.m.	Other Hours	4:00 p.m.–9:00 p.m.	Other Hours
Summer (June to September)	$0.62/kWh	$0.24/kWh	$0.37/kWh	$0.24/kWh
Winter (all other months)	$0.57/kWh	$0.22/kWh	$0.57/kWh	$0.22/kWh

Source: Self-Help Enterprises

Maintenance costs are assumed to be similar between all non-HVAC and plumbing options with no incremental maintenance cost for ECMs relative to the baseline case. The lifecycle cost analysis for HVAC options included varying annual maintenance costs representing a typical average for servicing per unit. Where ducts were installed, duct cleaning costs were incorporated. Costs were based on the Whitestone Facility Maintenance and Repair Manual and industry average costs for HVAC maintenance personnel costs sourced from industry cost index data (Whitestone Facility Maintenance Manual and RS Means) and indexed to Visalia, California. These costs are shown in Table B-2.

Table B-2: Maintenance Activities and Associated Annual Costs

Activity	Annual Cost
Annual maintenance for ducted split unit	$1,800/building
Annual maintenance for ductless split system	$4,800/building
Duct cleaning	$6,000/building
Annual maintenance for unit-based 50-gallon electric HPWH	$1,000/building
Annual maintenance for centralized 250-gallon electric HPWH	$120/building

Source: Self-Help Enterprises

Replacement costs are based on a 30-year lifetime for major equipment and assume that 50 percent of the estimated mechanical and plumbing cost will be replaced at end of life, along with the entirety of the battery cost. This is based on typical conceptual estimating values assuming that initial capital costs include elements (for example, ducts, studs, and structural support) that will not be replaced as regularly as equipment and intended to capture the PV panels and batteries.

Labor and materials for replacement costs are assumed to escalate at three percent per year. Values are based on the requirements in the CEC guidance for lifecycle cost assessment.

Electricity cost is assumed to escalate annually at 1.6 percent, benchmarked as required for Southern California Edison in the CEC lifecycle cost guidance.

Carbon emissions associated with electricity consumption can also impact the financial performance of the project if priced according to the cost of carbon in the State of California. To account for carbon impact, results were tested with and without a cost of carbon associated. The cost of carbon was based on the White House Interagency Working Group on Social Cost of Greenhouse Gases Technical Support Document on Social Cost of Carbon, Methane, and Nitrous Oxide. Costs were assumed based on a three percent discount rate for 2023 through 2052.

To account for alternative potential investment opportunities lost due to the investment in higher capital energy conservation measures, a three percent discount rate has been applied. This is consistent with guidance in the CEC lifecycle cost assessment guidelines.

A 30-year period was used for analysis of lifecycle cost. This represents both a typical mortgage duration and a typical benchmark for lifecycle cost studies.

The analysis also assumes a 10 percent down payment, 0.6 percent mortgage fee, 5.0 percent mortgage interest rate, and a 1.6 percent tax escalation rate. The property tax rate in Visalia is 1.25 percent; however, SHE has historically had success filing for a Welfare Exemption. Once granted, the Welfare Exemption reduces the property tax burden to zero percent. Experience has indicated this exemption is granted in less than three months from project opening, so the zero percent tax rate has been assumed for the lifetime of the project. Electricity rates for the project assume NEM 3.0.

Lifecycle Cost Analysis

This report performs lifecycle cost analysis using Net Present Value (NPV) as the metric for measuring lifecycle cost. The NPV is calculated from the sum of the discounted yearly net values over the 30-year lifetime of the building according to the equation below.

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

The analysis compares NPV of the proposed design to that of the standard design. Annual costs include the cost of owning the residences for 30 years, the capital cost of equipment, the maintenance and replacement costs, and the utility bill payments for electricity.