CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Demonstration of Affordable, Comfortable, and Grid-Integrated Zero Net Energy Communities

March 2024 | CEC-500-2024-014

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ACKNOWLEDGEMENTS

EPRI would like to thank the countless people and organizations who supported the many aspects of this project:

- BIRA Energy: Rob Hammon, Karl Johnson, and Ian Hammon-Hogan
- EPRI: Erin Jones, Siva Sankaranarayanan, Evan Giarta, Deborah Becker, Andra Rogers, and Richard Motroni
- Fresno Housing Authority: Dave Brenner, Michael Duarte, Brandon Gonzalez, and Janelle Miller
- Gary Klein and Associates: Gary Klein
- iTron: Phani Pagadala
- Kliewer and Associates: Ron Kliewer
- LINC Housing: Michelle Tirto and Monica Mejia
- Livio (Formerly Aron Developers): Rob Dowling
- New Buildings Institute: Bryce Seymour and Emma Riccardi
- Occidental Analytical Group: Ahmed Abdullah
- Peter Turnbull and Associates: Peter Turnbull
- Resource Refocus: Anna Larue, Margaret Pigman, and Vrushali Mendon
- Southern California Edison: Jerine Ahmed and Mark Martinez
- TRC Engineers, Inc: David Douglass-Jaimes, Julianna Yun-Wei, and Abhijeet Pande
- UC Davis Energy and Efficiency Institute: Dave Vernon, Angela Sanguinetti, and Sarah Outcault

Finally, the project team would like to thank Adel Suleiman and Anthony Ng (California Energy Commission) for their support and guidance on this project.

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

California has taken the lead toward ambitious greenhouse gas emission reduction targets as the state tries to meet its overall decarbonization targets – achieving carbon neutrality by 2045. California has set objectives for new home construction to reach zero net energy targets by 2020. Electrification of space conditioning, water heating, and cooking are critical components toward building decarbonization. Understanding the holistic performance and adoption of these technologies in the development of future communities is critical to meet California's decarbonization and zero net energy targets. To help support this, construction of new low carbon/zero carbon residential communities that incorporate advanced energy efficiency, electrification, and renewable energy technologies could also result in considerable California ratepayer benefits, including reduction in greenhouse gas emissions and advancing California's labor workforce.

This project's main objective was to understand how the development and construction of zero net energy homes with energy-efficient measures could help achieve California's decarbonization goals by demonstrating that zero net energy home development can be cost- effective for builders, developers, and their customers and tenants. This project included investigating how zero net energy concepts, such as building electrification and on-site renewable energy, can be implemented as part of the normal workflow of housing development/construction. Four new residential communities were designed, built, and analyzed to understand how best to build new homes in California to meet California's energy targets. This project included both market-rate and affordable housing communities, small- scale and larger-scale developments, and installations designed for various California regions. Results from this project include the positive economic and non-energy benefit impacts but also challenges with workforce availability and potential considerations to avoid energy burden for California's disadvantaged communities. Data from this project is also intended to help inform future California building codes and other energy stakeholders and developers interested in developing zero net energy communities.

Keywords: Zero net energy communities, building electrification, energy efficiency, building decarbonization

Please use the following citation for this report:

EPRI. 2023. *Demonstration of Affordable, Comfortable, and Grid-Integrated Zero Net Energy Communities*. California Energy Commission. Publication Number: CEC-500-2024-014.

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Background

California has taken the lead toward ambitious greenhouse gas emission reduction targets as the state tries to meet its overall decarbonization targets – achieving carbon neutrality by 2045. Residential and commercial buildings account for 25 percent of California's greenhouse gas emissions. To help address this large carbon emitting segment of California, improvements in new construction practices to design and construct low carbon/zero carbon communities along with the demonstration of advanced energy efficiency, electrification, and renewable energy technologies would result in considerable California ratepayer benefits, including reduction in greenhouse gas emissions and advancing California's labor workforce.

California has set objectives for new home construction to reach zero net energy targets by 2020 under the Energy Efficiency Strategic Plan. Electrification of space conditioning, water heating, and cooking are critical components toward building decarbonization. Energy-efficient solutions include heat-pumps for space conditioning and water heating, heat pump dryers, and induction cooktops. Understanding the holistic performance and adoption of these technologies in the development of future communities is critical to meet California's decarbonization and zero net energy targets.

This project's main objective was to understand how the development and construction of zero net energy homes with energy-efficient measures could help achieve California's decarbonization goals. Results from this project include the positive economic and non-energy benefit impacts but also challenges with workforce availability and potential considerations to avoid energy burden for California's disadvantaged communities. Data from this project is also intended to help inform future California building codes and other energy stakeholders and developers interested in developing zero net energy communities.

Project Purpose and Approach

To help support California meet its zero net energy targets, the project's main goal was to work with homebuilders, developers, and other residential construction industry stakeholders to design, develop, construct, sell, and occupy zero net energy communities across the state. This demonstration project sought to:

- **Design and construct four zero net energy communities** in different California climate zones.
- **Incorporate building electrification and renewable energy** as key components in the community design and construction.
- **Collect data** to better understand homebuyer and tenant perceptions of zero net energy communities and to understand actual energy usage of these communities and the building technologies that comprise them.

- **Engage in multi-stakeholder knowledge transfer** to ensure learnings and information are shared with different energy stakeholders in California and across the country.

Four new residential communities were designed, built, and analyzed to understand how best to design, develop, and construct new homes in California to meet California's energy targets. This project included both market-rate and affordable housing communities, small-scale and larger-scale developments, and installations designed for various California regions. Community design and construction activities were conducted with both large and small builders to establish current feasibility, familiarity, and comfort with zero net energy construction practices and approaches.

The project emphasized incorporating zero net energy concepts such as building electrification and on-site renewable energy into the normal workflow of housing development/construction. The intent was to demonstrate that zero net energy home development can be cost-effective for builders, developers, and their customers and tenants. Each community's project activity focused on:

- Cost-effective zero net energy communities design,
- Construction, customer adoption and/or onboarding
- Data acquisition, measurement and verification, and customer education
- Knowledge and technology transfer

Training market participants – builders, developers, tradespeople, community managers, and salespeople – to (minimally) assess and (ideally) enable zero net energy community market acceptance and increase stakeholder comfort with the advanced technology solutions applied for zero net energy home design proved to be feasible but challenging. This was challenging because California building codes evolved throughout the project's period of performance. The project adapted and refined the project objectives to maximize the effectiveness of the demonstration efforts while still retaining sight of the project's key objectives. Because each community has unique characteristics, piloting at multiple communities illustrated the variety of pathways to successful net-zero implementation.

Key Results

The project involved collecting both quantitative and qualitative data to understand opportunities and challenges for scaling up solutions that enable zero net energy communities in California. Energy consumption, carbon impacts, and energy bills were all analyzed through data collected from the project sites, including customer and occupant perceptions. The main results of this effort are summarized below:

- **Construction:**
    - Zero net energy communities are technically feasible and can be built at cost parity – potentially even more cost competitive than dual fuel alternatives.
    - Available construction trades and trade acceptance (critical for adoption) were limited – proper workforce development and training are still needed.

- **Homebuyer and Renter Perceptions:**
  - Zero net energy communities provide features that appeal to homebuyers and renters.
  - Non-energy factors are still main drivers of overall homebuyer and renter decisions.
  - Education on costs and benefits of zero net energy communities and building electrification technologies could help drive stronger market pull for these communities.
- **Data Analysis from Operational Data from Zero Net Energy Communities:** While, in general, the deployment of advanced electrification technologies when deployed as a "zero net energy system" shows overall bill savings compared to a dual-fuel California home, there are instances where electrification could have negative impacts on the occupant or whomever pays for the energy bill. It is important to continue to gather operational data to better help stakeholders understand what technologies and features of community development are impacting energy consumption. Tighter coordination is needed to improve design, planning, and interconnecting distributed energy resources such as rooftop solar and storage. Rate structures need to be assessed so that unintended energy burden is not placed on disadvantaged communities in California's transition to electrification.

Knowledge Transfer and Next Steps

Knowledge Transfer

This project conducted several activities to disseminate overall results, gathering insights from stakeholders to recognize where benefits and challenges with zero net energy was critical to the project. Each of the four communities had a unique mix of stakeholders. The six key knowledge transfer channels were:

- **Public technology transfer:** Press releases and public media events to draw attention to these energy-efficient communities.
- **Occupant technology transfer:** Surveys at the low-income multifamily housing developments.
- **Presentations and workshops:** Presentations and workshops to the state and national audience that addressed key elements for building electrification construction.
- **Technical advisory committee:** Multi-stakeholder peer advisory sessions for project technical feedback.
- **Industry roadmapping activities:** Identified key elements of a roadmap for a low-carbon future in buildings through surveys, interviews, and technical analysis.
- **Available resources and tools:** Provided accessible information on electrification and low-carbon building developments and retrofits.

Next Steps

This project demonstrated that while technically feasible and many times cost competitive to design, develop, and construct zero net energy communities, it will be important to do so in a way that does not result in negative impacts to the quality of life for California's residents and workforce. The following are the recommended next steps for deploying California's future zero net energy communities:

- Ensure that California's electrification and decarbonization efforts do not have unintended consequences such as increased energy burden – especially for California's disadvantaged communities.
- Consider the importance of energy and rate plans for zero net energy.
- Streamline interconnection processes of distributed energy resources.
- Advance training of California's construction workforce to deploy, commission, and maintain building electrification technologies.
- Right size California's grid, with a focus on affordability.
- Educate stakeholders of the value of zero net energy communities through continued collection of standardized operational data from zero net energy community projects.

CHAPTER 1: Introduction

California has taken the lead toward ambitious greenhouse gas (GHG) emission reduction targets[1] – achieving carbon neutrality by 2045.[2] Residential and commercial buildings account for 25 percent of California's GHG emissions.[3] This constitutes one of the highest carbon emitting industries in the state making it an important area to address to meet the state's decarbonization targets. Under the Energy Efficiency Strategic Plan, the state set objectives for new home construction to be built to zero net energy (ZNE) standards by 2020.[4,5] Previous work in this space found that in first-time homebuyer communities, market uptake was found to be satisfactory, indicating a high potential for reaching target energy use reductions.

Improvements in new construction practices to design and construct low carbon/zero carbon communities along with the demonstration of advanced energy efficiency, electrification, and renewable energy technologies would result in considerable California ratepayer benefits. These include reduction in GHG emissions and advancing California's labor workforce. Electrification of space conditioning, water heating, and cooking are critical components towards building decarbonization. In 2023, California announced a partnership with the world's 10 leading manufacturers of heating and cooling equipment to help support the deployment of 6 million heat pumps in California by 2030.[6] Energy-efficient electric cooking such as induction cooktops and laundry equipment such as heat pump dryers are also a key component for developing ZNE communities. Figure 1 shows an induction cooktop and heat pump dryers installed in an all-electric, ZNE community in Irvine, California.

[1] 2022. AB-1279 the California Climate Crisis Act. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1279. California Legislative Information.

[2] 2018. Executive Order B-55-18 to Achieve Carbon Neutrality., https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf. Executive Department, State of California.

[3] 2021. Assembly Bill 3232 and the California Building Decarbonization Assessment. https://www.energy.ca.gov/sites/default/files/2021-08/AB3232_Building_Decarbonization_Assessment_Factsheet_ADA.pdf. California Energy Commission.

[4] 2008. Energy Efficiency Strategic Plan. https://www.cpuc.ca.gov/-/media/cpuc-website/files/legacyfiles/e/5304-eesp-onepager.pdf; California Public Utilities Commission.

[5] EPRI. 2016. Grid Integration of Zero Net Energy Communities. Grid Integration of Zero Net Energy Communities: 3002009242. https://www.epri.com/research/products/3002009242. EPRI.

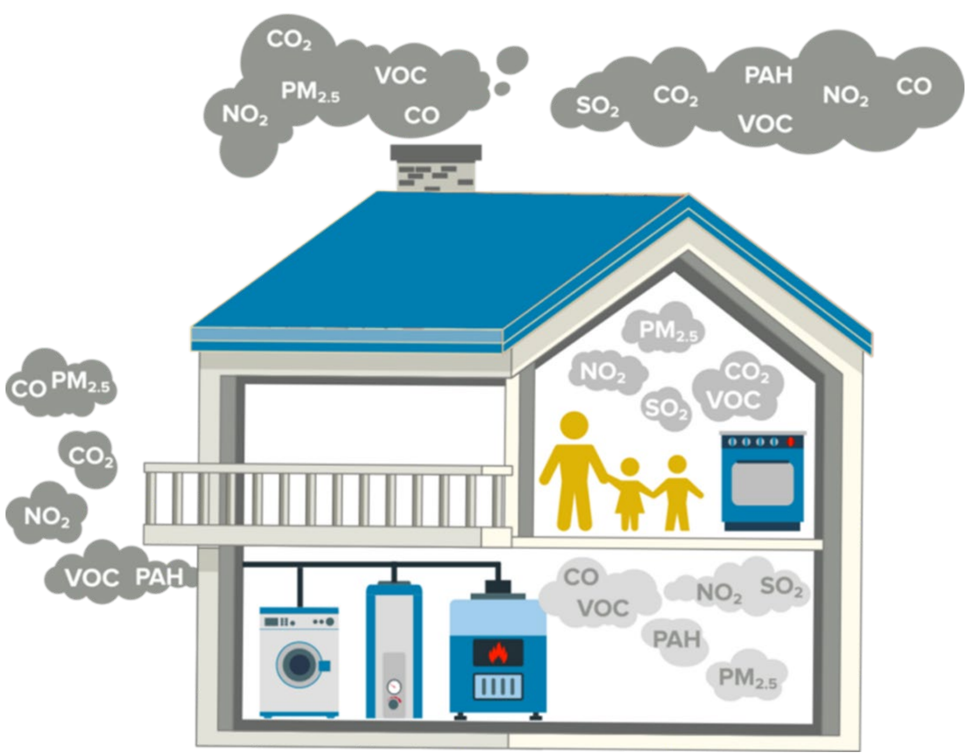
[6] 2023. Top Global Building Appliance Manufacturers and Distributers Commit to Help California Achieve Six Million Heat Pump Goal. https://www.energy.ca.gov/news/2023-10/top-global-building-appliance-manufacturers-and-distributors-commit-help#:~:text=SACRAMENTO%20%E2%80%94%20Today%2C%2010%20of%20the,heat%20pumps%20installed%20by%202030%20. California Energy Commission.

Figure 1: Induction Cooktop (Left) and Heat Pump Dryer (Right) Installed in All-Electric, Zero Net Energy Community in Irvine, California

Source: EPRI

Part of the momentum steering electrification forward is the increasing number of studies that show how end-use technologies energized by natural gas result in economic, indoor air quality, and health impacts. See Figure 2 for depiction of harmful pollutants released by natural gas-powered appliances (Fresh Energy, 2023).

Figure 2: Pollutants Released by Natural Gas-Powered Household Appliances



Source: Fresh Energy

While construction of new ZNE communities through building electrification is technically feasible, and there are market pulls and policy pushes to support its deployment, there are considerable hurdles the industry still faces to all-electric, ZNE homes.

- First, there is an overall construction workforce shortage. In a 2018 survey, the Association of General Contractors of America identified that[7] electrification faces considerable challenges. As University of California Census and California Department of Industry Relations data in 2021 shows, there is only one licensed electrician for every 478 housing units in California.[8] Lack of qualified workforce for existing construction needs makes it challenging to consider advanced construction approaches.
- Second is the lack of operational data and information of how advanced building electrification technologies are performing. While many organizations and industries now have sustainability and/or decarbonization metrics as part of their corporate key performance indices (KPI)s, lack of transparent information provided to key stakeholders makes it difficult for them to develop the necessary infrastructure to source, construct, and maintain these advanced construction practices.
- Finally, there is a concern that building electrification may put an unnecessary energy burden on California residents – especially in California's disadvantaged communities. This is caused by a combination of factors, including cost to upgrade building and utility infrastructure to electrify buildings and communities. More information is needed to understand how to construct buildings and communities in a manner that does not inadvertently burden certain California residents.

To support California toward its ZNE targets, this project's main objective was to work with homebuilders, developers, and other residential construction industry stakeholders to design, develop, construct, and occupy ZNE communities across the state. This demonstration project had four main objectives.

- **Design and construct four (4) ZNE communities** Four ZNE communities across the state were designed in a manner that showed cost-competitiveness to traditional builder developer approaches. Three builders and developers, two focused on affordable housing developments, were part of this project.
- **Incorporate Building Electrification and Renewable Energy:** The project worked with community stakeholders to assess feasibility of electrifying building technologies as well as deployment of distributed energy resources (DER) such as rooftop photovoltaic systems (PV) and customer-sited battery storage technologies.
- **Collect Data:** The project collected a combination of qualitative data and quantitative data to better understand: (1) homebuyer perceptions of ZNE communities, (2) tenant

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[7] 2018. 2018 Workforce Survey Results. https://www.agc.org/sites/default/files/Files/Communications/2018_Workforce_Survey_California.pdf. AGC of America.

[8] Pontecorvo, Emily. 2023. To get off fossil fuels, America is going to need a lot more electricians. https://grist.org/energy/electrician-shortage-electrify-everything-climate-infrastructure-labor/. Grist.

perceptions of first occupying ZNE communities, and (3) understand actual energy performance of ZNE communities and the building technologies that comprise them.

- **Engage in Multistakeholder Knowledge Transfer:** Multiple communities that span different California climate zones and utility service territories helped this project to gain a better understanding on issues and challenges for scaling-up ZNE community development. As a result, various knowledge transfer tools were assessed and developed as part of this project.

Through these main tasks, the project sought to bridge the gaps needed for developing approaches to scale-up ZNE new construction in California.

CHAPTER 2:
Project Approach

To achieve the project goals, four new residential communities were designed, built, and analyzed to understand how best to design and construct new homes in California. Two communities are multi-family residential units in Southern California designed to serve low-income families – with one of the communities serving people emerging from homelessness. The third community is a mixed-used, all-electric neighborhood revitalization project also serving disadvantaged communities in California's Central Valley. The fourth community, located in the San Francisco Bay Area, provides insights into the design and implementation of ZNE in the small, market-rate custom homebuilder's space. See Figure 3 for a picture of each of the four ZNE-ready communities.

Figure 3: Zero Net Energy Communities Constructed as Part of This Project

Belmont Community - Talbryn Drive

Compton Community- Nightingale

Pomona Community- Mosaic Gardens

Fresno Community- Monarch

Source: EPRI

Table 1 provides additional details about the project sites.

Table 1: Zero Net Energy Community Site Summaries

Project Location	Community Name	California Climate Zone	Construction Completed	Community Summary
Fresno	Monarch	13	2022	All-electric, mixed-use community consisting of 57 affordable housing apartments (Studio to 3-bedroom) and approximately 4,700 square feet of retail space.
Pomona	Mosaic Gardens	9	2016	Multifamily affordable housing consisting of 46 apartments (1-3 bedrooms). Customer-sited battery storage to help support common area loads and rooftop solar.
Compton	Nightingale	8	2019	Multifamily affordable housing consisting of 29 primarily one-bedroom apartments.
Belmont	Talbryn	3	2020-2021	4 single-family custom homes with solar/battery storage.

These new construction communities were approved and permitted under different state building efficiency code (California Energy Commission [CEC] Title 24) cycles (2013, 2016, and 2019). The project worked with community builder/developer teams to focus on newer requirements, such as improved building envelopes, building electrification technologies, and inclusion of on-site distributed generation and DER.[9] In addition to the design, development, and deployment of ZNE communities, the project intended to collect operational data at these communities to assess actual versus intended energy performance as well as perceptions of living and buying ZNE communities.

The project leverages additional insights into building performance and customer behavior using other parallel, ongoing projects that the project team conducted. The result is a more comprehensive understanding of how best to scale ZNE communities in California, founded on both detailed qualitative and quantitative data on building performance and occupant preferences across communities. See Figure 4 for examples of parallel, supplemental ZNE communities leveraged by the project to gain better insights into scaling ZNE community approaches.

[9] The projects were approved in different CEC Title 24 Building Code cycles as the project identified sites that would meet the CEC project requirements and backup documentation within the grant period of performance.

Figure 4: Parallel EPRI Zero Net Energy and Building Electrification Projects Leveraged by this Project

All Electric ZNE Community in Irvine, CA	ZNE Single Family Community in Central Valley, CA	Affordable Multifamily Housing in Davis, CA

Source: EPRI

The four communities, listed in Table 1, represent four distinct California climate zones. The primary criterion for design of the communities was the use of energy efficiency measures to minimize the need for distributed generation resources such as solar and/or energy storage. High-efficiency energy principles were applied, including improvements to building envelopes, insulation, and high-efficiency window glazing. In addition, all four community designs considered electrification of space heating, water heating, and cooking to enable overall building decarbonization. All communities electrified space heating using advanced heating, ventilation, and air conditioning (HVAC) systems, efficient lighting, on-site solar PV, and efficient appliances. Two of the four communities also installed battery storage systems, primarily to enable grid and community resiliency.

Project Tasks and Approach

Achieving the project's goals required the education of market participants–builders, developers, tradespeople, community managers, and salespeople–to assess and ideally enable ZNE market acceptance and increase stakeholder comfort with the advanced technology solutions applied for ZNE design. To meet the project's overarching goal, four sets of specific project tasks were established, centered on the goal of demonstrating ZNE home development as a practical, cost-effective approach for builders, developers, and their customers and tenants. Throughout the project, and as California building codes evolved throughout the project's period of performance, the team adapted and refined the project objectives to maximize the effectiveness of the demonstration efforts while still retaining sight of the following four key project tasks:

Task 1: Design for Cost-Effective Zero Net Energy Homes and Communities

The project plan called for working with diverse stakeholders, namely builders, developers, contractors, architects, and other project members to create cost-effective ZNE communities and to demonstrate that ZNE-capable homes and communities could achieve cost equivalence *without solar PV*. In service of this goal, the following specific needs were recognized and addressed:

- Identify and manage barriers for scalability of not only ZNE, but also all-electric, low-carbon/zero-carbon communities
- Understand supporting infrastructure needed to adopt and scale communities
- Establish feasibility for both market-rate and disadvantaged communities
- Extend applicability to both single family and multifamily buildings

Task 2: Perform Community Design, Energy Modeling and Data Analysis to Understand Scalable Zero Net Energy Community Development Approaches

The project assessed multiple building technologies, current and emerging, and assessed approaches to implement most cost effective, scalable methods for achieving ZNE community development. A combination of metrics was evaluated, including costs and carbon impacts, to provide critical inputs for upcoming developments in new ZNE building codes. To perform this task, the project completed the following:

- Collaborated with builders, developers, tradespeople, emerging technology providers, and the utility industry to design ZNE homes and communities. A multistakeholder approach should help increase the probability that ZNE community design and development are both scalable and feasible.
- Conducted energy modeling to estimate performance of ZNE communities.
- Collected lessons learned of the various barriers, challenges, and opportunities for specifying, contracting, constructing, and commissioning ZNE communities, building electrification technologies, and DER.

Task 3: Evaluate the Operational Performance of Zero Net Energy Communities

Through data monitoring and customer satisfaction tracking, the project evaluated market interest and the home occupants' engagement with ZNE homes and building electrification technologies. Energy data was collected on all ZNE communities to better understand energy use patterns. To succeed in this area, the project conducted ongoing assessments of customer perceptions in each community for adopting efficient electrification technologies (for example, heat pump water heaters and induction cooktops) and extensive data monitoring.

Task 4: Planning, Operation, and Management of Energy Infrastructure around Zero Net Energy Communities

The project evaluated how DER, energy efficiency, and demand response systems are implemented together to energy ZNE communities in practice. Further, the project explored how connected end-use technologies, distributed solar, and residential battery storage can enable

ZNE communities through successful integration with the grid. Success in this task required the project to understand the following:

- Challenges that arise with interconnection and permitting of distributed solar and storage
- Feasibility and value of building flexibility obtained through connected technologies, distributed solar, and storage in decarbonized communities
- Continued understanding of energy system planning, permitting, and interconnection as codes move from ZNE metrics of time-dependent valuation (TDV) to total system benefit (TSB), such that efficient electrification provides a means for decarbonization

Project Milestones

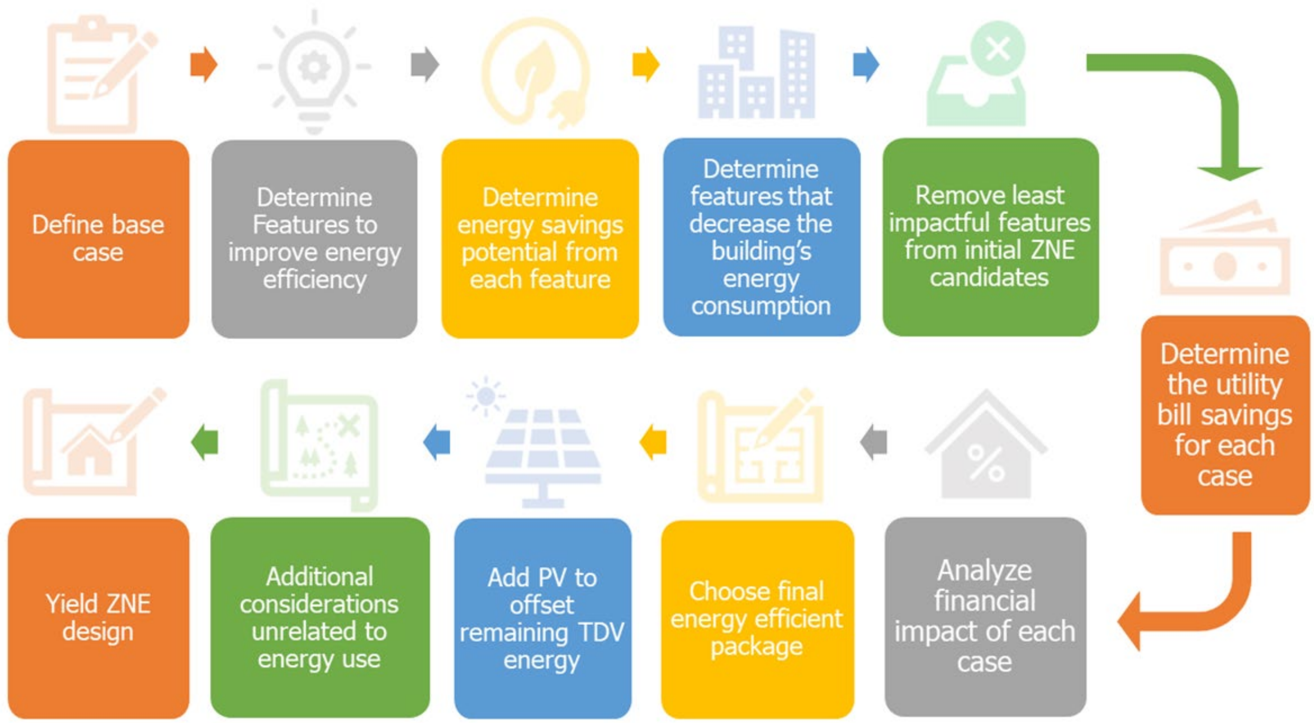
The project approach emphasized incorporating ZNE design into the normal workflow of housing development and construction in a variety of environments for new home communities. The project was organized into the following four distinct project milestones:

Milestone 1: Community Design

The project worked with community builders, developers, architects, and general building contractors to design ZNE homes for each community. Partnering with local utilities, the project used load profile models to anticipate energy system impacts for each community to minimize costs of electrifying these communities. In addition, the project developed building energy modeling packages to outline paths toward ZNE design. For instance, the energy modeling packages were used to analyze the tradeoffs between electric and gas appliances as well as identify the optimal set of DERs for each community.

The project recognized the challenges faced by the industry merging traditional home builder and developer design practices with energy efficiency, electrification, distributed generation, and other technology tools that builders and developers need to consider in developing ZNE/low carbon buildings and communities. To do this, a general workflow was used for identifying the most appropriate technologies to include in each building design.

Figure 5: Workflow Developed to Perform Zero Net Energy Community Design Milestone



Source: EPRI

Figure 5 illustrates the ZNE community design approach as a flowchart. In the first stages, a base case is defined, features that may improve energy efficiency are identified, and their energy savings potential is calculated. Features that improve the building's energy consumption become the initial set of ZNE technologies to consider. Value engineering activities are then conducted to engage all key stakeholder (developers, trades, and other community stakeholders) and ensure they weigh in on how feasible it is to support a shortlisted set of advanced building technologies before computing the cost savings to the customer for each option. Once the financial impacts are analyzed, a final set of features is defined, any essential considerations unrelated to energy use are addressed, and a final package is defined. At that point, PV can be added to offset any remaining energy use to yield a ZNE design.

The four communities followed this flowchart in different ways, guided by the timelines and necessities of each community and the point in the process at which the project entered the community development/construction cycle. At a high level, the process was aspirational, invoking collaborative concepts such as working with city planners to create energy-system-friendly communities. For example, when designing a multi-story building, a three-story home should not shade the PV on a neighboring two-story home. In addition, flat roofs are not the most requested option by potential homebuyers. However, west and/or south facing angled roofs that maximize solar energy generation would be ideal. City planning and customer needs took first priority. Delays in construction timelines took equal priority as the project was limited in its scope as some design choices would require additional project delays and costs such as re-permitting. However, opportunities remain in each situation, and new options arise to achieve ZNE. Where solar is not as cost effective, energy efficiency or improved energy control measures can boost building energy performance, thereby reducing the need for solar or other distributed generation sources. Overall, where compromises involved energy choices that were less impactful to the home buyer or home occupant (such as induction versus traditional electric cooktops), modest adjustments in other building factors can be made to compensate, such as adding more insulation or installing more efficient refrigerators.

The project had to "meet communities and community developers where they were" in the community development timeline/process to meet project requirements. The four communities were in differing levels of completion at the time this project commenced, impacting the decisions that could be made for each community without considerably impacting its project timeline and schedule. For example, the city had already approved key construction permits for the Compton community, including architectural design and mechanical, electrical, and plumbing layouts. In addition, they had already hired a general contractor with preferred trades and associated technology manufacturers. Revisiting technology selections would have considerably impacted the project schedule and budget. For example, while investigating the use of electric water heating systems in the Compton community, it was determined that a "drop-in" replacement for the previously specified centralized boiler system would have caused a considerable redesign in the existing plumbing and electrical specifications. As a result, timelines would have been drastically impacted by non-energy concerns such as established permitting processes, building loans, and other factors.

Both market rate and affordable housing development projects are subject to meeting timelines to enable profitability and/or secure the necessary financing, tax credits, and/or incentives that California developers need to consider and that facilitate community development. As the barriers and challenges discussed above, incentives, tax credits, and funding opportunities from utilities, local, state, and federal governments can significantly contribute to ZNE developments, especially ZNE affordable housing developments. For example, the Low-Income Housing Tax Credits, Affordable Housing and Sustainable Communities Strategies Program, Rental Assistance Demonstration (RAD) Green Incentive, and the Home Investments Partnerships Program (HOME) can help develop and preserve these communities, with RAD Green Incentive offering access for implementing green improvements. These types of initiatives aim to accelerate the development of clean, affordable, and reliable, ZNE housing. Utilities can also offer incentive programs to engage customers and builders into ZNE adoption, including but not limited to rebates and tax credits, net metering, alternative financing tools, and clean energy programs. In addition, there are several green financing programs to accelerate the development of ZNE residential communities, such as Freddie Mac/Fannie Mae and EaaS (Energy-as-a-Service) financing opportunities. What becomes challenging is that these incentives all have different requirements and timelines – putting a considerable amount of administrative overhead costs on a builder, developer, and/or other stakeholder that could benefit from these incentives. Therefore, it is common for builders and developers to not capitalize on potential incentives that are available to buy down the cost of advanced building technologies because of the time investment needed and a general shortage of industry workforce.

Milestone 2: Construction, Customer Adoption, and Onboarding of Zero Net Energy Communities

The builder and/or developer constructed, marketed, and sold (or occupied in the case of rental properties) the homes in the same manner as other homes and communities in their portfolios. Homeowners and/or occupants were informed of the features within their homes and the purpose of them. Working with the developers or the on-site project management staff, the project educated homeowners/tenants and gained their permission to collect information on their energy usage and experiences. The challenges associated with primary occupancy during the COVID-19 pandemic limited the personal interaction and onboarding that could be completed with occupants. To better understand the customer adoption and onboarding, the project solicited survey responses from residents at one of the low-income communities during the first days of occupancy and complemented this with similar work from another project. These surveys covered the community member's overall satisfaction, knowledge, education, attitudes, perceptions, and energy bills in their community. As for the construction adoption and onboarding, the project gathered information on developer experiences that focused on ZNE and other lower-carbon construction approaches. The project conducted workshops and interviews that brought together builders and stakeholders to discuss the perceived barriers, challenges encountered, and problem-solving approaches to help share results and lessons learned.

Milestone 3: Data Acquisition, Measurement and Verification, and Customer Education

The new homes were equipped with energy use monitoring systems capable of collecting energy information at the circuit level from each home. Onboarding and educational tools such as energy dashboards were also discussed and used if/when possible. Smart home features or energy management system features provided by technologies were also used to provide additional insights. For additional information on data acquisition and measurement and verification (M&V) plan, please see the project's *Supplemental Document – Measurement and Verification Plan.*

Milestone 4: Knowledge and Technology Transfer

This project conducted several activities to disseminate overall results, gathering insights from stakeholders to recognize where benefits and challenges with ZNE was critical to the project. Each of the four communities had a unique mix of stakeholders. The six key knowledge transfer channels were:

- **Public technology transfer:** Press releases and public media events to draw attention to these energy-efficient communities.
- **Occupant technology transfer:** Surveys at the low-income multifamily housing developments.
- **Presentations and workshops:** Presentations and workshops to the state and national audience that addressed key elements for building electrification construction.

- **Technical advisory committee (TAC):** Multi-stakeholder peer advisory sessions for project technical feedback.
- **Industry roadmapping activities:** Identified key elements of a roadmap for a low-carbon future in buildings through surveys, interviews, and technical analysis.
- **Available resources and tools:** Provided accessible information on electrification and low-carbon building developments and retrofits.

For additional information on knowledge and technology transfer, plans and activities, please see the project's *Supplemental Document – Technology Transfer Plan and Results.*

In each of the four project milestones, the project informed builders, developers, and/or prospective and actual residents, facilitated the incorporation of energy-efficient, low-carbon features, and learned how residents used those features in practice. Before and during this project, the project team demonstrated affordability for homeowners, profitability—at scale—for home builders, and successful grid integration of ZNE communities for electric utilities. Thus, this achieved one of the project goals to educate new home market stakeholders on the delivery of higher energy efficiency homes with lower GHG emissions.

The project deployed several key elements in this project to build confidence in the new ZNE approaches. New technologies were incorporated to show that many of these technologies, such as advanced heat pump systems, likely to be required under new codes, can operate successfully. This helped support trade familiarity of installing, commissioning, and maintaining these systems—something that was appreciated by builders and developers that were part of this project. By working directly with building industry professionals, results and insights from the project enabled optimized designs for ZNE communities while meeting current ZNE goals and driving further toward decarbonization by looking at where Title 24 building codes are looking to go. Because each community has unique characteristics, piloting at multiple different communities demonstrated the variety of pathways that can be taken enroute to successful net-zero implementation.

While the project was intended to encompass the process of designing, developing, and deploying ZNE communities with an eye toward low carbon/zero carbon communities, all of the communities experienced technical, financial, and timing considerations to align with the project timeline. As a result, the project pivoted in response to these challenges while ensuring that overall goals and requirements were achieved. For additional information on how the project made pivots due to these challenges, see Appendix A.

CHAPTER 3: Results

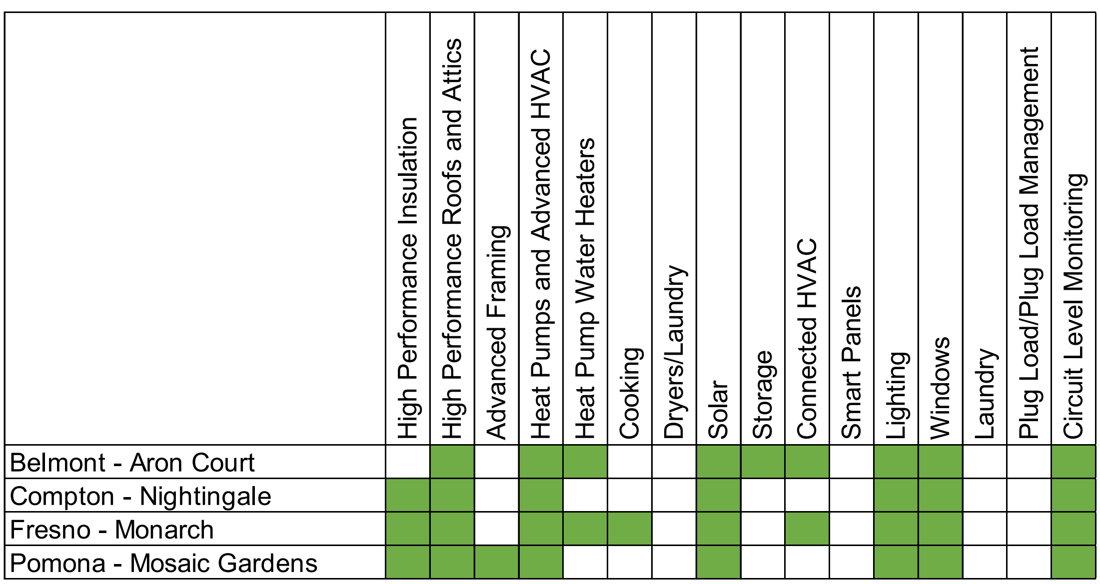
A key component of this project was the collection of both quantitative and qualitative data to understand opportunities and challenges for scaling-up solutions that enable ZNE communities in California. Energy consumption, carbon impacts, and energy bills were all analyzed through data collected from the project sites, including customer and occupant perceptions. Results are divided into the three sections below. For additional information of approach and methodology, please see *Supplemental Document – Measurement and Verification Plan.*

1. Lessons learned from ZNE community design and construction,
2. Customer perception of buying and renting ZNE communities, and
3. Results from quantitative energy data collected from newly constructed ZNE communities.

Lessons Learned from Zero Net Energy Community Design and Construction

The project was able to successfully design and construct ZNE communities across the state of California. Working with diverse stakeholders throughout this process at various periods of the design and construction process provided an insightful set of lessons learned, opportunities and challenges, for designing and constructing ZNE communities across the state. For technologies installed and technologies considered see Appendix B. For advanced end-use technologies deployed at each project ZNE community, see Figure 6 and Table 2. For additional information, please see *Supplemental Document - Designing and Constructing Zero Net Energy Communities* for additional information on the lessons learned.

Figure 6: Technology Classes Deployed as Part of Each Project Community



Source: EPRI

Table 2: Technology Deployment Summary to Zero Net Energy Communities

Community	Technology Deployment Summary
Belmont – Aron Court	Space heating and water heating were electrified with a two-stage heat pump and a connected heat pump water heater. Modular steel framing was considered but left off the final design because of costs. Residential storage and solar was also deployed.
Compton – Nightingale	Solar and high-efficiency HVAC and insulation. A centralized heat pump water heater was considered, but no drop-in replacements for a centralized boiler were available.
Fresno – Monarch	Space conditioning is a centralized VRF system. Water heating is a centralized heat pump water heater. High-efficiency insulation through spray foam insulation. Solar array and advanced window shading/glazing approaches.
Pomona – Mosaic Gardens	Space Conditioning is a high efficiency mini-split system. High efficiency spray foam insulation. Solar array and advanced window glazing.

Source: EPRI

See below for the main takeaways.

- Enabling an all-electric community is materialized by factors other than energy savings: non-energy benefits such as safety, personal comfort, and improved indoor air quality may support buyer adoption while other family priorities or lifestyle preferences such as desire for community amenities and limited comparable efficient electric technology options may pose challenges.
- The commercial availability of newer technologies, such as variable-speed heat pump systems, relied on skilled installers being able and willing to seek certification for installing that equipment. This is challenging to justify when the construction industry is experiencing a labor shortage—especially skilled trades.
- Using energy storage to supplement on-site solar generation and support a building's ZNE, electrification and/or decarbonization goals may be complicated and delayed because of needs to obtain utility and other Authorities Having Jurisdiction (AHJ) approvals. Utility interconnection approvals can take longer than expected which can create higher than expected initial utility bills due to the PV and/or battery energy storage system (BESS) not operational upon home occupancy.
- Incorporating passive energy efficiency measures such as low-emissivity glazing, vapor barriers, and insulation is effective, widely accepted, and may compensate for not implementing other more-advanced technology options. These passive measures also provide non-energy benefits such as improved indoor air quality.
- Effective implementation of ZNE measures such as advanced building electrification technologies or distributed generation should consider builders' costs for delays incurred

in the construction process, as builders' operations are subject to significant carryover costs throughout the cycle of planning, designing, building, and marketing new homes.

- Small-scale builders face additional barriers to ZNE community development, while large-scale builders can leverage a broader financial base and market power to attract financing and secure skilled labor and better prices on equipment.
- Added operation and maintenance (O&M) costs may be incurred to maintain and manage newer equipment. Specific training or a different skill set for on-site maintenance staff may be required to support the equipment.

Customer and Occupant Perceptions of Zero Net Energy Communities

To better understand customer perceptions of ZNE communities and efficient electrification technologies that comprise them, the project conducted several surveying activities to gain better insights on how potential homebuyers and renters perceived buying and living in ZNE communities in California. See Table 3 for three main objectives and steps this project took to fulfill this task.

Table 3: Main Objectives and Approach for Determining Stakeholder Perceptions of Zero Net Energy Communities

Objective	Approach
Understand homebuyer's first impressions and decision factors for buying ZNE homes	Surveying potential and actual homebuyers of California ZNE sites. Emphasis on homebuyer perceptions about electrification technologies such as heat pumps, induction cooktops, and heat pump dryers.
Understand occupant's first impressions when moving into ZNE communities	As this project transformed from market-rate sold communities to focusing primarily on multifamily rental communities (three are in disadvantaged communities in the State of California), the project surveyed community occupants at the time of first occupancy to understand their perceptions of these homes—with specific emphasis on perceptions of energy efficiency and building electrification technologies.
Perceptions of builders, contractors, and trades when designing, constraining, and maintaining ZNE communities	As building electrification interest increased in the industry during this project's period of performance, the project documented observations and lessons learned working with builders, contractors and trades who were brought in to support ZNE community construction as part of this project and in California.

See below for main takeaways divided into specific stakeholders. For additional information, please see *Supplemental Document - Customer and Occupant Perceptions of Zero Net Energy Communities* for a deeper dive into the insights.

Homebuyer Perceptions of Zero Net Energy Communities

Homebuyers were generally receptive toward understanding how advanced building electrification technologies could potentially provide consumer benefits. Through activities such as learning centers (See Figure 7), lunch and learns, and media articles, and interviews prospective homebuyers of California ZNE communities, the following main opportunities and challenges were identified.

Figure 7: Learning Centers Developed for Zero Net Energy Community and Technology Education

Source: DeYoung Properties

Opportunities for Scaling-Up Zero Net Energy Communities

- **Opportunity 1 – Zero Net Energy Communities Perceivably Provide Improved Indoor Air Quality and Safety:** During one tour of a ZNE community in Southern California, one prospective homebuyer noticed the difference in outdoor noise[10] compared to a community next door. Due to improved insulation, homebuyers perceive a sense of increase safety as they do not hear outdoor conditions. Technologies such as induction cooktops also provide increased family safety features. The induction cooktops' heating element directly heats cookware when in contact versus traditional cooking uses methods that heat ambient conditions around it. Induction cooking methods minimizes the opportunity for people, especially children, to get burned from touching hot things in the kitchen. This is especially important to families with small

[10] The community is built by an airport so outdoor noise is considerable.

children. Finally, studies show that electrification provides improved indoor air quality.[11] Messages around improved indoor air quality resonate especially for people with family members that have respiratory illnesses and/or Californians who have been impacted by air quality issues associated with wildfires or busy transportation corridors.

- **Opportunity 2 - Low-Risk Opportunities for Trialing Technologies as well as Instructional Demonstrations:** This project's knowledge transfer activities provided utilities ways to identify how people could get over their hesitation to adopt advanced electric technologies such as induction cooktops. Such programs included enlisting interested customers in trial induction cooktops and inviting celebrity chefs at events to show benefits of induction cooking.[12]
- **Opportunity 3 – Heat Pumps and Other Zero-Net-Energy Technologies do not Compromise Home Quality and Many Believe it Increased Home Quality:** One historic issue over electrification was that heat pumps and heat pump technology would compromise home performance. This is based on a perception that heat pumps do not work in cold weather and heat pump dryers leave clothes damp. However, lessons from this project showed that many prospective homebuyers believed that heat pumps and heat pump water heaters do not compromise home quality and even some prospective homebuyers requested to have heat pump technology.

Challenges for Scaling-Up Zero Net Energy Communities

- **Challenge 1 – Other factors more important than energy and energy costs:** While reduction in energy costs associated with investing in zero net energy communities are a potential benefit, many new homebuyers are still selecting homes for traditional non-energy reasons. Factors such as school districts, closeness to work, and desired floor plans still carry higher weight in buyers' minds than energy-related features and functions.
- **Challenge 2 – Homebuyers unsure of return on investment on zero net energy and building electrification technologies:** Many studies show how energy efficiency and rooftop solar offer potential value as critical components of California zero net energy communities[13,14,15] However, California homebuyers are still unsure over the return of investment for ZNE and electrification.

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[11] Barron, Manuel; Maximo Torero. 2016. Household electrification and indoor air pollution. https://www.ocf.berkeley.edu/~manuelb/Research/IAP/IAP-Jul2017.pdf. Journal of Environmental Economics and Management (2017).

[12] N.d. PG&E Induction Cooktop Loaner Program. https://pge-induction.myturn.com/library/. PG&E.

[13] Kahn, Matthew; Nils Kok. 2014. The capitalization of green labels in the California housing market. https://www.sciencedirect.com/science/article/abs/pii/S0166046213000574. Regional Science and Urban Economics.

[14] Argento, Robert; Xian Fang Bak; Lariece Brown. n.d. Energy Efficiency: Value Added to Properties & Loan Performance. https://sf.freddiemac.com/docs/pdf/fact-sheet/energy_efficiency_white_paper.pdf. Freddie Mac.

[15] Mikhitarian, Sara. 2019. Homes with Solar Panels Sell for 4.1% More. https://www.zillow.com/research/solar-panels-house-sell-more-23798/. Zillow.

- **Challenge 3 – There is an emotional attachment to gas cooking appliances:** While considerable benefits are associated with electrification of cooking, emotional attachments, and perception "flames" when cooking still carry weight in the eyes of choosing homes for perspective homebuyers. In addition, compatibility with specific cookware was also a concern when choosing to electrify cooking. As a result, the Belmont community chose to provide options for both electric and gas cooking. Compatible cookware was the main concern for the Fresno community to choose ENERGY STAR rated ranges and cooktops versus deploying induction cooktops. However, the Fresno community is evaluating induction cooktops via a small-scale pilot (five units) as part of its ZNE community.

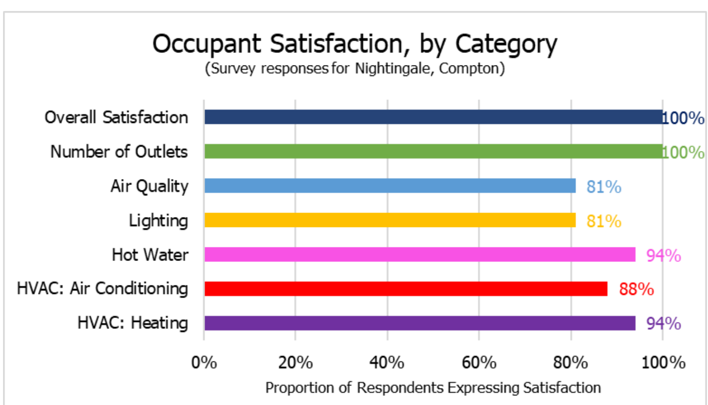
First Impressions of Living in a Zero Net Energy Community

Renters typically have a set of selection criteria when choosing a place to live. However, they are usually limited by what is offered by rental properties—especially when it comes to energy efficiency technologies such as high efficiency insulation or advanced electric water heating technologies. As a result, the project not only looked at prospective homebuyers but also at rental properties since 44 percent of California residents are renters.[16] Through interviews conducted at project sites as well as parallel and similar efforts conducted by the project team at other sites, the following main opportunities and challenges were identified.

Opportunities for Scaling-Up Zero Net Energy Communities

- **Opportunity 1 - High customer satisfaction of zero net energy and electrified communities:** All community occupants' part of this project experienced a high level of customer satisfaction when occupying their communities. See Figure 8 for overall occupant satisfaction at the Compton community.

Figure 8: Occupant Satisfaction of Compton Zero Net Energy Community and Associated Building Technologies



Source: UC Davis

[16] Johnson, Hans; Marisol Cuellar Mejia; Julien Lafortune; Cesar Alesi Perez. 2022. Homeownership Trends in California. https://www.ppic.org/blog/homeownership-trends-in-california/#:~:text=Statewide%2C%20only%2056%25%20of%20households,large%20cities%20and%20metropolitan%20areas. Public Policy Institute of California.

- **Opportunity 2 – Improved safety and indoor air quality:** Mold on windowsills (See Figure 9) and smell coming from heating and/or cooling systems typically signal poor air quality to tenants. Through tenant walkthroughs interviews, occupants of these ZNE communities noted that they saw the absence of condensate on windowsills and no smell from HVAC systems as an indicator of improved indoor air quality.

Figure 9: Mold on Windowsills can Lead to Negative Health Impacts

Source: istockphoto.com

Challenges for Scaling-Up Zero Net Energy Communities

- **Challenge 1 – Expectation that zero net energy equals zero bill:** Education is needed to manage expectations of ZNE not directly equating to zero bill as this can be a common misconception that was identified from these communities as well as previous ZNE community projects.[17]
- **Challenge 2 – Unfamiliarity with new technologies results in unforeseen usage of advanced building electrification technologies:** Advanced heat pumps usually provide improved comfort, convenience, and control to tenants. However, improved control has energy-impacting related results. For example, thermostats with improved control can help provide improved comfort and space conditioning, but also increased energy usage. Site-level information and estimates gained through energy modeling identified that there were considerable differences between estimated HVAC energy consumption and sub metered energy consumption in the Fresno community. Field visits and audits identified that thermostat setpoints were set at 64 degrees for cooling—compared to the estimated 72-76 degrees. Figure 10 shows how lower setpoints in the summer causes potential over-conditioning of spaces and increased energy consumption.

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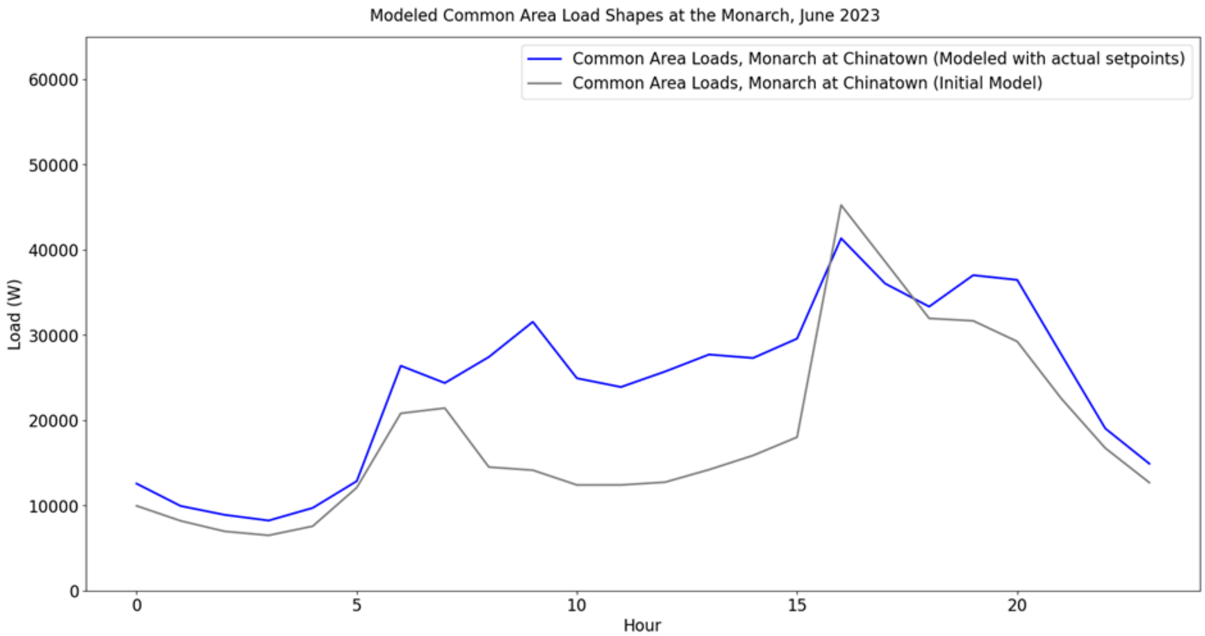
[17] Cite Fontana.

Figure 10: Estimated Energy Differences Associated with Different Assumed Thermostat Setpoints



Source: EPRI

Input Provided by Builders, Developers, and Trades on Developing, Constructing, and Maintaining Zero Net Energy Communities

While working on the project, the team recognized the importance of understanding not only the market's perception of ZNE communities, but also the people who will be specifying, building and maintaining these communities. The builders and developers that were part of this project were generally interested in exploring ZNE through building electrification as they valued the competitive advantage they would have over other builders in the area by pre-paring their supply chains and trades for upcoming code cycles. Several key lessons that were learned through the value engineering and design charrette discussions specifying building technologies. The project team gained an understanding on how contractors and trades receptiveness to bid on advanced technology projects as well as understanding property asset managers and maintenance staff's challenges perceptions of advanced building electrification technologies. The following main opportunities and challenges were identified:

Opportunities

- **Opportunity 1 - Long Term Energy Strategies:** Several builders and developers that were part of this project and its TAC have begun to include energy metrics as part of their overall corporate strategy. Market rate builders such as KB Homes and Meritage Homes have evaluated energy efficiency and renewable energy systems as part of ZNE projects in the state of California.[18,19] Affordable housing collaboratives such as the Stewards of Affordable Housing for the Future (SAHF) also have developed tools to design and develop low carbon affordable housing.[20] Increased interest in decarbonization has resulted in overall increased interest in decarbonization through electrification.

- **Opportunity 2 – Zero Net Energy and All-Electric New Construction are Becoming Cost Neutral to Dual Fuel Approaches:** With increased interest in building electrification technologies to enable ZNE communities, costs have considerably decreased – both for materials as well as labor.

Challenges

- **Challenge 1 –Trade Acceptance is Limited:** While costs have considerably decreased, availability of trades was limited. The Belmont project (equipment installed in 2020) as well as the Fresno project (equipment installed in 2021 and 2022) identified considerable trade shortages to install heat pumps at the time of construction of both communities. The Belmont community was not able to consider variable capacity heat pump systems as their preferred trades did not support commissioning of these systems. The project team had to connect preferred trades with heat pump water heating manufacturers to help the builder gain confidence in installing connected heat pump water heaters. Similarly, the Fresno community also experienced trades that were not willing to bid on both central heat pump water heating as well as variable refrigerant flow (VRF) commissioning. Only one contractor for each decided to bid on the Fresno project. Trade buy-in and training are important for scaling up ZNE community approaches that include advanced building electrification technologies.
- **Challenge 2 – Attrition/Turnover of Knowledgeable Stakeholders:** One challenge experienced by all communities as part of this project was attrition and turnover of knowledgeable staff members. For many community developers in California, including these host site communities, many times, these were the first-ever building electrification projects they conducted. While the construction industry already experiences considerable turnover, combining this with considerable shortage of California employees in the construction industry, it took a considerable amount of time and effort to work with newer members of the project partners, especially when there was a change in decision makers amongst the community development management or other stakeholders.

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[18] Hanley, Steve. 2022. KB Home Offers Energy Efficient, Connected Homes in California. https://cleantechnica.com/2022/11/20/kb-home-offers-energy-efficient-connected-homes-in-california/. Clean Technica.

[19] 2019. Meritage Homes Opens Nation's First All-Electric Zero-Net Energy Attached Condominium Community in Southern California. https://www.globenewswire.com/en/news-release/2019/04/12/1803540/6889/en/Meritage-Homes-Opens-Nation-s-First-All-Electric-Zero-Net-Energy-Attached-Condominium-Community-in-Southern-California.html. Global News Wire.

[20] 2023. The Multifamily Portfolio Carbon Emissions Roadmap Tool. https://sahfnet.org/resources/multifamily-portfolio-carbon-emissions-roadmap-tool. Stewards for Affordable Housing for the Future.

Analysis Results of Operational Data from Zero Net Energy Communities

Several insights were obtained from the operational performance at the ZNE communities constructed as part of this project. Table 4 summarizes the types of analyses conducted, the purpose of each analysis, and the overall takeaways from each analysis. For additional information, please see *Supplemental Document - Operational Data Collected from Zero Net Energy Communities*.

Table 4: Data Analysis Completed for this Project

Analysis	Purpose
Energy Usage	Determine energy use patterns such as months of highest energy use and energy use intensity (EUI). Used to benchmark energy performance for these communities
Electricity Bills	Understand energy costs paid for by occupants or property managers associated with ZNE and all-electric communities
Daily Load Shapes	Understand load shapes of communities and end-uses. Helps understand at what time communities use the most energy and what end-uses consume the most energy. Used to help utilities and energy companies plan infrastructure to support these communities
Peak Load Attribution	Understand occurrence and drivers of peak energy use in these communities
Load Duration Curves	Help utilities determine capacity needs of a particular community by assessing both peak power needs for the community as well as for how long peak power is needed
Load Factor Analysis	Understand coincident usage of end-use technologies as well as distribution of usage of end-use technologies
Controllable End-Use and DER Analysis	Understand potential to mitigate peaks through controllable loads and mechanisms such as demand response, peak shifting, and price signaling
Carbon Impacts	Assess performance of buildings as measured by different performance metrics adopted by the State of California. Includes TDV, TSB, and other marginal emissions metrics
Weather Dependence	Understand how impactful weather is on community peak energy consumption

General Energy Usage

For mixed fuel communities, this project supports previously published results showing what is feasible through efficiency upgrades for multifamily buildings.[21] See Table 5. Note that Table 5

[21] 2012. The Technical Feasibility of Zero Net Energy. Client report prepared for Pacific Gas & Electric Company. Arup.

provides electric energy use intensity and does not include any potential and actual contribution or impact of solar energy at these communities.

Table 5: Summary of Electric Energy Use Intensity for Multifamily Sites

Community	Electric Energy Use Intensity (kilowatt hours [kW]/square foot [sq. ft.])
Pomona	5.86
Compton	5.22
Fresno	9.82

Source: EPRI

The Fresno Community remains a significant outlier, with energy use patterns (as exemplified by energy use intensity that is, energy use normalized by square footage) exceeding what was predicted through modeling. ZNE-ready and electrified communities appear to exhibit energy use patterns that depart from conventional California buildings. Potential reasons why this is the case are still being explored by the project team but may include additional ventilation requirements, limitations in capturing behavioral loads (different thermostat setpoints), and limitations of energy models properly representing VRF operations. In general, for these ZNE communities that are part of this project, winter months appear to rival summer months in terms of total energy consumption. See Table 6.

Table 6: Month of Highest Electricity Use for Multifamily Sites

Site	Month of Highest Electricity Use	Season
Pomona	January	Winter
Nightingale	January	Winter
Fresno	July	Summer

Source: EPRI

For additional energy results, please see Appendix C.

Electricity Costs

In terms of utility bill patterns, electrification appears to produce a more even annual pattern, especially in multifamily buildings such as the Pomona, Compton, and Fresno communities. All three of those buildings have winter and summer energy bills that are either broadly comparable (Pomona, Fresno) or dominated by winter bills (Compton). Traditionally, for mixed fuel households, winter months have been associated with lower utility bills, as natural gas has been considerably cheaper than electricity in California. Considerations must be taken for electrification—especially for energy burdened households to not bear the disproportionate impacts of this clean energy transition. See Table 7.[22]

Table 7: Seasonal Utility Bills for All Multifamily Sites (Values in Parentheses Mean Resident Does Not Pay Bills and Actually Gets Compensated by the Utility for Providing Energy Back to the Grid)

Season	Average Electricity Bill, CA Residential Customer	Average Natural Gas Bill, CA Residential Customer	Weighted Average Electricity Bill, Pomona	Weighted Average Electricity Bill, Nightingale	Common Load Electricity Bill, Normalized by Apartments, Fresno
Winter	$538	$414	$187	$246	$875
Spring	$365	$143	($62)	($19)	$350
Summer	$521	$94	($169)	($74)	$367
Fall	$459	$137	($37)	($26)	$642

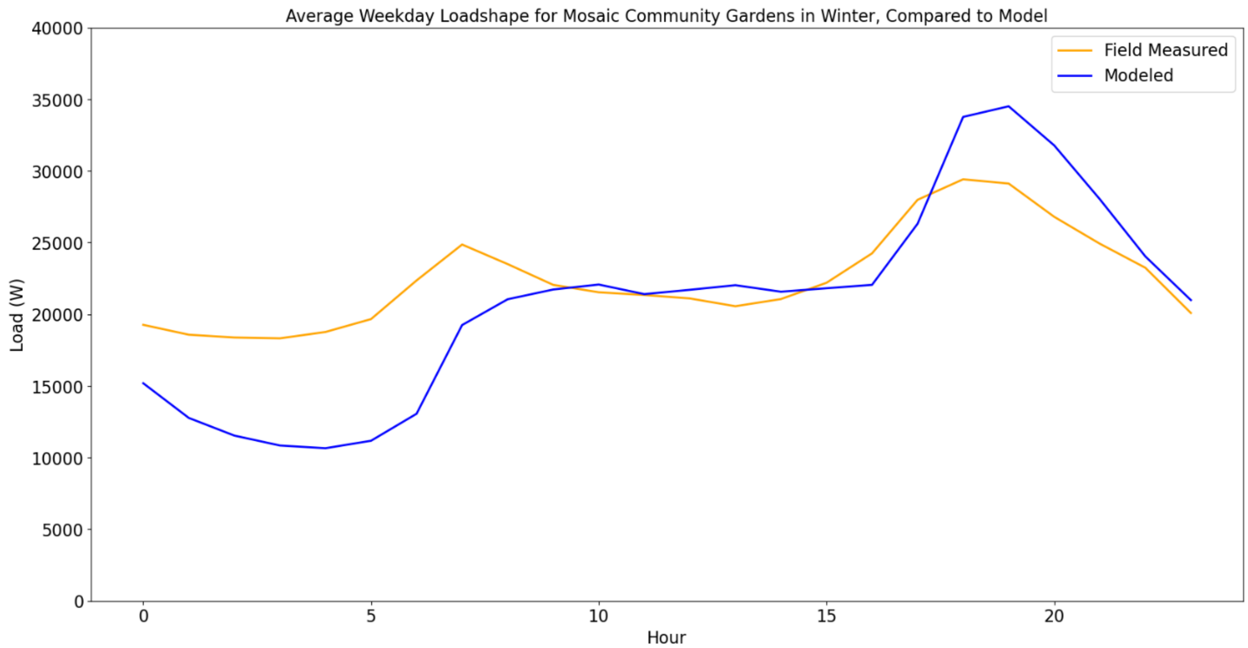
Compared to the average electricity bill paid in California, Pomona and the Compton communities both exhibit considerably lower bills—especially when considering benefits of both efficiency and solar. This finding suggests that optimization and other efficiency measures can offset the cost of electrification. The Fresno community, even when considering solar, did not save as much in electricity costs as the other two sites—and instead experienced higher costs even with solar in the fall. It is important to note that Fresno's climate (California climate zone 13) is more susceptible to high electricity costs due to its hot summers as well as colder winters. This result suggests that there is considerable need for cost conservation for this community. This reduction may be achieved through multiple means such as tariff selection and operational optimization of central systems. See Appendix D.

Load Shape Analysis

The following figures (Figure 11 through Figure 16) depict several load shapes collected for Pomona (Figure 11, Figure 12, Figure 13, and Figure 14), Compton (Figure 15), and Fresno (Figure 16) communities. For Pomona and Compton, those load shapes indicate that energy models may underestimate winter loads (especially morning winter loads in the case of Pomona) and overestimate summer loads. Those findings are important for grid planning in California, as the State has traditionally prioritized summer evening peaks.

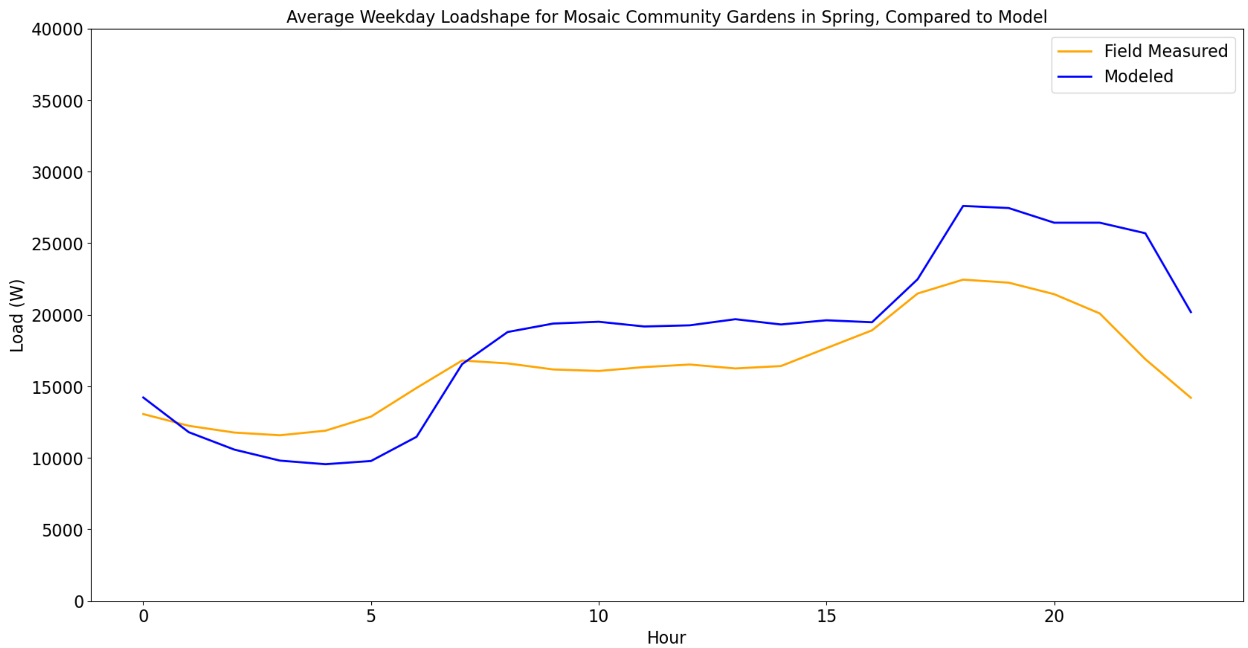
[22] Table 7 results: (1) are based on currently available collected data on the three ZNE communities, (2) are based on current community rate plans as chosen by the community, (3) assume successful solar interconnection of a solar array based on either available roof space or actual solar installations, and (4) any battery storage installed onsite is providing only backup power to the site (no grid management functions).

Figure 11: Average Weekday Winter Load Shape for Pomona Community Compared to Energy Simulations



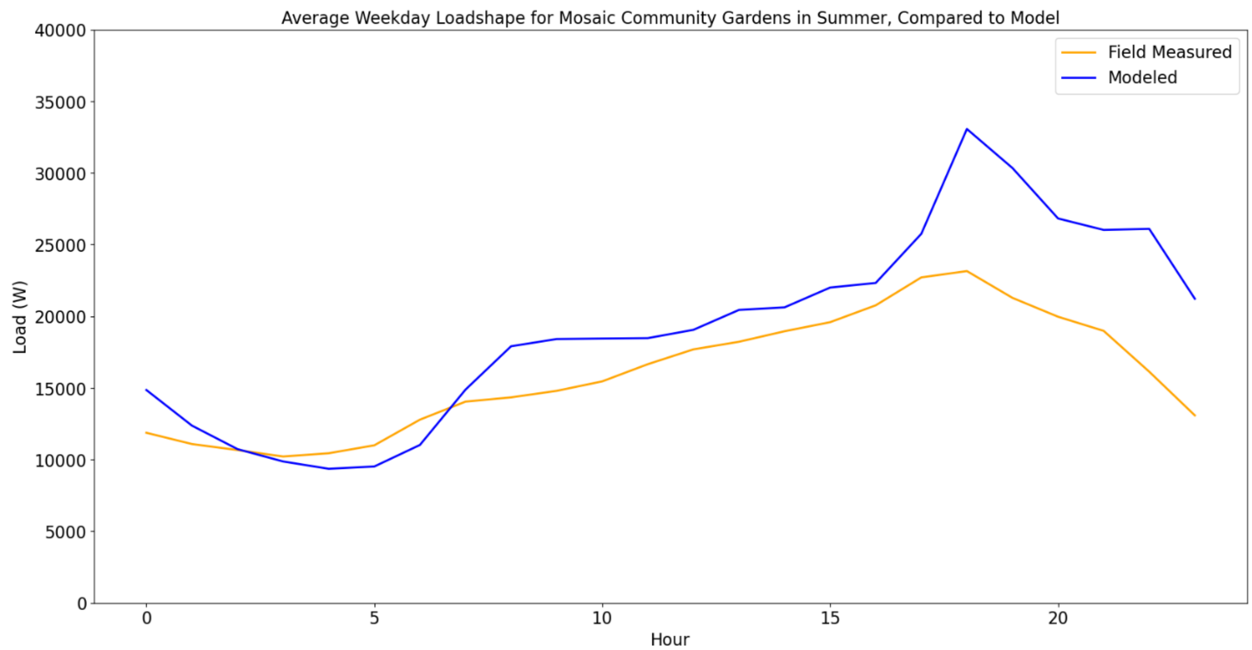
Source: EPRI

Figure 12: Average Weekday Spring Load Shape for Pomona Community Compared to Energy Simulations



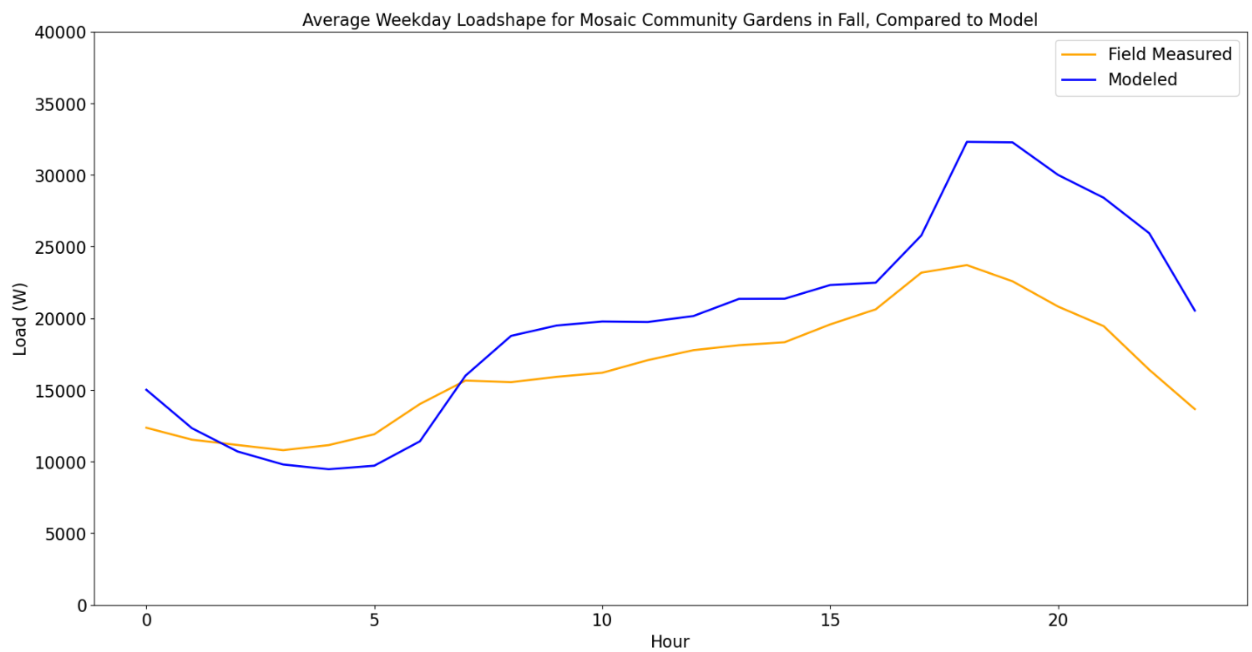
Source: EPRI

Figure 13: Average Weekday Summer Load Shape for Pomona Community Compared to Energy Simulations



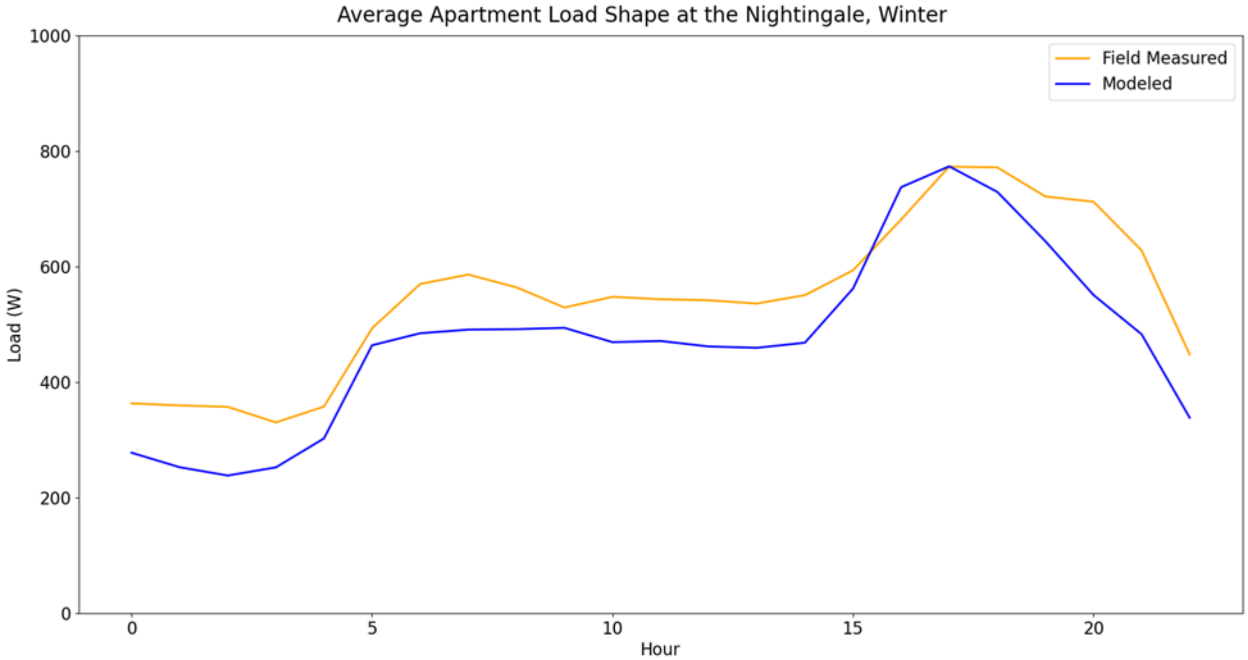
Source: EPRI

Figure 14: Average Weekday Fall Load Shape for Pomona Community Compared to Energy Simulations



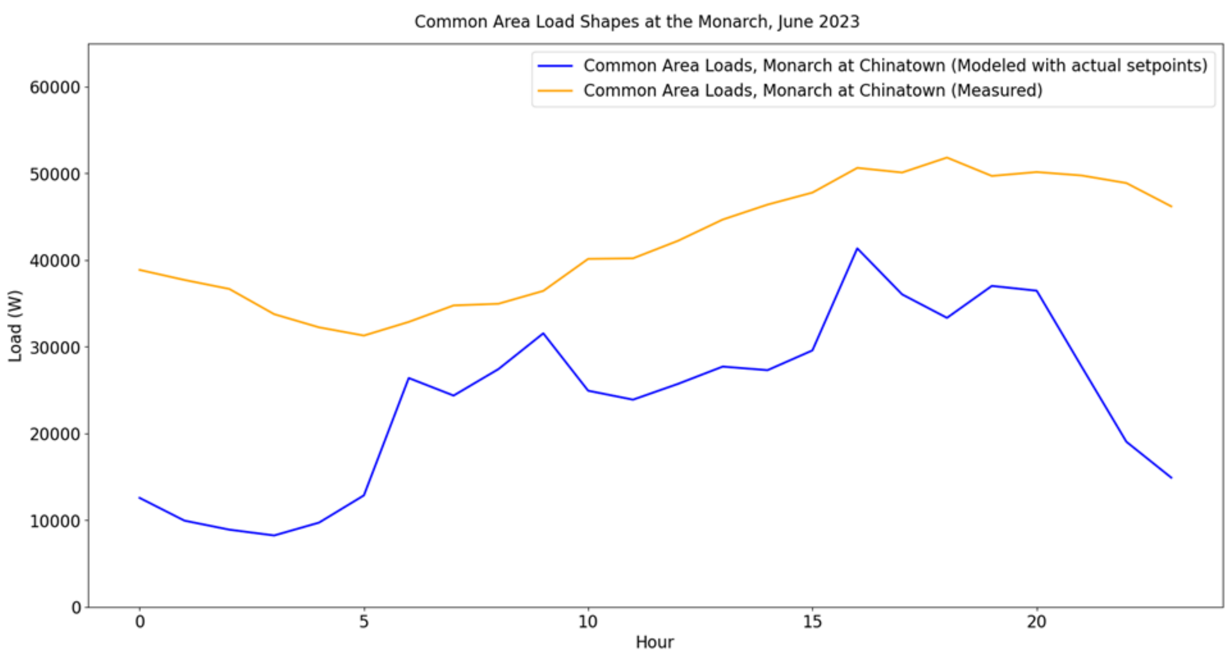
Source: EPRI

Figure 15: Average Weekday Winter Load Shape for Compton Community Compared to Energy Simulations



Source: EPRI

Figure 16: June 2023 Common Area Load Shape for Fresno Community Compared to Energy Simulations

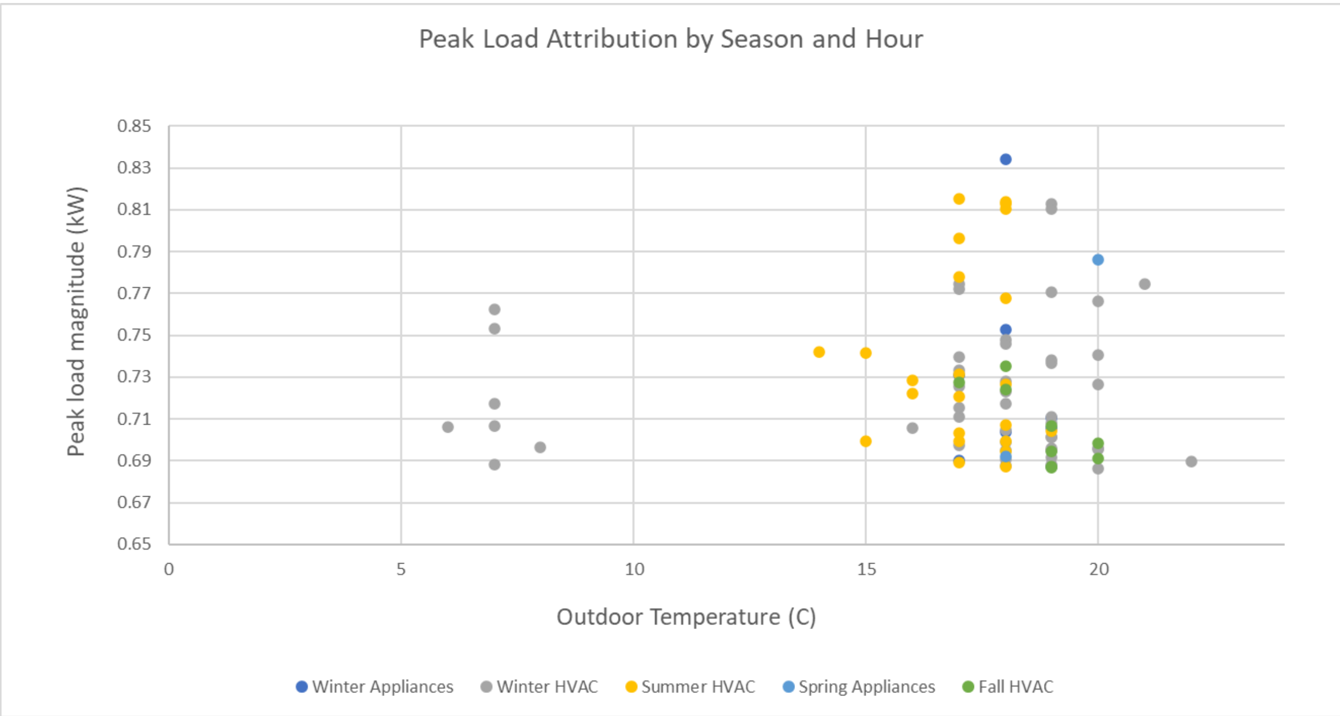


Source: EPRI

Figure 16 shows that the Fresno community, in contrast to the two other communities, exhibits a large difference between modeled and measured load profiles. Among the many reasons this may be attributed, are: (a) mismatches between thermostat setpoints defined by the models and those set by occupants, (b) less than envisioned operational optimization of loads such as common area lighting, (c) deficiencies in how energy models simulate variable refrigerant flow (VRF) systems under certain conditions (low load/overload), (d) changes in code brought about by the COVID-19 pandemic that required more constant ventilation.[23]

As with annual energy consumption patterns, load shapes further emphasize the trend of a shift towards winter peaks. For Pomona, nearly half of the top 100 peaks are winter peaks driven by heating. See Figure 17.

Figure 17: Top 100 Hours in the Year Where Pomona Community is Using the Most Energy, What Time of Day it Happens, and What End-Use is Using the Most Energy During those Times

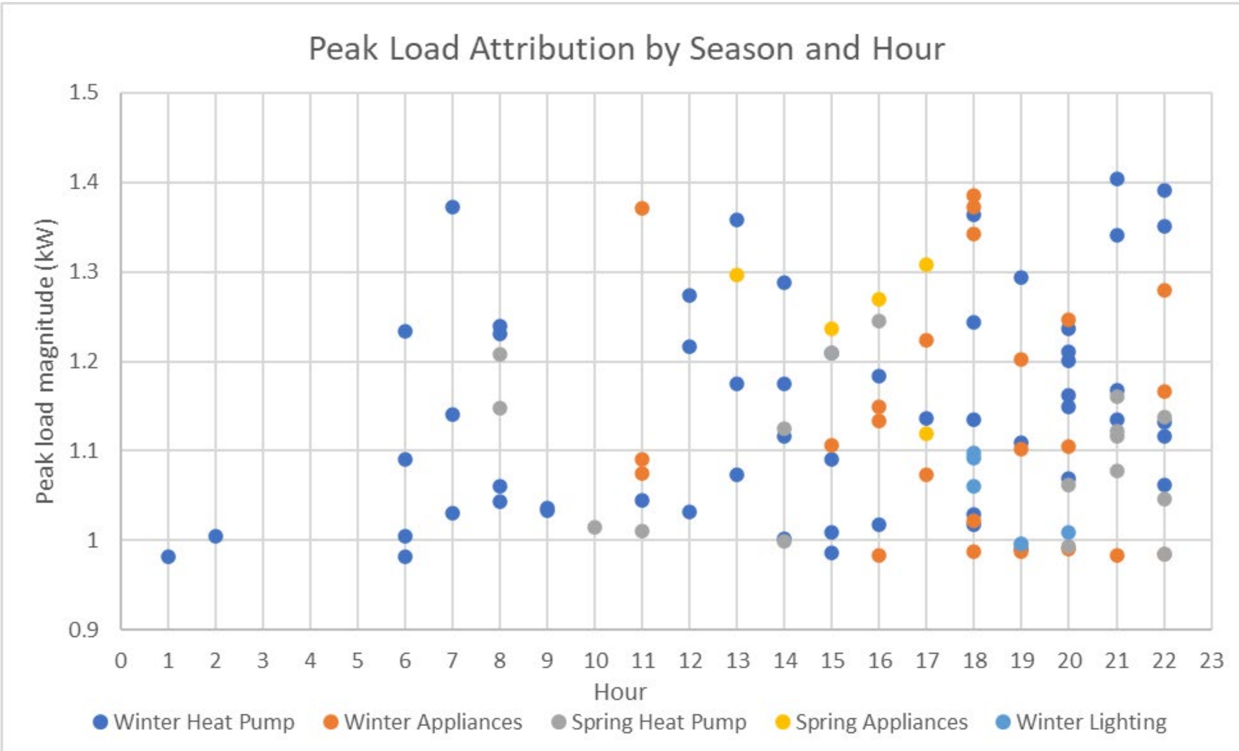


Source: EPRI

The Compton community exhibits a similar pattern, with heating peaks being very frequent. Cooling-driven peaks associated with air conditioning use in the summertime do not appear in the top 100 peaks at the Compton community. Another unique aspect of the Compton community's peak loads is the common occurrence of peaks due to noncontrollable loads such as appliances. See Figure 18.

[23] As a result of COVID-19, increased ventilation and filtration was required in this community as originally intended during community design. This is potentially resulting in increased HVAC usage than original energy estimates of this community obtained through energy simulations.

Figure 18: Top 100 Hours in the Year Where Compton Community (per Unit) is Using the Most Energy, What Time of Day it Happens, and What End-Use is Using the Most Energy During those Times



Source: EPRI

For additional load shape analysis conducted, please see Appendix E.

Additional Analysis Summary

Additional analysis was completed on California ZNE communities as part of this project; see Table 8 for a summary of these results. For additional information and results to support these outcomes, please see *Supplemental Document -Operational Data Collected from Zero Net Energy Communities*.

Table 8: Results Summary of Additional Analysis Completed on Project's Zero Net Energy Communities

Analysis	Results Summary
Peak Load Attribution	Electrification leads to more significant winter/heating driven community energy peaks. Certain buildings exhibit peaks driven by noncontrollable loads such as appliances due to energy efficiency.
Load Duration Curves	In multifamily buildings, it appears that energy models underestimate peak loads, so measured data is critical in understanding peak loads due to electrification. California performance metrics, a reflection of the canyon curve, may lead to

Analysis	Results Summary
	an oversizing of behind-the-meter PV to the extent that electric infrastructure may need to be sized based on back feed.
Load Factor Analysis	Opportunities may be present for energy use reduction for certain controllable and noncontrollable loads such as plug loads. Use of smart plugs may lead to less energy waste, for example. Load diversity of controllable end uses not as driven by weather (for example, heat pump water heaters) show less exacerbated energy peaks compared to those estimated by energy models.
Controllable End-Use and DER Analysis	Controllable end uses (HVAC, water heating) remain a significant driver of extreme peaks and significant mitigation is possible. Considerations need to be made to better understand cost of such an aggregation system, type of signaling sent to devices and California home occupants, impacts to overall comfort and convenience, and equitable deployment of such an energy control strategy.
Carbon Impacts	Evolving performance metrics reflect realities experienced in grid planning, especially the exacerbation of the duck curve to the point of becoming a canyon curve. Behind the meter DER become less valuable for code compliance purposes in this environment, replicating trend seen in project finance with the shift to Net Energy Metering (NEM) 3.0 framework for overgeneration valuation.
Weather Dependence	The traditional notion that extreme peaks are driven by cooling loads in California may not hold for communities optimized for efficiency and electrification. Electrification of transportation may considerably impact this in the future.

Source: EPRI

Results Summary

Through quantitative and qualitative data collected through the design, construction, and occupancy of the ZNE communities developed by this project, the main results of this effort are summarized below:

- **Construction**: ZNE communities are technically feasible, even in instances of building electrification/all-electric homes. These communities can be built at cost parity, potentially even more cost competitively than dual fuel alternatives. However, available trades and trade buy-in were limited for construction in these communities. Trade and industry acceptance and proper workforce development and training will be important to ensure proper installation, commissioning, and maintenance of these ZNE communities.
- **Homebuyer and Renter Perceptions:** ZNE communities have features that homebuyers and renters generally find appealing in some of the advanced building electrification technologies such as improved air quality, safety, and comfort. However,

other non-energy factors are still main drivers for overall homebuyer and renter decisions. Increased understanding and valuation of ZNE communities and building electrification technologies pose over less-efficient, more carbon intensive technologies should be considered to help drive stronger market pull for these communities.

- **Data Analysis from Operational Data at Zero Net Energy Communities:** While, in general, the deployment of advanced electrification technologies when deployed as a "ZNE system" shows overall bill savings compared to a typical California home, there are instances where electrification could have negative impacts on occupant or community energy bills. It is important to continue to gather operational data to better help stakeholders understand what technologies and features of community development are impacting energy consumption. Tighter coordination is needed to better design, plan, and interconnect DER such as rooftop solar and storage. Rate structures need to be assessed so that unintended energy burden is not placed on disadvantaged communities in California's transition to electrification.

CHAPTER 4: Conclusion

This project demonstrated that while it is technically feasible to design, develop, and construct ZNE communities, it will be important to do so in a way that does not result in negative impacts to the quality of life of California's residents and workforce. Consequently, this project's learnings emphasize the following next steps as they pertain to future work to design, develop, and deploy California's ZNE communities.

California building development should ensure electrification does not cause unintended consequences such as increased energy burden—especially for California's disadvantaged communities. The project showed that improvements in building efficiency and access to local renewable energy has both energy and non-energy benefits. Even more studies have been validating hypotheses that end-use technologies energized by gas result in not only economic impacts, but poor indoor air quality and health impacts as well. Gas stoves can release harmful pollutants in the air such as carbon monoxide.[24] Best practices such as proper ventilation as well as electrification of cooking have shown to provide improved indoor air quality benefits. This project collected qualitative data that shows homebuyers' and renters' interest in electrification technologies both for their energy and non-energy benefits is discussed in Chapter 3. Advancements in technology such as induction cooktops can also lead to improved safety and resiliency. See Figure 21 for an induction cooktop that can potentially be powered by a battery.

Figure 21: Induction Cooktop with a Battery Showcased at EPRI/CEC 2023 Building Electrification Summit at California Natural Resources Building in Sacramento, CA

Source: EPRI

[24] N.d. Indoor Air Pollution from Cooking. https://ww2.arb.ca.gov/resources/documents/indoor-air-pollution-cooking. California Air Resources Board.

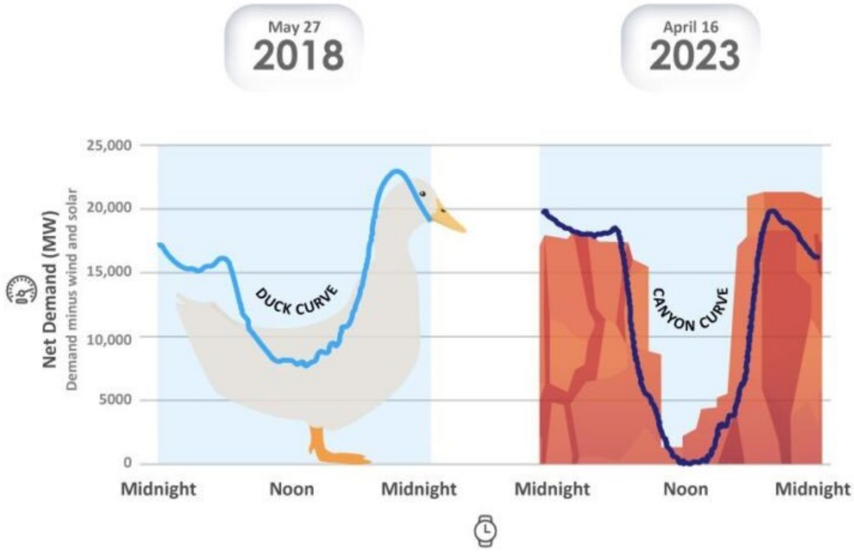
The average California resident pays approximately $2,700 a year for utility bill expenses–over 33 percent higher than the national average (Energy Sage, 2023). In general, data from these ZNE communities show that while project investment led to reduced energy costs on average, there were instances, such as the fall season in Fresno, where energy costs appeared higher due to the higher cost of local/regional electricity and relatively lower cost of natural gas in California. This project shows the importance of appropriate rates and rate plans. Changing rate plans for the Fresno community would have considerable impact on overall energy bills—especially when it comes to electrification. Integration and interconnection of DER, such as rooftop PV and battery storage, also plays a considerable role in ZNE community economics. Pomona and Fresno projects both experienced and continue to experience DER interconnection challenges. Streamlined interconnection processes to ensure positive economics are important so that communities are not burdened with technology (and associated operating costs) that is not interconnected/not supported. While California transitions to time of use rates, this will require the industry to provide additional tools that are both available and accessible to all California residents to not adversely impact one part of California's population from another.

The construction industry employs a considerable portion of California residents. Approximately 900,000 Californians work in the construction industry. Of this population, it is estimated that over 600,000 Californians work in residential new construction—3.5 percent of the state's labor force.[25] Advanced construction practices associated with building ZNE communities should consider advancing California's construction workforce. While this project showed that it was technically feasible to deploy all-electric, ZNE communities, there were considerable challenges that the project faced when getting local trade ally buy-in due to a combination of labor shortages and lack of a trained labor force. Belmont, Fresno, and Compton communities also faced considerable staff attrition, resulting in the need to continuously brief community champions and develop tools to educate preferred local trade allies to minimize overall disruption caused by the project. Projects such as this one should consider how to provide educational tools and resources that enable the professional advancement of California's construction workforce.

Effective energy system planning and community development are also important outcomes. This project identified that movement toward new California ZNE requirements driven by building code may increase the need for rooftop solar. The result could potentially be localized versions of the "canyon curve" as depicted in Figure 22.

[25] Siniavskaia, Natalia. 2023. Home Building Employment across States and Congressional Districts in 2021. https://eyeonhousing.org/2023/04/home-building-employment-across-states-and-congressional-districts-in-2021/#:~:text=Not%20surprisingly%2C%20the%20most%20populous,the%20state%20employed%20labor%20force. National Association of Home Builders Discusses Economics and Housing Policy (NAHB).

Figure 22: Canyon Curve (2023) vs. Duck Curve (2018) Associated with Increased Renewable Energy Adoption



Source: EPRI

Right sizing of California's grid will be important and should be focused on affordability. Data is needed from projects like this one to support utility efforts to ensure we neither overbuild (too costly) nor under-build (fail to prepare) the grid as California prepares for the electrification of the buildings and transportation sectors.

Finally, better understanding of what value ZNE communities can bring to different stake-holders is needed. This can be supported through continued collection of operational data from ZNE communities like the ones demonstrated by this project. California communities of the future are a points of: (1) integration of buildings and the built environment they create, (2) intersection of buildings and electrification technologies that enable decarbonization, and (3)intersection of buildings and the energy system that are built, operated, and maintained to support it. Builders and developers that were part of this project as well as its TAC all expressed the need for additional information to help them make better data-driven decarbonization investment decisions. Compton, Pomona, and Fresno communities' decision-makers directly expressed their interest in the project for its ability to provide more granular data to help their asset management and development teams make better strategic decisions in which building technologies to deploy in future new construction projects.

While this study did consider utility cost impacts of electrification and the electricity billing patterns of ZNE communities, it did not consider a full picture of all the costs that may be associated with all-electric, ZNE communities. Those costs include those associated with equipment, installation, upgrades to electrical infrastructure, operation, and maintenance. A clearer understanding of the cost burden ZNE communities relative to Title 24 would help stakeholders understand how the push to electrification and decarbonization may negatively impact the most vulnerable Californians. As an energy code, Title 24 does not require any kind of benchmarking or reporting for continuous compliance. Designs are evaluated at construction. However, with Assembly Bill 802 requiring benchmarking for large residential multifamily buildings, gaps between Title 24 certificates of compliance and actual performance will become more apparent and more costly (Austin, 2022). An understanding of where the differences in performance lie will be beneficial to building operators looking to comply with Title 24’s standards. Overall, a deeper understanding of what value ZNE communities can bring to the different stakeholders and decision makers, especially California residents and job force, is needed to continue to scale up ZNE and building electrification deployment.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
ADA	The Americans with Disabilities Act
AHJ	Authorities Having Jurisdiction
Behind the meter	Energy systems located on the customer's side of the utility meter
BESS	Battery Energy Storage System
BIPV	Building Integrated Photovoltaic System
Building envelope	Everything that separates the internal building from the external environment, such as the roof, doors, windows, floors, and walls.
DER	Distributed Energy Resources – energy generation units that are located on the consumer's side of the meter.
Distributed generation	When electricity is generated from sources near the point of use.
EaaS	Energy as a Service – customers pay for an energy service without having to make any upfront capital investments.
Building electrification/ decarbonization	Converting buildings to use electricity rather than natural gas or fossil fuels.
EUI	Energy Use Intensity
FHA	Fresno Housing Authority
GHG	Greenhouse Gas
HVAC	Heating, Ventilation, and Air Conditioning
KPI	Key Performance Indices
kW	kilowatt
LC	Low Carbon
Low-emissivity glazing	Window glass glazing that minimizes the amount of infrared and ultraviolet light that comes through the glass, reflecting heat.
M&V	Measurement & Verification
NEM	Net Energy Metering
O&M	Operation & Maintenance
PV	Photovoltaic Systems
TAC	Technical Advisory Committee
TDV	Time-Dependent Valuation
TSB	Total System Benefit
VRF	Variable Refrigerant Flow – provides heating and cooling by cycling refrigerant between an outdoor unit and indoor unit.
ZNE	Zero Net Energy - uses no energy that results in emissions.

References

Argento, Robert; Xian Fang Bak; Lariece Brown. N.d. *Energy Efficiency: Value Added to Properties & Loan Performance*. https://sf.freddiemac.com/docs/pdf/fact- sheet/ energy_efficiency_white_paper.pdf. Freddie Mac.

Arup. 2012. The Technical Feasibility of Zero Net Energy. Client report prepared for Pacific Gas & Electric Company. Arup.

Autodesk. *2018 Workforce Survey Results*. https://www.agc.org/sites/default/files/Files/ Communications/2018_Workforce_Survey__California.pdf. AGC of America.

Barron, Manuel; Maximo Torero. 2016. *Household Electrification and Indoor Air Pollution*. https://www.ocf.berkeley.edu/~manuelb/Research/IAP/IAP-Jul2017.pdf. Journal of Environmental Economics and Management (2017).

California Air Resources Board. N.d. *Indoor Air Pollution from Cooking*. https://ww2.arb.ca.gov/ resources/documents/indoor-air-pollution-cooking . California Air Resources Board.

California Energy Commission. 2021. *Assembly Bill 3232 and the California Building Decarbonization Assessment*. https://www.energy.ca.gov/sites/default/files/2021-08/AB3232_Building_Decarbonization_Assessment_Factsheet_ADA.pdf. California Energy Commission.

California Energy Commission. 2023. T*op Global Building Appliance Manufacturers and Distributers Commit to Help California Achieve Six Million Heat Pump Goal*. https://www. energy.ca.gov/news/2023-10/top-global-building-appliance- manufacturers-and-distributors-commit- help#:~:text=SACRAMENTO%20%E2%80%94%20Today%2C %2010%20of%20the,he at%20pumps%20installed%20by%202030%20. California Energy Commission.

California Legislative Information. 2022. *AB-1279 the California Climate Crisis Act*. https:// leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1279. California Legislative Information.

California Public Utilities Commission. 2008. *California Long Term Energy Efficiency Strategic Plan*. https://www.cpuc.ca.gov/-/media/cpuc-website/files/legacyfiles/e/5305-eestrategicplan.pdf.. California Public Utilities Commission.

Energy Sage. 2023. *Cost of Electricity in California*. https://www.energysage.com/local- data/ electricity- cost/ca/#:~:text=Learn%20more%20about%20how%20our,average%20 electric%20bi ll%20of%20%242%2C624. Energy Sage.

EPRI. 2016. *Grid Integration of Zero Net Energy Communities*: 3002009242. https://www.epri. com/research/products/3002009242. EPRI.

Executive Department, State of California. 2018. *Executive Order B-55-18 to Achieve Carbon Neutrality*. https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf. Executive Department, State of California.

Fresh Energy. 2023. What's up with natural gas in my home?

Global News Wire. 2019. *Meritage Homes Opens Nation's First All-Electric Zero-Net Energy Attached Condominium Community in Southern California*. https://www.globenewswire.com/en/news- release/2019/04/12/1803540/6889/en/Meritage-Homes-Opens-Nation-s-First-All- Electric-Zero-Net-Energy-Attached-Condominium-Community-in-Southern-California.html. Global News Wire.

Hanley, Steve. 2022. KB Home Offers Energy Efficient, Connected Homes in *California*. https://cleantechnica.com/2022/11/20/kb-home-offers-energy-efficient-connected- homes-in-california/. Clean Technica.

Johnson, Hans; Marisol Cuellar Mejia; Julien Lafortune; Cesar Alesi Perez. 2022.

Homeownership Trends in California. https://www.ppic.org/blog/homeownership- trends-in-california/#:~:text=Statewide%2C%20only%2056%25%20of%20households,large%20cities%20and%20metropolitan%20areas. Public Policy Institute of California.

Kahn, Matthew; Nils Kok. 2014. *The Capitalization of Green Labels in the California Housing Market*. https://www.sciencedirect.com/science/article/abs/pii/S0166046213000574. Regional Science and Urban Economics.

Mikhitarian, Sara. 2019. *Homes with Solar Panels Sell for 4.1% More*. https://www.zillow.com/research/solar-panels-house-sell-more-23798/. Zillow.

Pacific Gas and Electric. N.d. *PG&E Induction Cooktop Loaner Program.* https://pge- induction.myturn.com/library/. PG&E.

Patel, Sonal. 2023. *EPRI Head. Duck Curve Now Looks Like a Canyon Curve.* https://www.powermag.com/epri-head-duck-curve-now-looks-like-a-canyon/. PowerMag.

Pontecorvo, Emily. 2023. T*o Get Off Fossil Fuels, America is Going to Need a Lot More Electricians*. https://grist.org/energy/electrician-shortage-electrify-everything-climate-infrastructure-labor/. Grist.

Siniavskaia, Natalia. 2023. *Home Building Employment across States and Congressional Districts in 2021*. https://eyeonhousing.org/2023/04/home-building-employment-across-states-and- congressional-districts-in-2021/#:~:text=Not%20surprisingly%2C%20the%20most%20populous,the%20state%20employed%20lab or%20force. National Association of Home Builders Discusses Economics and Housing Policy (NAHB).

U.S. Energy Information Administration. *2022. EIA - Independent Statistics and Analysis: State Energy Data System*. U.S. Energy Information Administration.

Westmoreland, Lauren. 2023. *The Multifamily Portfolio Carbon Emissions Roadmap Tool*. https://sahfnet.org/resources/multifamily-portfolio-carbon-emissions-roadmap-tool. Stewards for Affordable Housing for the Future.

Young, Austin. 2022. Everything you Need to Know about California Assembly Bill 802. https://www.ivy-energy.com/blog/assembly-bill-802. Ivy Energy.

Project Deliverables

Additional project deliverables to help dive deeper into specific topic addressed by this project are divided into two deliverable types: (1) Supplemental Documents and (2) Remaining Project Deliverables.

Supplemental Documents

Supplemental Documents are intended to provide complementary material to this Final Project Report. They are intended to provide additional details so that readers can gain additional information on specific project results and approaches.

- Chow, Angelica, Kayla Nettesheim, and Ben Clarin. 2023. *Supplemental Document - Customer and Occupant Perceptions of Zero Net Energy Communities.* California Energy Commission.
- Daher, Mazen, Ben Clarin, and Maggie Sheng. 2023. *Supplemental Document - Operational Data and Results Collected from Zero Net Energy Communities.* California Energy Commission.
- Nettesheim, Kayla, Herb Yaptinchay, and Ben Clarin. *Supplemental Document – Technology Transfer Plan and Results.* California Energy Commission.
- Sheng, Maggie, Herb Yaptinchay and Ben Clarin. 2023. *Supplemental Document - Designing and Constructing Zero Net Energy Communities*. California Energy Commission.
- Sheng, Maggie, Mazen Daher, Herb Yaptinchay, and Ben Clarin. *Supplemental Document – Measurement and Verification Plan.*

Remaining Project Deliverables

Remaining Project Deliverables are other deliverables that can serve as stand-alone reports. Work reported by these deliverables was completed as part of this project to satisfy subtasks requested by this project's statement of work.

- Ahmed, Abdullah. *Community Solar Feasibility and Business Models.* 2022. California Energy Commission.
- Douglass-Jaimes, David and Abhijeet Pande. *Zero Carbon Homes: Builder Pathways and Impacts on New Construction Programs.* 2022. California Energy Commission.
- Hammon-Hogan, Ian and Karl Johnson. *2021 Building Electrification Workshop Summary.* 2021. California Energy Commission.
- Outcault, Sarah, Eli Alston-Stepnitz, Angela Sanguinetti, Ashley DePew, and Cinthia Magana. *Decarbonizing Affordable Housing: Case Studies on Developer Experiences with New Construction.* 2021. California Energy Commission.

- Outcault, Sarah, Eli Alston-Stepnitz, Angela Sanguinetti, Ashley DePew, and Cinthia Magana. *Occupant Experience in Selected Lower Carbon Affordable Multi-family Housing Communities.* 2021. California Energy Commission.
- Outcault, Sarah, Eli Alston-Stepnitz, Angela Sanguinetti, Ashley DePew, and Cinthia Magana. *Occupant Satisfaction with All-Electric & Zero-net Energy Affordable Multi-Family Housing.* 2021. California Energy Commission.
- Seymour, Bryce and Emma Riccardi. *Developer's Playbook to All-Electric, Low Carbon Communities.* 2023. California Energy Commission.