CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Varieties of Prefabricated Envelope Solutions for California Low-rise Buildings

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- Association for Energy Affordability
- David Baker Architects
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PREFACE

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

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities — Pacific Gas and Electric Company, San Diego Gas & 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.

Varieties of Prefabricated Envelope Solutions for California Low-rise Buildings is the final report for EPC-19-036 conducted by the Rocky Mountain Institute, Association for Energy Affordability, RDH Building Science, and David Baker Architects. The information from this project contributes to the Energy Research and Development Division's Electric Program Investment Charge Program.

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

ABSTRACT

The decarbonization of California's building sector has fostered the need for global collaboration on emerging technologies. REALIZE California (hereafter referred to as REALIZE-CA) is an innovative approach to decarbonizing aging multifamily affordable housing statewide. By focusing on the rapid deployment of streamlined retrofit packages tailored to the most common building typologies in the state's multifamily affordable housing stock, REALIZE-CA provides a roadmap for transforming buildings and communities.

To scale deployment of zero net carbon retrofits, significant advances in the standardization and delivery of envelope retrofit systems are needed. European retrofit markets have successfully achieved this by creating unitized, prefabricated, airtight, and high R-value panels that are hung from the building exterior and include high performance windows and doors. A complete roof and wall townhouse retrofit can be installed in as little as one day. These types of prefabricated retrofit panels, however, are not available in the United States or designed to serve California's building stock and climate.

Through this project, REALIZE-CA demonstrated emerging prefabricated envelope solutions as part of a standardized retrofit package for California's aging multifamily buildings. Specifically, the research team designed, fabricated, and tested two variations of prefabricated envelope panel prototypes on the most common multifamily building typology in California: low-rise, wood-frame buildings. Project findings demonstrate the following:

- Light-touch envelope solutions are sufficient for package deployment in the California affordable multifamily retrofit market at this time.
- Improving the market's access to insulated over-cladding strategies will require greater funding coordination and quantification of non-energy benefits.
- Whole-building retrofits can be more cost-effective than traditional, site-built renovation/rehabilitation projects.
- Industrialized panelization is not the key to unlocking this opportunity.

Keywords: decarbonization, retrofit, multifamily, affordable housing, deep energy retrofit, prefabrication, emerging technologies, panelized envelope systems, exterior insulated finish systems

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Executive Summary

Despite the success of California's various decarbonization programs, there are still clear opportunities to develop scalable approaches to retrofitting multifamily buildings that address barriers to rapid deployment of standardized equipment packages.

REALIZE California (referred to as REALIZE-CA) was funded by awards from the California Energy Commission's Electric Program Investment Charge program, which invests in scientific and technological research to accelerate the transformation of the electricity sector to meet the state's energy and climate goals. As a coordinated portfolio of awards, REALIZE-CA standardized, tested, developed, and demonstrated standardized retrofit packages in multifamily buildings in disadvantaged communities statewide in an effort to reduce equipment and installation costs.

The Varieties of Prefabricated Envelope Solutions for California Low-rise Buildings project (EPC-19-036) funded the design, fabrication, and demonstration of two prefabricated panelized retrofit systems on a typical California low-rise multifamily building. Specifically, REALIZE-CA deployed a panelized exterior wall insulation and finish system at its Southern California demonstration site (Corona Del Rey Apartments) and compared it to a panelized exterior roof retrofit in the Central Valley (Vera Cruz Village Apartments) and a site-built nonpanelized envelope retrofit in the San Francisco Bay Area (Light Tree Three). This comparison examined factors conductive to scale, such as installation time, tenant disruption, energy and cost savings, wall and roof insulation value, ventilation properties, structural integrity, and technological readiness.

State Climate Nexus

Building construction in the United States has seen minimal improvements since the late 1940s. Residential and commercial buildings consume 70 percent of electricity and account for more than one-third of energy-related carbon emissions in the country (U.S. DOE, 2023).The majority of existing buildings in the United States, both residential and commercial, use energy inefficiently and were not built to meet contemporary performance requirements. These include, but are not limited to, structural performance criteria that have largely remained unchanged since the post-World War II period.

Exterior insulation and finish systems are the primary technology used today to address existing building envelopes in deep energy retrofits, offering the opportunity for significantly improved insulation and air and moisture performance in older structures without the weight and complexity of layered assemblies. These envelope retrofits are typically built in place using a fragmented procurement and installation value chain, which can result in high costs, occupant disruption, inconsistent installation quality, and poor confidence in long-term building performance.

Project Purpose and Approach

This project explored incorporating prefabricated exterior insulation and finish system panels into a standardized retrofit package for multifamily buildings throughout California. Panelized exterior insulation retrofits (as opposed to field-applied exterior insulation and finish systems) offer the potential to exceed current building code and efficiency standards through a vertically integrated design, testing, installation, and servicing business model. Above all, although exterior insulation and finish systems have few precedents in retrofits for wood-frame construction, they are lightweight, which is a critical design criterion for California's building stock. In addition to aligning prefabricated panelized system design/development with California's energy efficiency and greenhouse gas reduction goals, this project sought to provide non-energy benefits to tenants, including improved indoor environmental quality, thermal and acoustic comfort, and better resilience during extreme weather events.

Key Results

Overall, pilot learnings demonstrated that panelized retrofit solutions could support energy retrofits at scale in aging multifamily units across California, but only in limited applications. The project team determined that, while panelized retrofit wall systems can provide energy, acoustic, and indoor environmental quality benefits, factors such as cost and other data demonstrated that the majority of California's building stock, including multifamily housing, may not need aggressive envelope interventions — that is, conventional, market-ready envelope upgrades using commercially available technologies are sufficient for decarbonization.

As summarized in RMI's Market Guidance Report data and demonstrated by field-testing multiple retrofit approaches, much of California's building stock will not require substantial envelope upgrades in standard package deployment (Webster et al., 2024). Instead, conventional "market-ready" envelope upgrades using commercially available equipment/ materials, such as storm windows, additional insulation (wall and/or attic), and air sealing, are sufficient for standard package deployment. However, and as stated in this report's "Conclusion" chapter, additional research is needed to determine the viability of panelized envelope solutions in cold climate zones, as a larger percentage of retrofit-eligible buildings will require more aggressive envelope interventions. In summary, multifamily retrofit packages incorporating panelized envelope upgrades are best suited to building stock with the following characteristics:

1. Existing walls are uninsulated and windows need replacement.
2. There is sufficient capital available to fund upgrades to the building enclosure (e.g., scheduled rehabilitation).
3. Exterior stucco and interior plaster or drywall are free of asbestos or funded through owner contributions.
4. The property has a simple building geometry with minimal overhangs, entryways, and protrusions, since these limit the efficiency of a panelized envelope retrofit because

they make it more difficult to seal/waterproof, to create a panel layout with standardized dimensions, and to install the panels.

5. The property is not a historic or an architecturally significant building or otherwise limited by local architectural design standards. Panelized envelope retrofits are unlikely to meet the requirements for planning department or historic review board approval in these circumstances.

CHAPTER 1: Introduction

Residential and commercial buildings consume 70 percent of electricity and account for more than one-third of energy-related carbon emissions in the United States (U.S.). The majority of existing buildings in the country, both residential and commercial, use energy inefficiently and were not built to meet contemporary performance requirements. These include, but are not limited to, structural performance criteria that have largely remained unchanged since the post-World War II period. In California, this results in older multifamily affordable buildings being particularly vulnerable to seismic events and the impacts of deferred maintenance.

In addition, multifamily buildings account for about 25 percent of the residential building stock in the United States (U.S. Census Bureau, 2021). The business-as-usual approach to retrofitting multifamily buildings is time-consuming, disruptive, bespoke, and costly, resulting in low retrofit rates (approximately 1 percent per year) (Egerter, 2018) unrealized energy savings, and poor indoor living environments.

U.S. facade manufacturers have been slow to respond to the need to develop industrialized high-performance building envelope solutions, encompassing innovative products for roofing, walls, and windows, for multifamily building retrofit packages. There remains no large-scale, standardized or industrialized approach for retrofitting energy-inefficient existing buildings, and there is no single domestic player in the industry that offers a turnkey solution. As a result, there is a major opportunity to explore deeper energy efficiency in the nation’s multifamily buildings.

In California, in particular, older multifamily housing stock also faces the additional challenge of being built with light, wood-framed construction at high risk of water or pest damage and sub-par seismic performance. These risks complicate decarbonization goals, increasing cost and complexity, and are not addressed by existing incentive programs. Retrofits combining envelope performance upgrades, such as prefabricated roofing and panelized wall products, with structural repairs would dramatically reduce vulnerability to seismic events while improving resilience to extreme weather, increasing thermal comfort, and reducing emissions and operating costs.

Exterior insulation and finish systems (EIFS) are the primary technology used today to address existing building envelops in deep energy retrofits, offering the opportunity for significantly improving insulation as well as air and vapor barrier performance in older structures to enable improved thermal comfort and reduced operating emissions and energy consumption. These envelope retrofits are typically built in place, using a fragmented procurement and installation value chain, which can result in high costs, greater occupant disruption, inconsistent installation quality, and poor confidence in long-term building performance.

Panelized exterior insulation retrofits (as opposed to field-applied EIFS) offer the potential to exceed current building code and efficiency standards through a vertically integrated design, testing, installation, and servicing business model. The purpose of this project was to demonstrate cost-effective prefabricated EIFS panels as part of standardized zero carbon aligned retrofits for multifamily housing in California. In addition to aligning prefabricated panelized system design/development with California's energy efficiency and greenhouse gas (GHG) reduction goals, this project sought to provide non-energy benefits to tenants/ ratepayers, including improved indoor air quality, thermal and acoustic comfort, and resilience during extreme weather events. The project team was also tasked with developing a zero net energy (ZNE) retrofit package for multifamily housing under a suite of California Energy Commission (CEC)-funded awards (referred to as REALIZE-California, or REALIZE-CA), and this project funded the prefabricated wall panels demonstrated at the Corona Del Rey Apartments in Corona, California.

The project also had a number of research and development objectives related to envelope measures for wall panels and window integration at Corona Del Rey Apartments, as follows.

Objectives related to envelope measures for wall panels were to:

- Connect the panels to the existing building.
- Use a pre-engineered aluminum rail system.
- Optimize the size of panels to reduce joints intention (intention of installing larger panels in the future).
- Increase the R value above R8.

Objectives related to envelope measures for window integration were to:

- Evaluate the potential for simplifying panel installation by using panels with windows preinstalled into the rough opening.
- Limit the weight to less than 4 pounds per square foot.
- Limit the weight to less than 3 pounds per square foot.

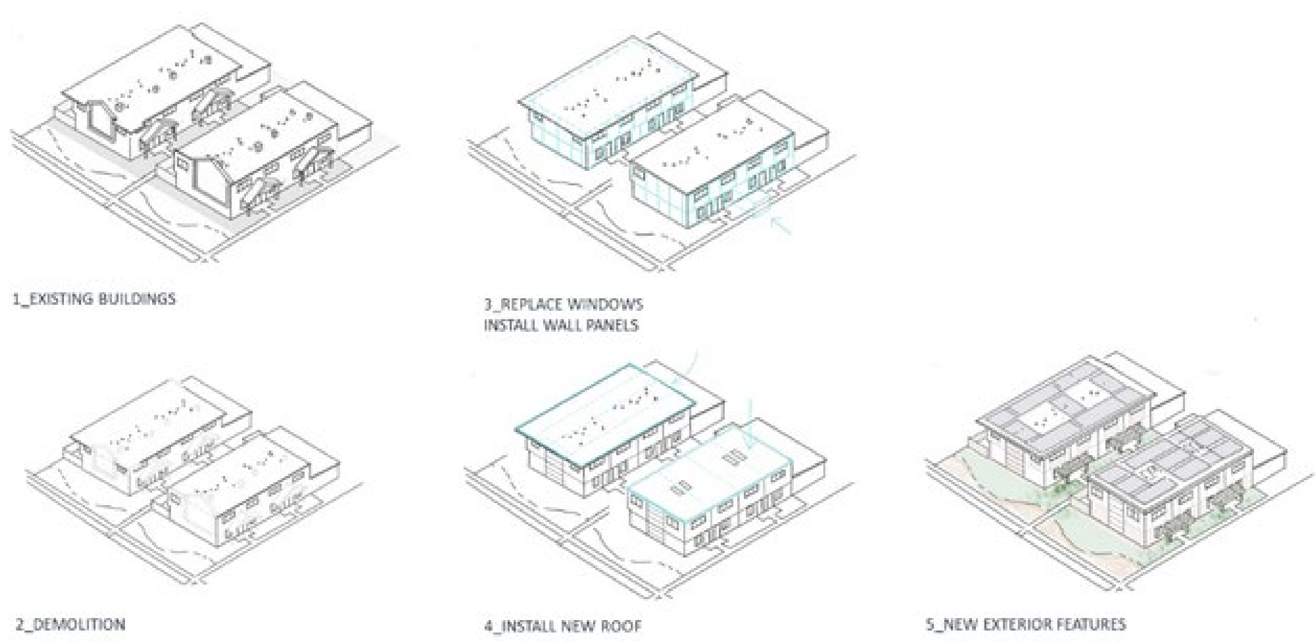
The intended audience for the program included affordable housing organizations and tenants, advanced construction manufacturers (especially those fabricating prefab exterior/outsulation envelope products), the building trades, green lenders, policy makers, and the residential energy-efficiency industry writ large. This audience, along with their respective markets, was targeted due to the volume of retrofit-eligible multifamily units statewide, as well as the opportunity to address seismic upgrades through envelope improvements in standardized retrofit packages.

CHAPTER 2: Project Approach

The project's initial inspiration was the Energiesprong retrofit program in the Netherlands. Energiesprong retrofits utilize prefabricated and emerging technologies in a package that can be rapidly deployed across the country's geometrically simple, low-rise multifamily housing, built primarily from masonry. At the outset of the EPC-10-036 research, the central hypothesis was that exterior prefabricated envelope systems incorporating advanced insulation, high-performance windows, and robust air sealing would enable standardization, scalability, and disruption-free deployment of zero carbon building designs. Figure 1 illustrates the facade retrofit process developed throughout the project. The team intended to achieve the following objectives associated with this process:

- Design and test prefabricated exterior facade panels for zero net carbon (ZNC) retrofits in California's multifamily buildings.
- Fabricate at least two panelized retrofit systems for installation and monitoring at the Corona Del Rey demonstration site.
- Identify if/how prefabricated exterior panel systems could scale throughout California's multifamily market.

Figure 1. REALIZE-CA Prefabricated Exterior Retrofit Process



Source: David Baker Architects

To develop, deploy, and assess the commercial feasibility of prefabricated exterior retrofit panels, the project team's initial strategy aligned with the design efforts under the CEC's EPC-17-040 REALIZE research. It began with identifying the most common multifamily building types statewide and developing preliminary retrofit guidelines, based on energy modeling and structural analysis results, to identify retrofits and technologies for non-intrusive, rapid delivery. Demonstration sites were selected to align with typology results, and manufacturing partners were brought onto the team to fabricate and lab test retrofit technologies for deployment. Retrofit variations were deployed and monitored across three demonstration sites, with the goal of understanding how prefabricated industrialized approaches performed compared to commercially available, but under-utilized, solutions for low-rise multifamily buildings in California. The demonstration site list is as follows:

- Corona Del Rey Apartments — 1148 D St., Corona, CA 92882
- Vera Cruz Village Apartments — 631 Rd. 210, Richgrove, CA 93261
- Light Tree Three Apartments — 1804 E. Bayshore Rd. #100, East Palo Alto, CA 94303

Our partners in these efforts were:

- Architect — David Baker Architects (DBA)
- Energy consultant — Association for Energy Affordability (AEA)
- Structural engineer and envelope consultant — RDH Building Science (RDH)
- Scanning workflow — Signetron
- Building owner — National CORE Community Renaissance

Market Characterization Study

The first step in developing standardized retrofit solutions required identifying common building types. In 2020, AEA conducted a market characterization study to determine the most common buildings within the California multifamily building stock. Analysis determined wood-frame, low-rise typology types to be the most common in the multifamily building stock, collectively representing over 2 million units across California. The team used these findings to guide demonstration site selection and to ensure that the technologies developed would be able to scale across typologies, predominantly comprising garden-style, townhouse, and "loaded-corridor" (with rooms on one side or both sides of a corridor) buildings, with two-story structures consisting of between 5 and 49 units being the most common (RMI and AEA, 2019).

Demonstration Sites Existing Conditions

Three demonstration sites were selected to best align with the market characterization study: Corona Del Rey, Light Tree Three, and Vera Cruz Village. Table 1 outlines the existing envelope conditions of each demonstration site.

Table 1. REALIZE-CA Demonstration Site Existing Conditions

Site Name	Corona Del Rey	Light Tree Three	Vera Cruz Village
Property Ownership	National Core Inc.	Eden Housing	Self Help Enterprises
Year Built	1964	1966	1993
Climate Zone	Southern California, 10	Bay Area, 3	Central, 13

Site Name	Corona Del Rey	Light Tree Three	Vera Cruz Village
Square Feet	178,880	37,126	50,194
Building Typology	Townhomes, 2-story; 2 bedrooms	Townhome, 2-story and loaded corridor 4-story; mix of 2 and 3 bedrooms	Townhomes, 1-2 story; mix of 2, 3, or 4 bedrooms
Seismic Retrofit	Yes	Yes	No
Wall Insulation	Uninsulated 2x4 wood frame walls	Stucco siding; wood framed, 2x4 studs, insulation levels to be confirmed	R19 - loose fill cellulose insulation at ceiling
Ceiling/Roof Insulation	Uninsulated flat roof; mix of white TPO and torch down roof with gray granules	Flat roof, no attic; little to no insulation; age unknown.	Pitched roof with conventional trusses 24" on center; attic vents every third rafter bay and at the gable ends; asphalt shingles
Windows	Single-glazed aluminum	Vinyl framed single hung, double pane	Double-pane aluminum frame
Slab	Slab on grade	Slab on grade	Uninsulated slab

Source: REALIZE-CA Demonstration Data, RMI and AEA

Manufacturer Selection

To select panel manufacturing partners, the REALIZE-CA team began with a broad survey of technologies that held potential for the retrofit application. These included three-dimensional (3D)-printed and molded fiberglass panels to lightweight pre-cast concrete, light-gauge steel sandwich panels, structurally insulated panelized systems, and cork. Overall, panel products fell into two main categories: lightweight nonstructural panels and heavyweight structural panels. After honing panel design criteria and identifying several companies that had an interest in and the capability of developing and deploying a product in the timeframe of the grant, the project team issued a solicitation. This process narrowed options considerably, in conjunction with results from structural analysis undertaken by RDH. Meeting the structural design criteria for low-rise, wood-framed buildings in California's seismic zones was a significant research and development (R&D) effort in developing the façade panels. Research by RDH showed that any exterior wall panel would need to remain under 4-5 pounds to avoid triggering costly seismic retrofits on the target building types, depending on the weight of the existing building. The research identified removal of existing cladding before applying the retrofit panels as a means of limiting additional weight gain from the building retrofit. This was one challenge not dealt with in the Energiesprong program, because its building stock is mostly masonry, whereas in California the building stock is mostly wood framed. Manufacturers would need to focus their R&D on achieving this goal while maintaining window integration into the panel for a second demonstration at the Corona del Rey site. This weight limitation removed many novel approaches. Ultimately, five manufacturers responded to the solicitation and the team selected Dryvit-Tremco because it satisfied several interests:

- An existing product (Fedderlite-M panelized EIFS) ready to use in a novel application
- A willingness and the capability to develop a new product (Revitalite), a similar panelized EIFS product with a fiberglass structural frame capable of supporting a window
- A vision for vertically integrated design, manufacturing, and project delivery, including envelope and systems integration with an attractive whole-envelope warranty
- Seriousness and pragmatism about the challenges and building science involved with a panelized retrofit of a wood-framed building

3D Scanning Workflow

The team collaborated with Signetron, a start-up developing a workflow to capture high-resolution 3D scans of existing buildings and translate the point-clouds into digital models that could be used for panel fabrication. The purpose was to drastically reduce error and labor (cost and time) associated with verifying existing building measurements to the level of accuracy required for a streamlined and air-tight result, given the irregularities typical of existing buildings. Panels need to hang and connect to this underlying structure, so it is essential to understand where and in what condition it is in. Signatron took a laser scan of each building at both demonstration sites, Corona Del Rey and Vera Cruz Village, which created a 3D point-cloud model of the scanned building, and it converted these into digital models of the buildings. Signatron provided the results to the panel manufacturer, Dryvit-Tremco, to assist in panel layout design and planning.

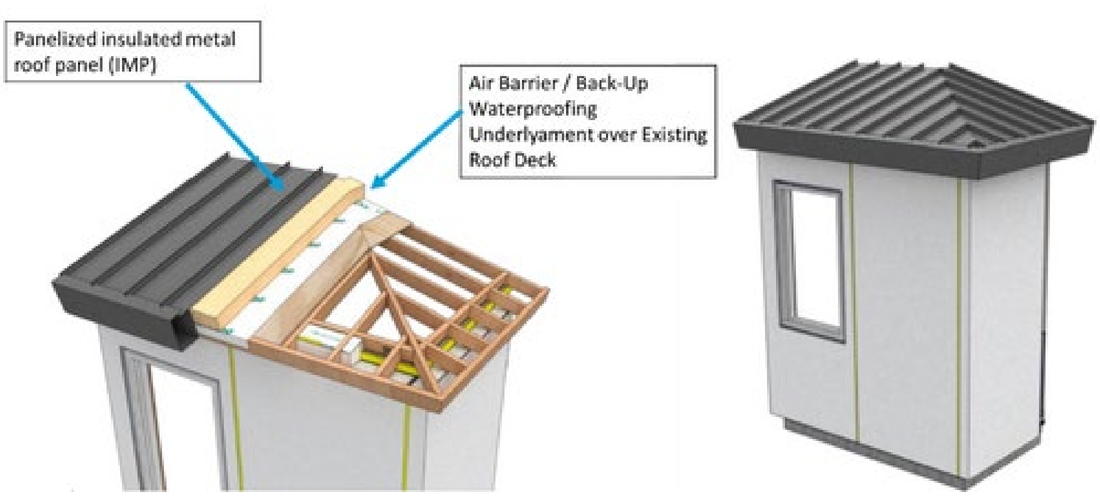
Retrofit Variation

In parallel with identifying prefabricated panel manufacturers, the REALIZE-CA team examined the suitability of EIFS panels for deployment in targeted multifamily stock statewide by conducting robust parametric energy modeling and analysis of typology structural characteristics. Findings were synthesized to develop preliminary envelopes retrofit package guidelines applicable for multifamily low-rise buildings across California. REALIZE guidelines and methods informed RMI's 2023 *Accelerating Residential Building Decarbonization Market Guidance to Scale Zero-Carbon-Aligned Buildings* Market Guidance Report, developed by the Advanced Building Construction (ABC) Collaborative, in partnership with the United States Department of Energy and several of its national laboratories; this provides state-level recommendations for appropriate zero carbon aligned retrofit packages for U.S. residential building stock (Webster et al., 2024). It is accompanied by an interactive dashboard, which allows users to estimate retrofit package scaling, according to factors like package specifications (package assignment) and estimated installation costs. While site-specific physical and capital needs, as well as REALIZE's initial guidelines, primarily guided technology selection, the team decided to align demonstration and commercialization efforts with the

Market Guidance Report -recommended scalable retrofit solutions (Webster et al., 2024, pp. 39-60).

Findings from REALIZE-CA energy modeling and RMI's Market Guidance Report showed that exterior wall retrofits were not always necessary to achieve ZNC retrofit goals, prompting the team to set up a comparative field study to best identify scalable envelope retrofit methods. For instance, results showed that moving the thermal and air barrier from the attic to the roof deck would limit duct losses and offer a net benefit to the building's overall energy efficiency. Meanwhile, REALIZE prototype energy models indicated that 2x6 walls with existing insulation did not yield significant-enough energy cost savings. For the Vera Cruz demonstration, which already had wall insulation, the team instead proposed studying an exterior roof retrofit using insulated metal panels (IMP), which are lightweight, prefabricated assemblies of standing seam metal encapsulating polyisocyanurate foam insulation (Figure 2).

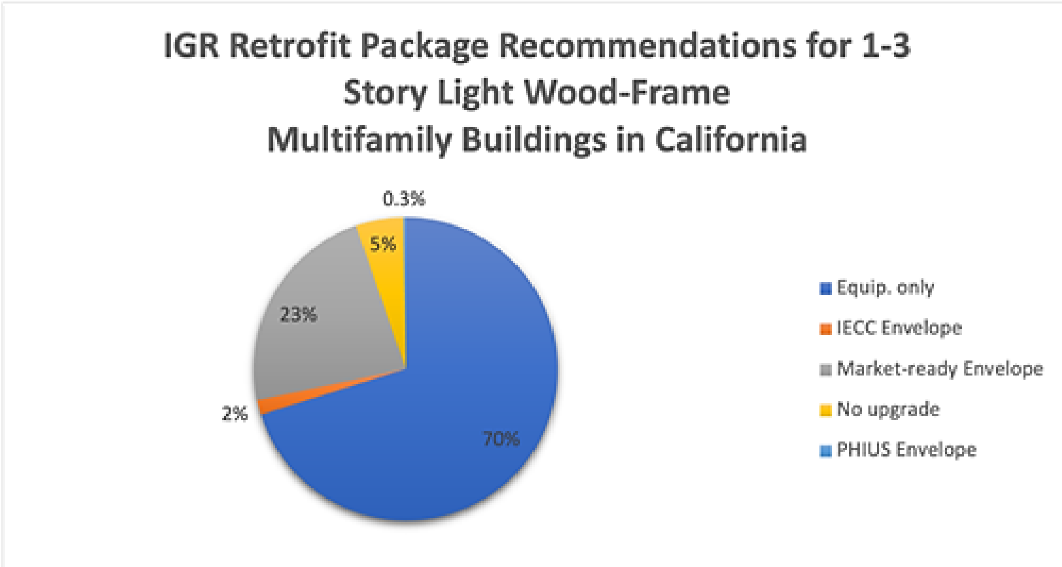
Figure 2. IMP Roof Schematic



Source: EPC-17-040 Emerging Technologies Report, DBA

Although IMPs are an established product for commercial buildings, they had yet to be installed as a retrofit for light wood-framed residential buildings at the time of demonstration. IMPs cannot be used on roofs sloping less than one-half inch per foot, ruling out the flat roofs found at the Corona Del Rey demonstration site, and a whole envelope panelized EIFS demonstration. IMPs could be used in conjunction with panelized EIFS on buildings with pitched roofs and attics, but the Vera Cruz demonstration site already had sufficient wall insulation. Similarly, results from the Market Guidance Report (Figure 3) indicated that only a small proportion of California residential buildings would benefit from more substantial envelope upgrades, to either the International Energy Conservation Code or Passive House Institute U.S. performance standards.

Figure 3. Recommendations for Zero Carbon Aligned Energy Retrofits



Source: Market Guidance Report, 2023, RMI

Replacing all major end-use equipment with high-efficiency electric equipment, or upgrading the building envelope with conventional, market-ready solutions such as replacement double-pane vinyl or fiberglass windows, would be sufficient to effectively decarbonize California's housing sector. For these reasons, the team decided to assess the energy and utility savings, and thermal and moisture performance attributed to prefabricated EIFS retrofit panels, via a comparative study of the following envelope retrofits across three demonstration sites.

A detailed list of measures and specifications for each retrofit variation demonstrated is as follows:

1. **Package A. New heating, ventilation, and air conditioning (HVAC) + No envelope upgrade**
    - **Demonstration Site: Corona Del Rey Rest of Site (ROS)**
    - Heating and Cooling: Ductless Mini-split; Heating Seasonal Performance Factor (HSPF) 11, Seasonal Energy Efficiency Ratio (SEER) 19.2
    - Water Heating: Central Heat Pump (HP), Coefficient of Performance (COP) 3.97
    - Envelope: No Change
2. **Package B. New HVAC + Prefab wall panel (R-15 - Low R-Value)**
    - **Demonstration Site: Corona del Rey 205 Isabella Way**
    - Heating and Cooling: Ductless, All-in-One (AIO) wall, packaged terminal heat pump (PTHP) COP 3.4
    - Water Heating: Central HP, COP 3.97
    - Roof/Attic R-Value: (R-30) Rigid foam with single-ply polyvinyl chloride (PVC) roofing
    - Wall/Floor R-Value: (R-19) Prefabricated wall panels with insulation, waterproofing and fluid-applied air barrier
    - Windows: Title 24 Compliant
    - Air Leakage: 1 ACH50 (air changes per hour at 50 pascals) benefit

3. **Package C. New HVAC + Prefab wall panel (R-21 - High R-Value)**
    - **Demonstration Site: Corona del Rey 217 Isabella Way**
    - Heating and Cooling: Ceiling Fan + Ductless, AIO wall, PTHP COP 3.4
    - Water Heating: Central HP, COP 3.97
    - Roof/Attic R-Value: (R-30) Rigid foam with single-ply PVC roofing
    - Wall/Floor R-Value: (R-21) Prefabricated wall panels with insulation, waterproofing and fluid-applied air barrier
    - Windows: Title 24 Compliant
    - Air Leakage: 1 ACH50 benefit
4. **Package D. New HVAC+ Site-built envelope retrofit**
    - **Demonstration Site: Light Tree Three**
    - Heating and Cooling: Ductless, Mini-splits, HSPF 9.5, SEER 20
    - Water Heating: Central Low Global Warming Potential (GWP) HP, COP 3.97
    - Roof/Attic R-Value: (R-30) Tapered rigid foam on roof-deck
    - Wall/Floor R-Value: (R-15) Batt insulation in wall cavity
    - Windows: Title 24 Compliant
5. **Package E. New HVAC + Conventional envelope**
    - **Demonstration Site: Vera Cruz ROS**
    - Heating and Cooling: Rooftop, Packaged HP; HSPF 9, SEER 16.5
    - Duct Sealing/Insulation: New, in unconditioned space: sealed 10 percent and insulated to R-8
    - Water Heating: In-unit HP, Uniform Energy Factor (UEF) 3.75
    - Roof/Attic R-Value: (R-38) Attic insulation and Attic Air Sealing
    - Wall/Floor R Value: No upgrade
    - Window Solar Heat Gain Coefficient (SHGC): Title 24 Compliant
    - Air Leakage: Mix of air sealing methods: Aerobarrier and manually applied spray foam
6. **Package F. New HVAC + Prefab roof panel (AIO HP)**
    - Demonstration Site: Vera Cruz Bldg. 619
    - Heating and Cooling: Ceiling, AIO HP; COP 4.90, SEER 12.4 (bed/bath) and 1 PTHP (living room)
    - Heating and Cooling: Ceiling, AIO HP; COP 4.90, SEER 12.4 (bed/bath) and 1 PTHP (living room)
    - Duct Sealing/Insulation: New, brought in conditioned attic space and insulated
    - Water Heating: In-Unit HP, UEF 3.75
    - Roof/Attic R-Value: (R-30) Prefabricated roof panels and (R-19) attic insulation
    - Wall/Floor R Value: Elastomeric paint applied to exterior wall
    - Window SHGC: Title 24 Compliant
7. **Package G. New HVAC + Prefab roof panel + Split direct expansion HP**
    - Demonstration Site: Vera Cruz Bldg. 615
    - Heating and Cooling: Split direct expansion heat pump; HSPF 12, SEER 17
    - Duct Sealing/Insulation: New, brought in conditioned attic space and insulated

- Water Heating: In-unit HP, UEF 3.75
- Roof/Attic R-Value: (R-30) Prefabricated roof panels and (R-19) attic insulation
- Wall/Floor R Value: Elastomeric paint applied to exterior wall
- Window SHGC: Title 24 Compliant

Testing Scope to Inform EIFS Performance

For a complete picture of the thermal and moisture performance of EIFS panels, the project team used a combination of hygrothermal (heat and moisture) modelling, blower door air leakage testing, water testing, and sensors to measure temperature, relative humidity, moisture content, and dew point of the existing and retrofit assemblies.

The approach to analyzing the existing building structure after installing the retrofit panel system included the following features:

- Hygrothermal modeling using WUFI Pro version 6.5
- Blower door air leakage testing per American Society for Testing and Materials (ASTM) E3158
- Wall sensors embedded into existing walls with retrofit panels to measure the thermal, moisture performance, temperature, and relative humidity of the new wall assembly.
- Use of infrared imaging and smoke pencils to help determine areas of air leakage before and after the retrofit.
- Comparison of hygrothermal modeling to data collected and matching the modeled performance to assess for performance concerns. The project team collected building performance data for one year of building occupancy.

Hygrothermal modeling assumptions

Using WUFI Pro version 6.5 (a software program used to perform hygrothermal calculations on building components), the project team performed hygrothermal (heat and moisture) modeling for the Corona Del Rey demonstration site to assess the performance and moisture risk of the exterior wall retrofit technology. Models of the existing uninsulated walls and of the retrofit panels installed over existing walls treated with a fluid-applied Tremco ExoAir 230 air barrier were used to evaluate the moisture accumulation and condensation risk, and long-term durability of the proposed retrofit panel system compared to the existing walls and roofs, or compared to traditional site-built retrofit options. Materials were modeled using material properties from manufacturer data if the information was available. Where manufacturer data were not available, general nonspecific estimates were used from building science literature. Models were conservatively set as north-facing walls with worst case driving rain. Due to the low sun exposure (and therefore drying potential) at north elevations, these assumptions were used as a conservative estimate compared to real-world scenarios. Modeled walls were subject to three years of recorded weather or weather data from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, ending two months before retrofit to allow sufficient drying time. Most rainwater (99 percent) was assumed to be deflected by exterior cladding, with 1 percent of rain reaching the back of the cladding.

Blower door air leakage testing

Blower door air leakage testing was conducted per ASTM E3158 Standard Test Method for Measuring the Air Leakage Rate of a Large or Multizone Building, to determine the air leakage rate in terms of cubic feet per minute per square foot of envelope (cfm/sf) at 75 pascals. Testing was performed pre-retrofit, mid-construction, and post-retrofit. The pre-retrofit test was important to verify the amount of improvement from the retrofit panel and air sealing strategies. RDH worked in collaboration with the Western Cooling Efficiency Center at the University of California, Davis (UC Davis) team to complete air infiltration testing. Whole-building air leakage testing was conducted at the Corona Del Rey, but not at the Vera Cruz demonstration site. At Vera Cruz Village, compartmentalization testing by the UC Davis Western Cooling Efficiency Center measured leakage before and after roof panel retrofits, where individual units were pressurized while adjacent units remained at natural pressure.

Indoor air quality monitoring

Air quality performance was measured using sensors to monitor indoor air temperature, outdoor air temperature, and airborne particulate matter (PM) with a diameter of 10 microns or smaller. Due to limited tenant participation, results were available only for the Corona Del Rey and Vera Cruz Village sites.

Indoor air quality sensors were installed in tenant apartments to monitor pre- and post-retrofit conditions. Concentrations were calculated from the 99th percentile of daily data on worst-case condition outdoor air quality (OAQ) summer days, post retrofit.

Energy and Emissions Performance Assumptions

To better understand the effects of different whole-building retrofit approaches across demonstration sites in various climate zones, the team used weather normalized building-level utility data and evaluated energy use intensity (EUI) reductions between existing, post all-electric energy efficiency (EE) retrofits, and post-EE plus solar retrofit time periods. Baseline and retrofitted periods were weather normalized, using 10-year rolling averages of heating degree and cooling degree days from local weather stations, respective of project site.

Due to construction delays, retrofits completed at the Corona Del Rey project were limited to six months of post-retrofit summer data; thus, all energy results were adjusted to reflect summer retrofit impacts. A follow-up analysis is needed to evaluate retrofit impacts during winter months. For retrofits with larger sample sizes (8 to 40 apartments), post-retrofit energy usage was averaged, while those with smaller samples (4 to 8 buildings) were individually evaluated.

Operational greenhouse gas emissions impacts were calculated by applying the U.S. Environmental Protection Agency's conversion factors for metric tons of carbon dioxide equivalent (MTCO2e) per kilowatt-hour (kWh) at $0.000394 and MTCO2e per therm at $0.0053.

Upfront Cost and Utility Bill Savings Assumptions

Cost analysis further illustrated retrofit differences and was reported in two categories: upfront cost, based on prevailing wage rates, and utility bill savings per apartment per month. Upfront capital expenditures were represented without incentives and represented only hard costs associated with energy retrofit work, excluding solar and general and administrative expenses. Lifecycle cost was discussed for one retrofit but not for all. Utility bill savings were calculated using an effective electric and gas utility rate that was derived from actual monthly electricity and gas bills, at the building level, associated with the post-retrofit condition. The same effective rate was then applied to both pre- and post-energy usage, to remove bill impacts associated with utility rate escalations and better estimate impacts associated with changes in energy efficiency pre- and post-retrofit. Utility cost savings reflect summer months and were presented on a utility cost savings per apartment per month estimate. Almost all residents use California Alternate Rates for Energy (CARE) rates, which discount electricity bills by 30 percent to 35 percent and natural gas bills by 20 percent.

CHAPTER 3: Results

The project team analyzed the thermal and moisture performance of specific EIFS technologies and evaluated upfront cost, construction labor hours, energy, and utility bill savings for different envelope approaches bundled into whole building retrofits. Aside from achieving efficiency and GHG reduction goals, retrofits also provide non-energy benefits to tenants, including improved indoor air quality and thermal and acoustic comfort.

Retrofits were deployed across three demonstration sites chosen to reflect common existing conditions that aligned with the REALIZE-CA low-rise multifamily typology, representing 3.2 million multifamily units statewide, or about 25 percent of California households (RMI and AEA, 2019). As discussed in the previous section, retrofit variations were monitored with the goal of understanding how prefabricated industrialized approaches performed, compared to commercially available but under-utilized solutions for low-rise multifamily buildings in California. Envelope variations are detailed in Table 2 and a full list of measures and specifications is described in the previous chapter.

Table 2. Package Variation Across Demonstration Sites

Package Name	**A**	**B & C**	**D**	**E**	**F & G**
	Equipment Only	**Prefab Wall Panel (low and high R values)**	**Site-built Wall Panel**	**Conventional Envelope**	**Prefab Roof Panel**
Building Site	Corona Del Rey ROS	Corona Del Rey Bldgs. 205 and 217	Light Tree Three Bldg. X	Vera Cruz ROS	Vera Cruz Bldgs. 619 and 615
Apartment Count	152	8	5	41	8
Envelope					
New Windows		X	X	X	X
Attic Insulation and Air Sealing				X	
Improved Wall Air Tightness		X	X		X
Above-Deck Roof Insulation		X	X		X
Insulated Metal Panel Roof System					X
Wall Gut-Retrofit and Reclad			X		
Panelized EIFS Wall System		X			

Source: REALIZE-CA Demonstration Data, RMI and AEA

Site Energy and Emissions

Table 3 shows site savings for demonstrated packages when comparing pre-existing conditions to post-EE retrofit conditions. Overall, sites achieved a 28-percent reduction in electricity usage for already electrified end-uses (CEC required a minimum of 10 percent) and a 53-percent reduction in MTCO2e. These results are inclusive of solar for sites with systems already under construction.

Table 3. Energy-Use Intensity and Emissions Intensity by Site*

Site Name	Site Energy Use Intensity (kBtu/sf/yr)			GHG Emissions Intensity		% Total Improvement — Post-EE + Solar		
	Pre-retrofit	Post- EE Retrofit	Post-EE+ Solar Retrofit	Pre-retrofit	Post-EE + Solar Retrofit	% kBtu	% kWh	% MTC02
Total						**66%**	**28%**	**53%**
Corona Del Rey (Only 6 months of summer)**	16.8	9.6	solar in progress	268.8	199.2	40%	2%	26%
Light Tree Three	51.1	14.0	11.0	257.5	77.0	81%	43%	70%
Vera Cruz Village	48.1	20.9	10.8	192.6	60.2	78%	53%	69%

*Electricity savings represent only measures already using electricity in the pre-retrofit period.
**Corona Del Rey results are based on 6 months of summer data (other sites include 12 months of data).
kBtu/sf/yr=thousand British thermal units per square foot per year
Source: REALIZE-CA Demonstration Data, RMI and AEA

Results by Retrofit Type

The following sections evaluate whether retrofit approaches including prefabricated or industrialized technologies offered greater construction time, energy savings, and utility cost reductions, compared to conventional retrofit solutions, while also assessing the benefit-to-installed-cost ratio of these technologies without solar.

Envelope Costs and Installation Person-hours

This section discusses incremental cost differences between envelope approaches and highlights specific areas for cost optimization. Table 4 shows the incremental per-apartment installed cost associated with envelope measures using prefabricated envelope systems that deviate from envelope retrofits utilizing more traditional site-built retrofit options.

Table 4. Incremental First Cost per Apartment of Prefabricated Envelope Features That Deviate From Conventional Site-built Envelope Design

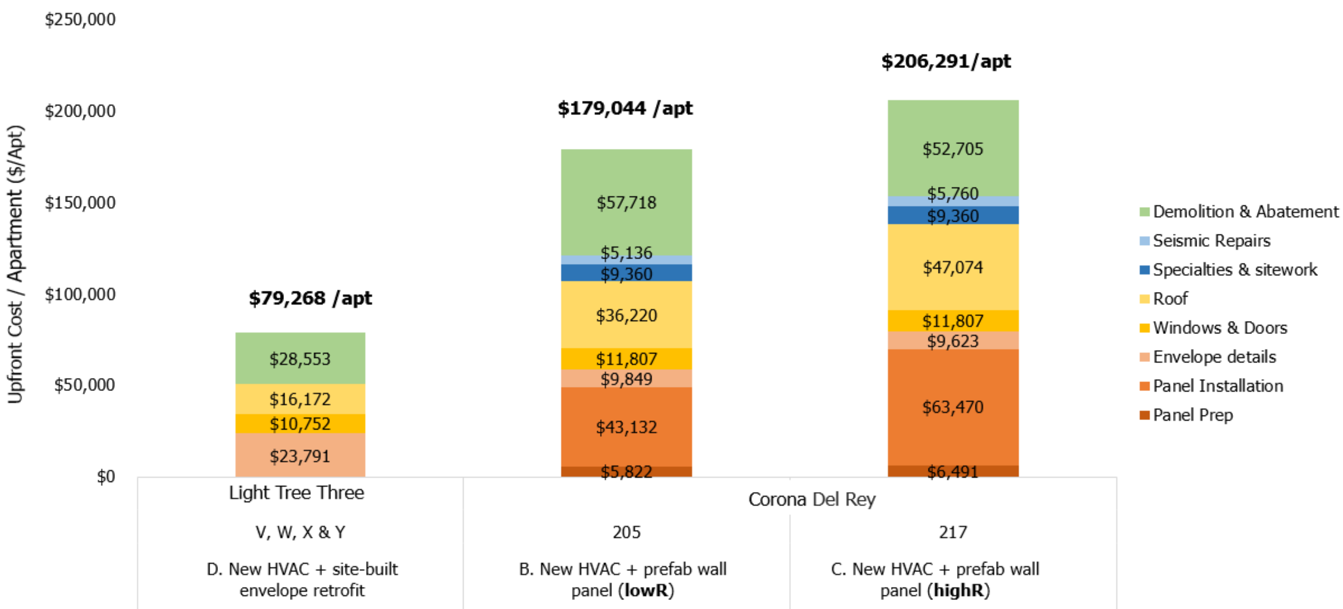
Site-built Design	Pre-fabricated Design	Incremental $/Apt First Cost Increase (+)
Attic insulation (R-38) + air sealing	Insulated roof panel (R-30) + sealing	+ $56,517 to $60,798
Wall cavity insulation (R-15) Roof insulation (R-30)	Insulated wall panel (R-15) Roof insulation (R-30)	+ $99,776

Site-built Design	Pre-fabricated Design	Incremental $/Apt First Cost Increase (+)
Wall cavity insulation (R-21) Roof insulation (R-30)	Insulated wall panel (R-21) Roof insulation (R-30)	+ $127,023

Source: REALIZE-CA Demonstration Data, AEA

Specifically, Figure 4 focuses on EIFS wall panel systems, which were demonstrated at Corona Del Rey, compared to envelope retrofits using traditional site-built retrofit options, which were demonstrated at Light Tree Three. The project team found the total envelope measure cost of the prefabricated panelized system to be nearly 2.2 times to 2.6 times higher than the cost for the site-built option. As shown in Figure 5, almost a third (26 percent to 32 percent) of this cost is attributed to demolition and abatement. Given that the EUI performance of R-21 prefabricated wall retrofits was 38 percent better than the Light Tree site-built system, there may be a cost premium that is tolerable for some developers; however, to enhance the viability of prefabricated wall retrofits in future projects, it is critical for wall panelization and panel preparation costs combined to come closer to the site-built envelope detailing cost, which requires an 80-percent to 165-percent cost compression.

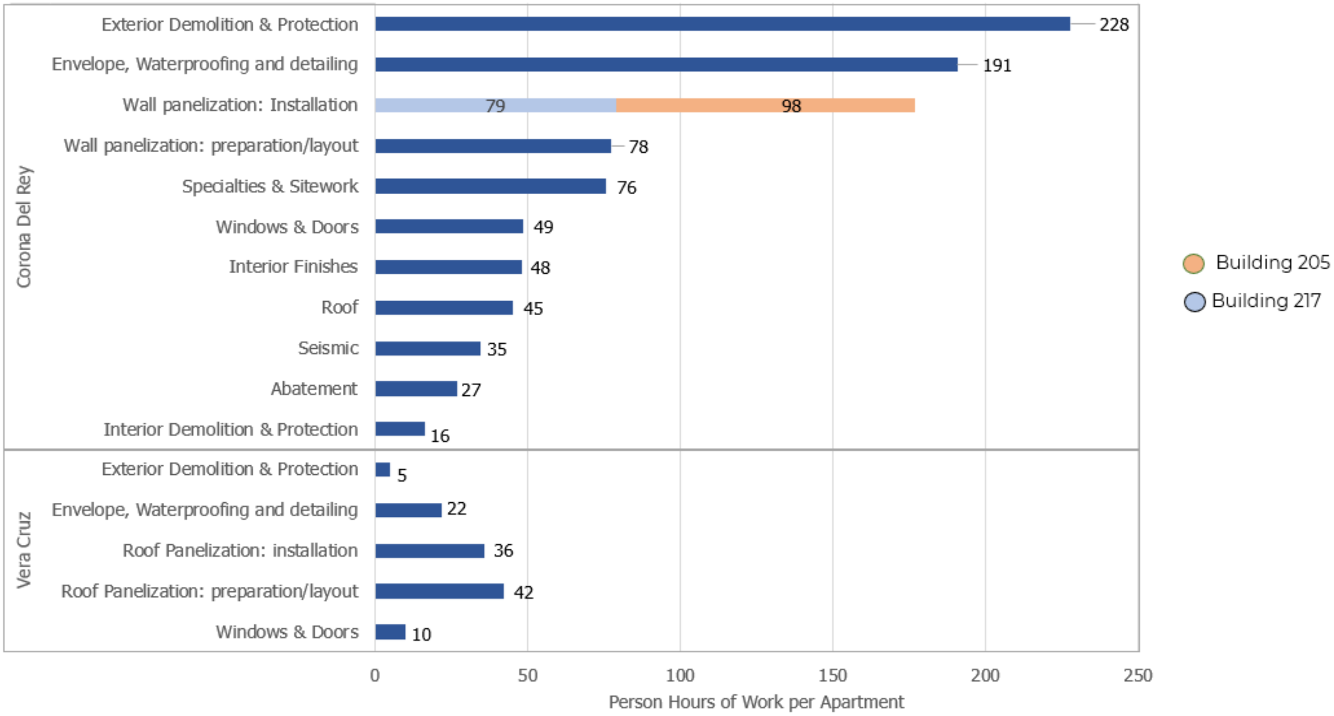
Figure 4. Installed Cost per Apartment Comparison: Site-Built Versus Prefabricated Envelope Measures



Source: REALIZE-CA Demonstration Data, AEA

Further investigation of labor hours (Figure 5) shows that demolition and abatement were very expensive and invasive, accounting for, conservatively, a third of the total person-hours of the job. When looking at relative costs and relative work, the waterproofing and detailing work (20 percent of labor hours) was a lot more involved and required more coordination than anticipated. Streamlining coordination of on-site trades and gaining experience with multiple installations could reduce the labor intensity for this scope.

Figure 5. Person-hours per Apartment Between Prefabricated Envelope Retrofits

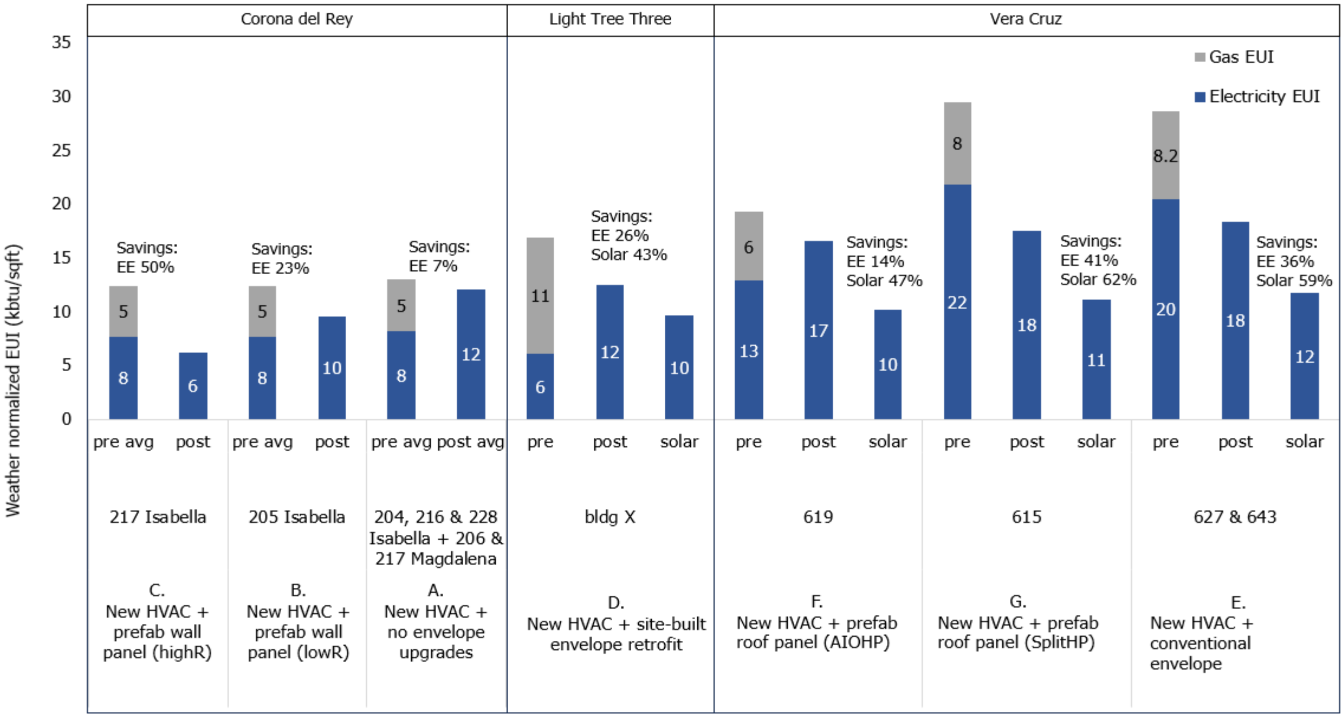


Source: REALIZE-CA Demonstration Data, AEA & DBA

Whole-building Retrofit Energy Performance

Figure 6 shows EUI reductions between existing, post-all-electric-EE retrofits, and post-EE plus solar retrofit time periods for summer months. As reflected in Figure 6, EUI reductions between pre-retrofit and post-EE retrofits (not including solar) for all demonstrated options range from 7 percent to 50 percent. Both the highest and the lowest saving retrofits are exhibited at the Corona Del Rey project — the highest savings attributed to package "B. New HVAC + prefab wall panel (high R)" (50 percent) and the lowest for "A. New HVAC + no envelope upgrade" (7 percent), which is an average across multiple buildings. Comparing these two retrofits offers the full range of potential savings for an uninsulated existing building receiving an electrification retrofit — one with no envelope upgrades and the other with the most envelope measures and the thickest R-value (R-21) recommended by the REALIZE envelope guidelines.

Figure 6. Summer, Weather Normalized EUI by Fuel Type



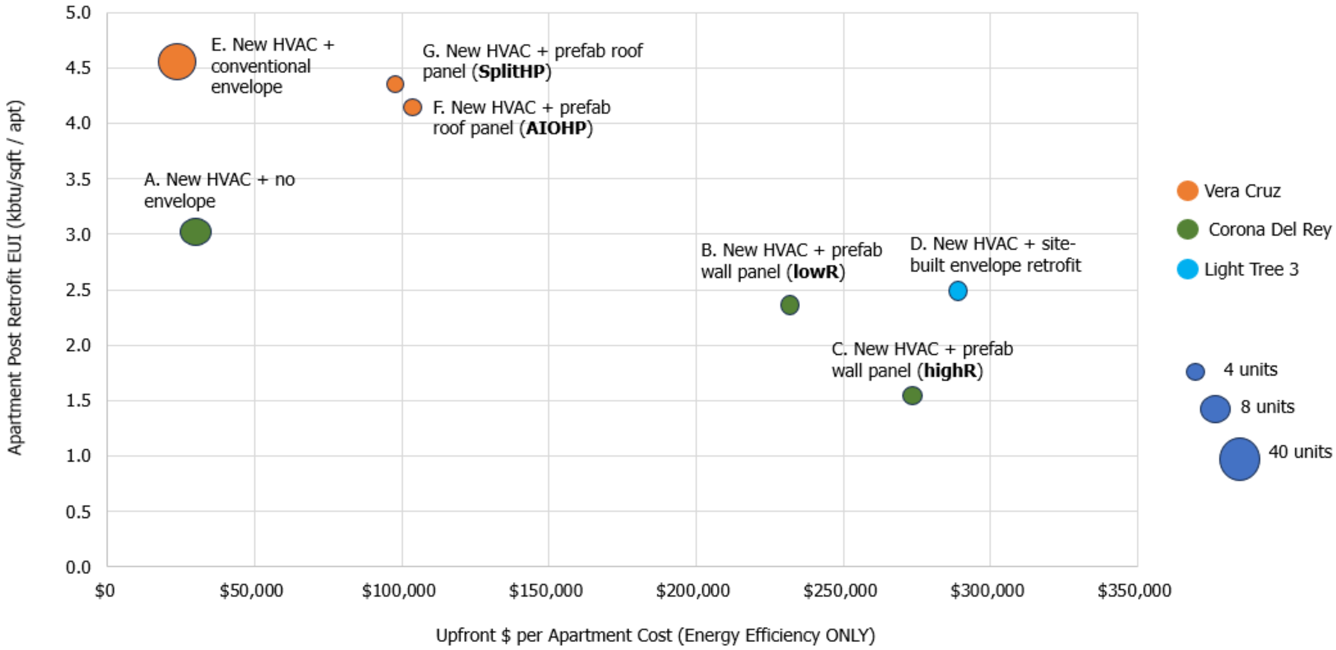
kBtu/sqft=thousand British thermal units per square foot
Source: REALIZE-CA Demonstration Data, AEA

Pairing electrification with solar also presented an opportunity for further energy reduction, and all REALIZE-CA demonstration sites have installed, or are planning to install, solar. Combined post-EE and solar results achieve 23 percent to 38 percent more operational energy reductions than EE alone.

Whole-building Retrofit Upfront Costs Relative to Energy Savings

Figure 7 provides a retrofit-by-retrofit comparison of total installed cost per apartment, relative to post-retrofit EUI per apartment. Post-retrofit EUI values are generally clustered by bedroom size, with most buildings falling into the two-bedroom or those with a higher mix of three- to four-bedroom categories.

Figure 7. Summer, Post-EE Retrofit Only: Apartment Energy Use Intensity to Upfront Cost per Apartment



Source: REALIZE-CA Demonstration Data, AEA

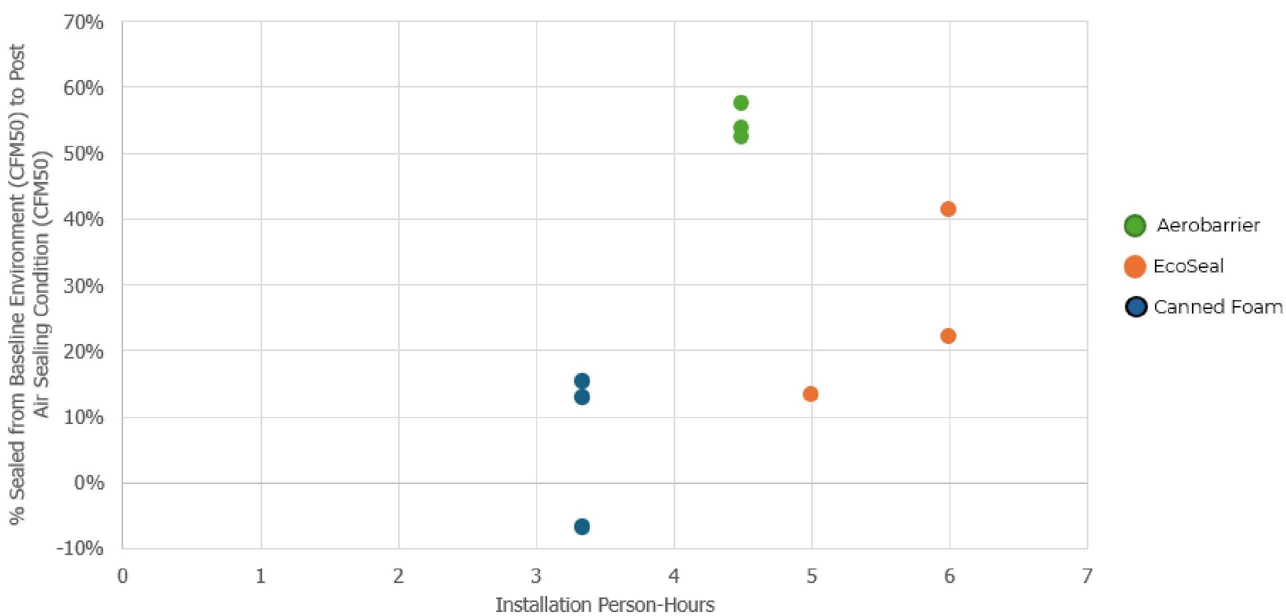
The Corona Del Rey prefabricated wall retrofit demonstrated significant EUI improvements when wall R-values were increased, although the associated incremental costs posed a financial challenge for future scalability. With a 5-percent difference in total retrofit package cost between "B. Prefab wall panel (low R-value)" to "D. Site-built envelope," total costs per apartment were similar but were largely driven by different measure costs. The site-built envelope retrofit's largest cost was associated with a demonstration of a low GWP (global warming potential) central water heating plant, while retrofit B was driven by envelope and interior finish measures. When drilling down into an envelope cost comparison between the two, the project team saw an incremental envelope cost of $99,776 per apartment for about the same R-value (R-15), which did not justify the relatively modest 4-percent EUI reduction per apartment between the two retrofits.

However, a more significant 38-percent EUI improvement was achieved when the prefab wall retrofit R-value was increased to R-21. Attributing additional savings to the presence of ceiling fans remains a consideration, and further disaggregation of these factors could be valuable for future research. Despite the enhanced performance, the incremental cost of the R-21 prefabricated wall panel retrofit ($127,023 per apartment) remained a substantial financial barrier. The high incremental cost highlighted the need for cost-reduction strategies for long-term financial feasibility of these retrofits. Specific opportunities for envelope cost reductions are discussed in the "Envelope Cost and Installation Person-hours" section.

Retrofits incorporating prefabricated roof retrofits offered notable EUI improvements compared to market-ready envelope measures, yet the higher costs suggested that targeting more affordable solutions could facilitate broader adoption. IMP roof retrofits exhibited a 5-percent to 11-percent post-retrofit EUI improvement relative to market-ready envelope measures, inclusive of attic insulation and mixed attic air sealing methods. With costs for prefabricated roof retrofits approximately four times higher, targeting a reduction to approximately $23,000 per apartment would have made this a more scalable solution.

Two of the four attics in the market-ready retrofit building were air sealed with Aerobarrier, an aerosolized elastomeric sealant, which is still considered an emerging technology. Based on compartmentalization air leakage testing results performed by UC Davis (Figure 8), Aerobarrier demonstrated superior apartment leakage reductions (50 percent to 60 percent percent) compared to manual sealing with foam (14 percent). While it is hard to know whether the performance relative to the IMP roof retrofit package was due to this technology or not, further investigation into the IMP at a lower cost point, paired with attic Aerobarrier, could serve as a more cost-effective solution while further enhancing overall energy savings over conventional envelope approaches.

Figure 8. Vera Cruz: Aerobarrier Attic Sealing Air Leakage Results Compared to Conventional Air Sealing Methods

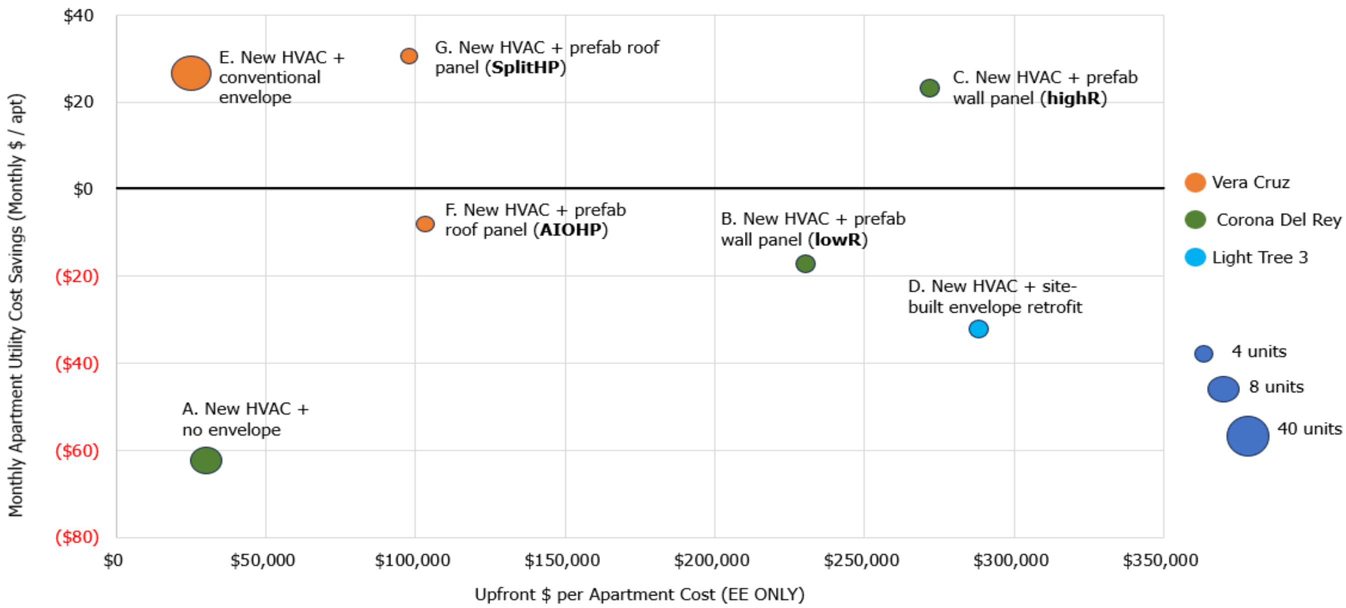


Source: REALIZE-CA Demonstration Data, AEA

Upfront Costs Relative to Utility Bill Savings

Despite California's mild climate, envelope retrofits can lower utility bills when compared to equipment-only swap-outs, but cost recovery is challenging and cannot be overcome with energy savings alone. When comparing utility cost savings per apartment per month for the "A. No envelope upgrade" retrofit, utility cost savings for all other retrofits were consistently higher (47 percent to 150 percent). However, Figure 9 reveals that energy bill savings of electrification without solar were insufficient to cover the full costs of electrification. Small returns were likely due to high electricity rates, but the project team also saw inconsistent savings across the same retrofit type. This is likely due to varying tenant behavior. For example, packages including roof panel retrofits achieved a range of average utility savings per month per apartment ($8 to $31) across the same property. Ultimately, even packages with the highest bill savings did not achieve sufficient energy savings for reasonable cost recovery (i.e., payback period).

Figure 9. Summer, Post-EE Retrofit Only: Estimated Monthly Apartment Utility Cost Savings to Whole Building Retrofit Cost per Apartment



Source: REALIZE-CA Demonstration Data, AEA

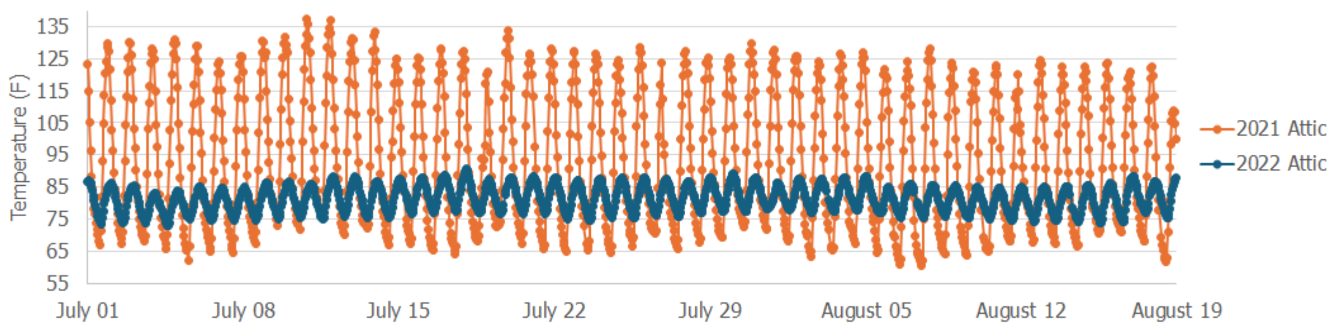
When evaluating the life-cycle cost, even the most cost-effective conventional envelope retrofit ("E. Conventional envelope"), with an initial investment of $20,000 per apartment, presented challenges in recovering costs through utility savings alone. Despite yielding the second-highest utility cost savings at $27.52 per month per apartment, the 30-year net present value analysis indicated a payback period extending beyond 30 years. Even after applying available incentives, the payback was reduced only to 24 years, highlighting the need for innovative financing. To improve the financial viability of these retrofits and accelerate their widespread adoption, it is essential to pair envelope upgrades with electrification, solar integration, and/or the monetization non-energy benefits. For example, factoring in the societal cost of carbon associated with operational carbon savings enhances the value proposition. By incorporating these broader benefits into the lifecycle cost analysis, we can better bridge the financial gap needed to make these more financially accessible and widespread.

Thermal Comfort and Indoor Air Quality

To evaluate non-energy benefits across retrofits, thermal and air quality performance were measured using blower door air leakage testing and sensors to monitor indoor air temperature, outdoor air temperature, and airborne PM with a diameter of 10 microns or smaller (PM10).

At Vera Cruz, attic temperatures were measured before and after the IMP demonstration during the same summertime period. Outdoor air temperatures were found to be similar across measurement periods, but attic temperatures were notably more stable post-retrofit. As shown in Figure 10, pre-retrofit attic temperatures showed a striking degree of overheating in the vented attic where the HVAC distribution was located, regularly swinging in 60 degree Fahrenheit (°F) (33 degree Celsius [°C]) fluctuations daily. Attic temperatures measured after roof panel installation were dramatically lower and more stable, fluctuating by 10°F to 15°F (6°C to 8°C) daily. Benefits of this stability are twofold: improved thermal comfort and reduced workload on mechanical systems by mitigating the impact of extreme temperature differentials. As a result, HVAC equipment operates more efficiently, leading to lower energy consumption and the potential for increased service life.

Figure 10. Attic Air Temperatures, With Versus Without IMP Roof Retrofit



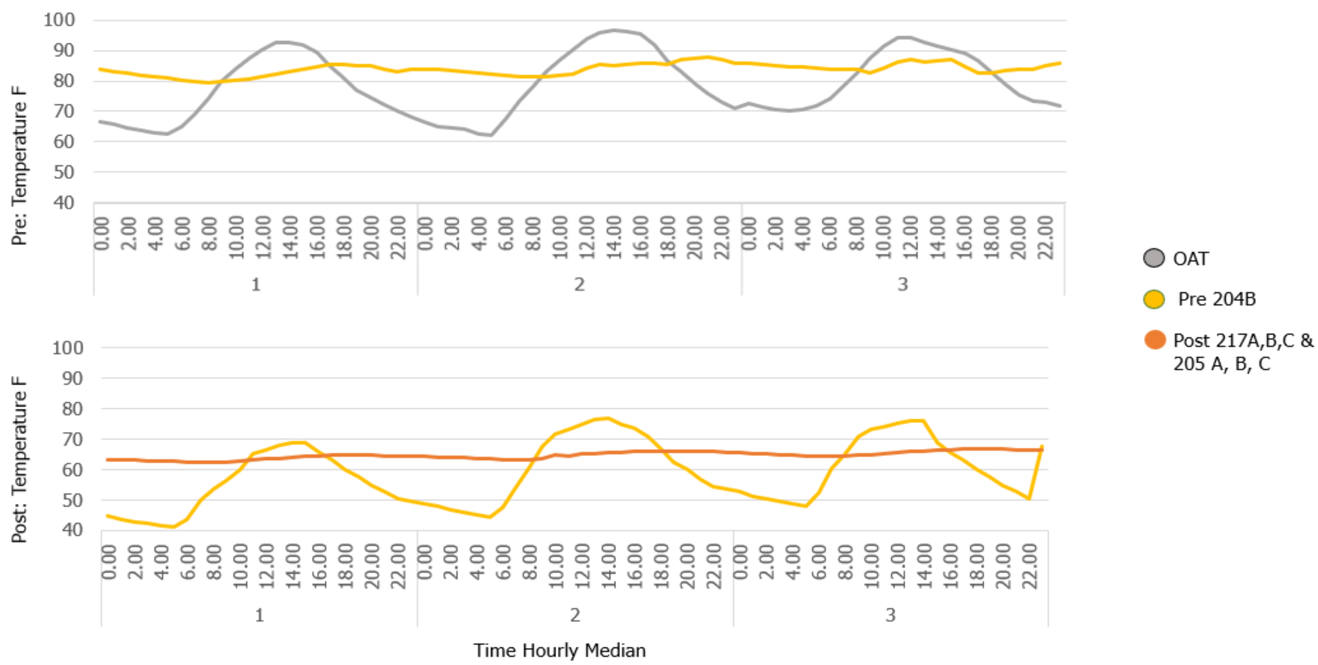
Source: REALIZE-CA Demonstration Data, RDH

Since the attic was directly adjacent to occupied spaces, these temperature measurements served as a proxy for thermal comfort within the apartments. Additionally, the controlled temperature and reduced air leakage indicated that indoor air quality improvements were occurring in units, since the reduced uncontrolled air leakage and improved ventilation in apartments meant that outdoor pollutants were less likely to infiltrate indoor spaces.

Figure 11 shows average indoor apartment temperatures at Corona Del Rey in response to outdoor air temperature, before and after the panelized wall retrofit. Fluctuations in indoor air temperatures stabilized and were reduced by 60 percent, from 9.4°F (5.2°C) pre-retrofit fluctuations to 3.6°F (2°C) post-retrofit fluctuations, implying that comfort in apartments was also more stable.

Figure 11. Corona Del Rey: Apartment Indoor Air Temperatures Relative to Outdoor Air Temperatures, Pre- and Post-retrofit

Indoor Temp. Fluctuation	pre 9.4	post 3.6
min	79	63
max	89	66

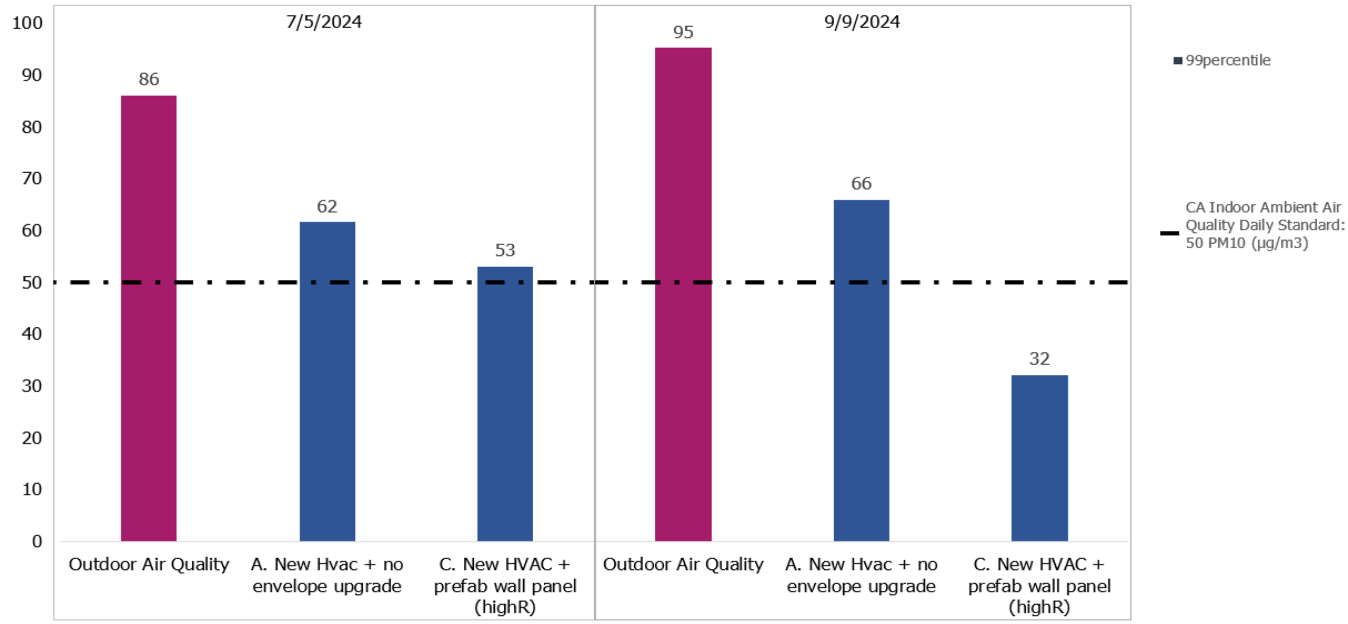


Source: REALIZE-CA Demonstration Data, AEA

Figure 12 demonstrates the protective benefits of Corona Del Rey retrofits in shielding residents from the two summer days with the highest “poor” rating of OAQ conditions. On select days, the OAQ exceeded the California indoor ambient air quality (CIAAQ) daily standard for PM10 by a factor of two.

The maximum concentrations inside envelope-retrofitted apartments were, on average, 52 percent lower than the OAQ levels, aligning more closely with acceptable CIAAQ limits compared to apartments without envelope retrofits. In the absence of envelope retrofits, PM10 concentrations were 30 percent lower than OAQ but still 20 percent to 25 percent higher than acceptable daily limits. While tenant behavior may introduce additional sources of indoor PM10, mitigation of OAQ by envelope retrofits suggests health and resilience benefits, such as reduced respiratory risks and enhanced resilience to climate-related air pollution events, all of which are particularly pertinent in California’s smog challenges and increasingly intense wildfire seasons.

Figure 12. Post-retrofit Indoor Air Quality PM10 Concentrations During Worst-case Outdoor Air Quality Concentrations



Source: REALIZE-CA Demonstration Data, AEA

Demonstration Site Challenges

California Housing Typology Limitations

Panelized solutions are currently not well-suited for the targeted California multifamily housing inventory, for several reasons, including architectural diversity, seismic concerns, and workforce challenges; all of these were considered by the project team when it was specifying and deploying packages across climate zones that employed both emerging technologies and commercially available solutions.

For example, California's moderate climate and light wood-framed building stock has limited structural capacity due to its age (adherence to antiquated building codes). This makes it difficult to recover over-cladding costs from energy savings or time and cost-compression attributed to scale. Even simple buildings present special conditions that are usually addressed in bespoke fashion, and dry rot repair is often required. The pilot demonstrations showed that more conventional improvements like effective air sealing, attic insulation, and window replacement can achieve substantial benefits without overhauling the market.

Disaggregated Supply Chain

At the Corona Del Rey and Vera Cruz projects, contractors bypassed a general contractor model, instead managing trades directly. This decision led to contracting inefficiencies, scope gaps, and schedule delays (for example, issues with mechanical penetrations and procurement and installation of roof vent installation, which would likely have been addressed by a general contractor's oversight).

Additionally, building owners requested the use of their own preferred vendors for some construction scope, which was coordinated with their respective property maintenance staff instead of with the construction team at large. This further complicated scheduling and supervision, resulting in insufficient oversight across trades.

Challenges With Turnkey and Integrated System Delivery

At the Corona Del Rey demonstration, the project team selected Dryvit-Tremco as a partner due to its claim of vertical integration, with the expectation that it would handle the entire envelope retrofit process — ranging from verifying site measurements and designing and fabricating the insulated wall panels, to delivering and installing a complete envelope retrofit, including windows, doors, roof, and trim — all under a single turnkey contract and warranty. However, this integrated approach did not materialize as planned, leading to challenges with panel installation and model-based site measurement inefficiencies.

At the Vera Cruz demonstration site, insulated metal panels had to be installed by roofers certified for that product. However, they were not familiar with this product and were not equipped to, for example, verify structural attachment for submittal and permit review. They were also unable to complete basic accessory details correctly, such as gutters and downspouts, because of their unfamiliarity with the roof panels.

Managing New Technologies Risk

Emerging technologies introduce both significant potential and inherent risks, particularly during their demonstration in real-world applications. First, ensuring that owners are able to operate, maintain, and repair new systems easily and independently throughout the building lifecycle minimizes reliance on third-party vendors or proprietary components. This approach promotes operational flexibility and reduces long-term operational risk. Second, avoiding overly complex or potentially unreliable technologies, particularly for low-income residents, who may be more vulnerable to system failures, is critical. The team strategized around potentially confusing controls or usability by creating specific operation guides for residents and ensuring that maintenance staff underwent specific equipment training to deal with unforeseen operational issues. By balancing the need for cutting-edge innovation with considerations of reliability and accessibility, the team ensured that demonstration of emerging technologies would not compromise safety or functionality of the building systems.

CHAPTER 4: Conclusion

The project findings determined that panelized retrofit solutions could support energy retrofits at scale in aging multifamily units across California, but only in limited applications. The key benefits of panelized envelope retrofits are likely to be realized, first, in heating-dominated climates (such as the northeastern United States), where the cost and emission savings associated with deep energy retrofits are the greatest, justifying the increased cost of these retrofits when compared with equipment-only or conventional envelope upgrades. Deep panelized retrofits are appropriate for a small number of residential buildings in California in heating-dominated climate zones and could also provide additional seismic performance improvements in pre-1980 light wood-frame buildings requiring seismic retrofits.

In addition to the cost challenges just described, the Corona Del Rey pilot demonstration has also highlighted the challenges associated with installation of retrofit panels on buildings with complex exterior geometries, especially overhangs. Such protrusions require additional abatement work, raising costs and extending project timelines on retrofit projects. Of the building typologies that were the focus of this research, this challenge is most prevalent on townhouse and garden-style buildings. These challenges may limit the applicability and cost-effectiveness of panelized retrofits in California's low-rise multifamily light wood-frame residential stock.

Key project findings are as follows:

- **Light-touch envelope solutions are sufficient for package deployment in the California affordable multifamily retrofit market at this time.**
    - Promising, more-intensive emerging products for this market include Aerobarrier and insulated metal roof panels, as well as nonpanelized forms of over-cladding and exterior insulation.
    - Most buildings in the targeted building stock have deficient assemblies and substantial deferred maintenance that cannot be addressed by incentives alone.
- **Improving the market's access to insulated over-cladding strategies will require greater funding coordination and quantification of non-energy benefits.**
    - This requires integrating/stacking funding from programs supporting affordable housing renovation and preservation, like federally funded, state-administered Low-Income Housing Tax Credits.
    - Monetization of non-energy benefits such as indoor air quality, thermal and acoustic comfort, and building resiliency are also necessary to capture the total value proposition of whole-home retrofits.

- **Whole-building retrofits can be more cost-effective than traditional, site-built renovation/rehabilitation projects.**
- **Industrialized panelization is not the key to unlocking this opportunity.**
    - While it was important, vertical integration was not enough to achieve desired cost and labor efficiencies. Future efforts with different structures and institutional leadership could be found otherwise.
    - Considerable additional investment is required to commercialize the panelized solution market.
    - The 3D scan workflow demonstration was promising, but it is not the most important cost to target for cost-compression.

Subject to additional efforts to improve cost compression, and to additional research and development to maximize the potential benefits of retrofit panels with respect to seismic performance, retrofit panel products could form part of a vertically integrated deep energy retrofit package to meet the needs of the California market. This project's construction and field validation over the remainder of 2022 will lay the groundwork for future commercialization and scale-up of this industrialized deep energy retrofit approach for California.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
3D	three-dimensional
ABC	Advanced Building Construction
ACH50	air changes per minute at 50 pascals
AEA	Association for Energy Affordability
AIO	all-in-one
ASTM	American Society for Testing and Materials
°C	degrees Celsius
CARE	California Alternate Rates for Energy
CEC	California Energy Commission
cfm/sf	cubic feet per minute per square foot
CIAAQ	California indoor ambient air quality
COP	Coefficient of Performance
DBA	David Baker Architects
EE	energy efficiency
EIFS	exterior insulation and finish systems
EPIC	Electric Program Investment Charge
EUI	energy use intensity
°F	degrees Fahrenheit
GHG	greenhouse gas
GWP	global warming potential
HP	heat pump
HPSF	Heating Seasonal Performance Factor
HVAC	heating, ventilation, and air conditioning
IECC	International Energy and Conservation Code
IMP	insulated metal panel
kBtu	thousand British thermal units
kBtu/sqft	thousand British thermal units per square foot
kWh	kilowatt-hour
MTCO2e	metric tons of carbon dioxide equivalent
OAQ	outdoor air quality
PM	particulate matter

Term	Definition
PM10	particulate matter with a diameter of 10 microns or smaller
PTHP	packaged terminal heat pump
PVC	polyvinyl chloride
R&D	research and development
RDH	RDH Building Science
REALIZE-CA	REALIZE California
RMI	Rocky Mountain Institute
ROS	rest of site
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
Title 24	Title 24 – California Building Standards Code regulating energy efficiency, water efficiency, and safety for residential and commercial buildings
UC Davis	University of California, Davis
UEF	uniform energy factor
U.S.	United States
WUFI	Wärme Und Feuchte Instationär, which translates to Heat and Moisture Transiency
ZNC	zero net carbon
ZNE	zero net energy

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Project Deliverables

- Task 2 – Prototype Design
- Task 3 – Prototype Production and Testing
- Task 4 – Demo and Installation
- Task 5 – Measurement & Verification (M&V)
- Task 6 – Commercialization
- Task 7 – Evaluation of Project Benefits