CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Mass Deployment of Energy Efficiency Retrofits in Multifamily Homes in California

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- Association for Energy Affordability
- David Baker Architects
- RDH Building Science
- University of California, Davis Western Cooling Efficiency Center

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.

Mass Deployment of Energy Efficiency Retrofits in Multifamily Homes in California is the final report for EPC-17-040 conducted by the Rocky Mountain Institute. 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

REALIZE California (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.

REALIZE-CA was funded by awards from the California Energy Commission's Electric Program Investment Charge (EPIC) 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 retrofit technologies in multifamily buildings statewide, while aggregating retrofit demand and addressing financing barriers.

Technologies for the REALIZE-CA retrofit package were selected based on learnings from pilot demonstrations funded by California Energy Commission awards: EPC-17-040, Mass Deployment of Energy Efficiency Retrofits in Multifamily Homes in California; EPC-19-032, Mechanical Pods; and EPC-19-036, Varieties of Prefabricated Envelope Solutions for California Low-rise Buildings. REALIZE-CA retrofits are customizable and feature all-electric appliances, high performance roof systems and windows, and commercially available envelope upgrades. The program retrofitted over 350 units of multifamily affordable housing units (300,000-plus square feet) in disadvantaged communities throughout California, conducting demonstrations at four apartment complexes in Corona, Richgrove, Fresno, and East Palo Alto, California.

Key results include, but are not limited to:

- Reduced emissions, energy consumption and utility bills for tenants/ratepayers.
- Overall, portfolio-wide savings, achieving a 21-percent reduction in electricity usage for already electrified end uses and a 43-percent reduction in metric tons of carbon dioxide equivalent (MTCO2e) when comparing pre-existing conditions to post-energy-efficiency retrofit conditions. These results include solar for sites with systems already under construction.
- Improved building resilience.
- Improved indoor air quality and thermal comfort for tenants/ratepayers.
- Workforce partnership with the State Building and Construction Trades Council of California.
- Preservation of affordable housing.

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

California has a large multifamily inventory, comprising primarily low-rise apartments built in the 1960s and 1970s. While a smaller share of the state's overall greenhouse gas emissions is attributable to residential buildings, these apartments rely primarily on natural gas appliances for their heating and cooling and the technologies required to electrify them are already available. As a result, electrification of the state's aging multifamily buildings represents a significant opportunity to reduce greenhouse gas emissions, potentially lower utility costs, and make buildings safer.

REALIZE California (REALIZE-CA) is a programmatic effort to scale energy-efficiency retrofits in California's affordable multifamily buildings. By focusing on the rapid deployment of streamlined retrofit packages tailored to the most common buildings in the state's multifamily affordable housing stock, REALIZE-CA provides a roadmap for transforming buildings and communities.

REALIZE-CA was funded by awards from the California Energy Commission's Electric Program Investment Charge (EPIC) program, which invests in scientific and technological research to accelerate transformation of the electricity sector to meet the state's energy and climate mandates. As a coordinated portfolio of awards, REALIZE-CA standardized, tested, developed, and demonstrated retrofit technologies in over 300,000 square feet of multifamily buildings in disadvantaged communities statewide, while also aggregating retrofit demand.

Key Results

- Over 3 million units of existing multifamily housing, representing 25 percent of households statewide, are eligible to receive the recommended/REALIZE-CA retrofit package.
- Scale can be achieved using emerging and commercially available technologies:
    - Technologies highlighted in the Netherlands' Energiesprong program (mechanical pods and prefab panelized wall systems) are not necessary to deploy a retrofit package that can be scalably deployedin the multifamily retrofit market at this time.
    - Products developed for California's particular market conditions did show strong promise, including new insulation products and heat pump equipment.
- Some degree of vertical integration of delivery entities can improve scale and cost compression.
    - Delivery entities, including general contractors and energy savings companies, should be nimble enough to leverage, train, and expand the existing workforce.
- Energy bill savings and incentives are insufficient to cover the full cost of multifamily retrofits in states with high electricity rates, like California. This is due to the cost premium for electric equipment, although operational savings from decreased usage/improved envelope performance can occasionally offset these costs.

- Monetizing non-energy benefits and leveraging non-energy funding to achieve a basic standard of livability (comfort, health, resilience) are critical for retrofits of pre-Title 24 structures, and these should be prioritized in the future.

Project Purpose and Approach

The project was initially inspired by the Energiesprong retrofit program developed in the Netherlands. That approach utilizes prefabricated and emerging technologies to rapidly deploy whole-building retrofits for the country's multifamily housing. REALIZE-CA aimed to adopt this approach by developing a standardized retrofit package for California's low-rise multifamily housing. Specifically, REALIZE-CA sought to:

1. Standardize energy efficiency retrofits to double energy efficiency in existing multifamily buildings by 2030.
2. Reduce retrofit package costs by 50 percent while increasing financing options for efficiency measures.
3. Develop a business model driven by demand aggregation and manufacturer participation.

The team began to identify the most common multifamily typologies statewide and developed preliminary retrofit guidelines, based on energy modeling and structural analysis results, to identify technologies for non-intrusive, rapid delivery. Two other EPIC grants — EPC-19-032, Mechanical Pods, and EPC-19-036, Varieties of Prefabricated Envelope Solutions for CA Low-rise Buildings — became a part of this research effort, with a focus on fabrication and lab testing technologies for commercialization. Multiple whole-building retrofit packages were deployed and monitored across four demonstration sites to understand how industrialized approaches performed in comparison to commercially available but under-utilized solutions for multifamily buildings in California.

The retrofit technologies that were demonstrated included:

- Replacement of single-pane sliding windows with double-pane windows to meet the Title 24 energy code.
- High-performance installation detailing to improve resilience and quality.
- The use of AeroBarrier, an aerosolized elastomeric sealant, to seal attic leaks more effectively than manual spray foam methods.
- The removal of old insulation and the installation of R-44 blown-in cellulose insulation where existing insulation was below R-30 (blown) or R-38 (batt).
- The installation of Villara AquaThermAire, a 3-in-1 heat pump providing space heating, cooling, and hot water using a single compressor, for one of the sites.
- The demonstration of a high-static ducted mini-split heat pump and a split heat-pump water heater for the other sites.
- Improved indoor air quality, thermal comfort, and acoustic comfort for residents.

Demonstration sites were selected to align with typology results:

- Corona Del Rey Apartments — 1148 D St., Corona, CA 92882
- Vera Cruz Village Apartments — 631 Rd. 210, Richgrove, CA 93261
- King's View Manor — 949 E. Annadale Ave., Fresno, CA 93706
- Light Tree Apartments — 1804 E. Bayshore Rd., #100, East Palo Alto, CA 94303

The finalized REALIZE-CA retrofit is an outcome of prototype demonstration results and features all-electric appliances, high-efficiency heat pump mechanical systems, high performance roof systems and windows, as well as light envelope upgrades when/where necessary.

State Climate Nexus

The primary natural gas end uses in multifamily buildings are the space heating components of heating, ventilation, and air conditioning systems and domestic hot-water systems. Electrification of these systems will have the greatest impact on carbon reductions. However, because the benefits of electrification go beyond carbon reduction, electrification should span all fossil-fuel-burning systems and appliances, including stoves and ovens, clothes dryers, pool and spa heaters, and other miscellaneous equipment. For example, electrifying gas cooking appliances like ovens and stovetops can improve indoor air quality for residents, which is especially important for children's health (Lin et al., 2013). Additionally, once a building is electrified, the property can be removed from the gas distribution network, a crucial part of California's long-term decarbonization strategy.

Accelerating the electrification of multifamily buildings aligns with the direction of California's statewide decarbonization initiatives. The multifamily sector will help meet the efficiency and greenhouse gas reduction objectives of policies such as Senate Bill 350 (Clean Energy and Pollution Reduction Act, 2015), Senate Bill 1477 (Low-emissions Buildings and Sources of Heat Energy, 2017–2018), Assembly Bill 3232 (Zero-emissions Buildings and Sources of Heat Energy, 2017–2018), and Assembly Bill 1232 (Affordable Housing: Weatherization, 2019–2020).

Environmental Benefits

This research project achieved its electricity reduction goals (a minimum 10-percent reduction in electricity usage across the portfolio of at least 300,000 square feet of multifamily buildings located in disadvantaged communities in electric investor-owned utility service areas). An overview of key project results is outlined in Table ES-1, by demonstration site.

Table ES-1: Energy Use Intensity and Emissions Intensity by Site*

Site Name	Site Energy Use Intensity (kBtu/sf/yr)			Greenhouse Gas 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						**55%**	**21%**	**43%**
Corona Del Rey (Only 6 months)**	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%

Site Name	Site Energy Use Intensity (kBtu/sf/yr)			Greenhouse Gas 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
Vera Cruz Village	48.1	20.9	10.8	192.6	60.2	78%	53%	69%
King's View Manor	51.0	38.7	solar in progress	265.8	168.3	24%	4%	17%

*Electricity savings reflect measures already using electricity in the pre-retrofit period.
**Corona Del Rey results are based on 6 months of summer data, as opposed to 12 months.
EE=energy efficiency; kBtu=thousand British thermal units; kBtu/sf/yr=thousand British thermal units per square foot per year; kWh=kilowatt-hour
Source: REALIZE-CA Demonstration Data, RMI & AEA

Economic Benefits

Deploying standardized retrofit packages can both provide stable careers for interested trades and contractors and transform residential construction. REALIZE-CA partnered with the California State Building and Construction Trades Council of California to focus on these careers, incorporating existing statewide training infrastructure and signatory contractors.

By breaking down the standard retrofit package according to trade, REALIZE-CA found that, on average, package installation required 7 core trades and between 13 to 15 workers. These core trades will be able to update their respective apprenticeship/training curriculums for standardized package equipment and develop strategies for (signatory) contractor training.

Additional benefits include the preservation of nonsubsidized affordable housing. Building conditions like age, location, and other market factors allow nonsubsidized affordable properties to offer rents that are affordable to lower income households. As there are over one million nonsubsidized affordable units in 38,643 properties statewide (California Housing Partnership, 2024), REALIZE-CA can play a vital role in preventing these properties from losing their affordability, due to owner decisions to opt out, sell, or convert these properties to market rate.

Health Benefits

Due to the negative health impacts and poor indoor air quality resulting from gas appliances and substandard ventilation, tenants of REALIZE-CA demonstrations experienced improved indoor air quality, as demonstrated by demonstration-site measurement and verification data. The standard REALIZE-CA package is also projected to increase tenant safety during extreme weather events, such as heat waves and wildfires, when tenants are most impacted by indoor air quality and access to cooling.

In addition, the REALIZE-CA package was designed so that tenants can remain in place during installation, mitigating fears of displacement and avoiding relocation issues during construction. And, while this wasn’t the case at every pilot demonstration, since some building owners were able to relocate tenants as part of a larger site capital improvement project, the REALIZE-CA retrofit package can be installed without tenant displacement.

Knowledge Transfer and Next Steps

SVCE Multifamily Electrification Direct Install

REALIZE-CA currently supports the Association for Energy Affordability's Silicon Valley Clean Energy (SVCE) Multifamily Direct Install proposal, which funds all-electric retrofitting of (deed-restricted) affordable multifamily properties in the SVCE service territory. The REALIZE scope includes direct install program support, including, but not limited to, typology study, retrofit package specifications, case studies, and communications support.

Multifamily Retrofit Program Design

REALIZE-CA identified several opportunities to export program learnings and amplify impact, including assisting state energy offices in the development of state-funded residential retrofit programs and administration of Inflation Reduction Act funding. Specifically, REALIZE-CA provided guidance to state energy offices in Washington and Oregon during the award period, as follows.

- The Washington Inflation Reduction Act Administrator RFP adopted most of the recommendations REALIZE-CA provided through the Washington Building Decarbonization Coalition, including:
    - Both Inflation Reduction Act home energy programs (Home Efficiency Rebates and Home Electrification and Appliances Rebate) are to be implemented by a single, statewide administrator responsible for:
        - Outreach and community engagement (including incentive website).
        - Energy assessment and project scoping.
        - Management of contractor training network.
        - Incentive administration and financing.
        - Commissioning and quality assurance.
        - Reporting and data collection.
- Oregon Senate Bill 1823, One-Stop Shop, requires the Oregon Department of Energy to establish a statewide clearinghouse (resource) for energy-efficiency incentive administration across programs; this includes a universal app for energy-efficiency incentives.

Challenges and Future Research

REALIZE-CA identified several challenges and considerations for future research:

- **The Energiesprong Approach** — For a number of reasons, including architectural diversity, seismic concerns, and workforce challenges, this strategy is not very effective in retrofitting the targeted multifamily housing inventory.
- **Integrated System Delivery** — Despite efforts to contract turnkey delivery providers, the level of vertical integration required to achieve the anticipated cost and time savings does not currently exist in the market. In addition, due to building owners' preference for preferred vendors and limitations regarding contractor selection for panel

installation, it was impossible for the project team to utilize a general contractor model. This led to contracting inefficiencies, scope gaps, and schedule delays.

- **Emerging Technologies** — REALIZE-CA deployed a number of emerging technologies in various standardized retrofit packages. Each technology represented potential and risk, as several are not commercially available and certain products required new warranties and training for building owner maintenance staff and tenants. Future research should continue to strike a balance between innovation and the reliability and practicality concerns of building owners and tenants.

CHAPTER 1: Introduction

Life is hard. Retrofitting multifamily buildings doesn't have to be.

Over the course of 7 years, REALIZE-CA developed the technological and market breakthroughs required to scale multifamily net-zero-carbon energy efficiency (EE) retrofits in California. In doing so, the project supported the state's achievement of its energy mandates by demonstrating the environmental, economic, and health benefits of a standardized retrofit program in one of the state's largest building typologies: multifamily housing. In 2021, 3 million of California's 13.1 million residential units were apartments (U.S. Census Bureau, 2024). The California Energy Commission (CEC) found that space heating and water heating end uses drive 88 percent of residential fossil-fuel consumption. This was accomplished by deploying and studying a variety of all-electric EE retrofit packages composed of emerging technologies and commercially available solutions.

California's building sector accounts for 25 percent of the state's greenhouse gas emissions, making building decarbonization a top priority in meeting California's climate change mandates. REALIZE-CA has developed a preliminary set of standardized retrofit packages for multifamily buildings, which constitute roughly 31 percent of California's dwelling units (Webster et al., 2024), and tested their performance in the real world on several demonstration sites throughout the state.

In the United States, current holistic building-retrofit solutions are multi-layered, expensive, and difficult to capitalize, resulting in low adoption rates and limited opportunities to decarbonize buildings. Primary cost barriers include costly envelope improvements and non-energy capital improvement needs, like structural repairs or plumbing distribution issues. As a result, REALIZE-CA retrofit packages were designed to address common deferred maintenance issues for targeted buildings and to avoid projects requiring more aggressive envelope measures.

REALIZE-CA addressed the numerous barriers to scaling EE retrofitting of multifamily properties statewide, which include complex financial arrangements for low-income multifamily housing owners, insufficient access to capital, substantial building stock with high levels of deferred maintenance, and under-served or remote locations of residents (Scavo et al., 2016). Additional building owner concerns include an unclear value proposition, a lack of confidence in achieving savings, and project technical complexity.

The goal of REALIZE-CA was to standardize retrofit packages that can be installed relatively quickly with minimal tenant disruption and to develop a business model that addresses the barriers to large-scale adoption of EE retrofits in multifamily housing in disadvantaged communities. Specifically, project objectives:

1. Standardized retrofits to double EE in existing multifamily buildings by 2030.
2. Reduced retrofit-package costs by 50 percent while increasing financing options for efficiency measures.

3. Developed a business model driven by demand aggregation and manufacturer participation.

CHAPTER 2: Project Approach

The project was initially inspired by the Energiesprong retrofit program developed in the Netherlands. This approach combines two key prefabricated technologies — exterior envelope systems and all-in-one mechanical systems — into a fully integrated whole-building retrofit designed for the country's geometrically simple, masonry housing stock. At the start of the REALIZE-CA project, the team aimed to adopt this approach to enable standardized and scalable deployment of zero-carbon retrofits in California.

Market Characterization

The first step in developing standardized retrofit solutions required identifying the most common multifamily building types statewide, which categorized California's multifamily buildings by factors including vintage, mechanical systems, and climate zone. Analysis determined wood-frame, low-rise typologies to be the most common in the multifamily building stock, collectively representing over 2 million units across California. For a detailed description of the typology study findings, see the *REALIZE Building Characterization* report (RMI and AEA, 2019). The team used these findings to guide demonstration site selection and to ensure that technologies developed would be able to scale across typologies, predominantly comprising garden-style, townhouse, and "loaded-corridor" buildings (a building with rooms on one side or both sides of a corridor), with two-story structures consisting of between 5 and 49 units being the most common.

Demonstrated Retrofit Variation

To identify retrofit approaches applicable for the targeted multifamily building stock statewide, the team conducted robust parametric energy modeling and analysis of typology structural characteristics. Findings were synthesized in preliminary retrofit guidelines. Methods of that effort informed RMI's *Accelerating Residential Building Decarbonization Market Guidance to Scale Zero-Carbon-Aligned Buildings* report (MGR), which was developed by the Advanced Building Construction (ABC) Collaborative in partnership with the United States Department of Energy and several of its national laboratories (Webster et al., 2024). The MGR provides state-level recommendations for appropriate zero-carbon-aligned retrofit packages for United States residential building stock. It is accompanied by an interactive dashboard (Webster et al., 2024), 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 project team decided to align demonstration and commercialization efforts with the MGR-recommended scalable retrofit solutions (found on pages 39 to 60).

In parallel, it became clear that Energiesprong-specific industrialized technologies were not yet available in the U.S. market. As a result, two other initiatives funded by the Electric Program Investment Charge (EPIC) — EPC-19-032, Mechanical Pods, and EPC-19-036, Varieties of

Prefabricated Envelope Solutions for California Low-rise Buildings — were integrated into the REALIZE-CA retrofit effort. These projects focused on collaboration with manufacturing partners to support product development, fabrication, and laboratory testing of technologies for deployment.

Findings from REALIZE-CA energy modeling and RMI's MGR report showed that exterior wall retrofits were not always necessary to achieve zero-net-carbon retrofit goals, prompting the team to set up a comparative field study to best identify scalable retrofit methods. Multiple whole-building retrofit approaches were deployed and monitored across four demonstration sites. Retrofit specifications and details are discussed in the "Results" section of this report (see Chapter 3). Testing across sites enabled a comparison of technologies representing varying levels of market readiness and prefabrication. Performance metrics and installation were assessed, with particular attention paid to minimizing occupant disruption and enabling rapid delivery of retrofit solutions for low-rise multifamily buildings in California. Demonstration sites were selected to align with typology results:

- Corona Del Rey Apartments — 1148 D St., Corona, CA 92882
- Vera Cruz Village Apartments — 631 Rd. 210, Richgrove, CA 93261
- King's View Manor — 949 E. Annadale Ave., Fresno, CA 93706
- Light Tree Apartments — 1804 E. Bayshore Rd., #100, East Palo Alto, CA 94303

REALIZE-CA Retrofit

By aggregating demand according to owner portfolios with common building characteristics, this research project sought to leverage volumetric pricing while establishing a consistent project pipeline that could be deployed within a matter of weeks through trained contractor networks statewide. It is also important to note that, although retrofit packages were specified for targeted buildings, the project team's approach was meant to be iterative — actively leveraging learnings across demonstrations and adapting for future deployment across other typologies.

The finalized REALIZE-CA retrofit is an outcome of demonstration results and features all-electric appliances, high-efficiency heat pump mechanical systems, high performance roof systems and windows, as well as light envelope upgrades when/where necessary. Although the package is standardized with typical design details and specifications, it can be adapted to the unique conditions of each building. The project developed the REALIZE-CA Design & Installation Guide (AEA et al., 2024), which includes package product specifications and drawings (design details) to ensure efficient permitting and proper installation by contractors.

Perhaps most importantly, the package can be deployed using commercially available components, although specified emerging technologies, such as the Villara AquaThermAire (AQTA) and AeroBarrier, can also be used in package deployment. An overview of desirable building characteristics for the recommended package is shown in Table 1.

Table 1: Preferred Building Criteria

Location	Priority project areas/regions with the greatest number of multifamily affordable units (Central Valley, Southern California, San Francisco Bay Area)
Owner portfolio size	3-5+ sites
Affordability	Serving 30% to 80% AMI
Vintage	Any
Historic status	Listed historic buildings are not eligible.
Stories	1 to 2 stories
Structure	Conventional wood framing
Exterior wall	Insulated or uninsulated
Cladding	Any
Attic	Any
Roof	Any
Windows	Any
Electrical capacity	Buildings without adequate electrical capacity are not eligible.
Heating system	Any (ducted or packaged, gas or electric)
Cooling system	Buildings without existing air conditioning are not eligible.
Hot water system	Unitized only. Central water heating is not eligible.
Appliances and fixtures	Any

Source: REALIZE-CA Design & Installation Guide

Existing Conditions

Deterioration, including plumbing failures, structural deficiencies, and hazardous materials that could prevent the work or constitute active life safety hazards for occupants, must be addressed by owners to be eligible. Unless funded as part of the owner's scope in a planned capital improvement or rehabilitation, the criteria shown in Table 2 would (likely*) render a prospective building ineligible.

Table 2: Problematic Building Conditions

Plumbing failures	Major capital repairs (e.g., significant active leaks) must be resolved prior to package installation.
Structural failures	Major capital repairs must be resolved prior to package installation.
Mold, organic growth	If mold/organic growth is present at the site, the building-owner-proposed scope of work must be sufficient to resolve the issue (e.g., insufficient bathroom ventilation versus a significant waterproofing issue).

Asbestos, lead	The standard retrofit is designed to not significantly disturb surfaces that may be contaminated with lead or asbestos, so the presence of these materials must be disclosed, since it will impact eligibility.
Cladding condition	Existing cladding must not show signs of significant bubbling or cracking, or other evidence of wall waterproofing failure.
Firewalls	The fire separation between units must be intact.
Electrical	Knob and tube wiring or other recalled electrical products must be replaced by the building owner.
Duct condition	Ductwork must be accessible and sealable, or in good condition. Asbestos on ductwork must be accessible for remediation or removal.

*Note: Pending field audit verification and other factors considered by the project team.
Source: REALIZE-CA Design & Installation Guide

Market Solutions

REALIZE-CA explored new financing mechanisms throughout the project, including strategies to solve the split-incentive issue. The split-incentive issue is particularly challenging in deed-restricted affordable housing buildings, where tenants pay their utilities and owners are unable to recover the upfront costs for deep efficiency upgrades over time through energy savings.

In addition, affordable multifamily building owners have relatively few options for financing major capital improvements unless upgrades coincide with a major recapitalization event. The project defined periods outside of such recapitalization events as "mid-cycle." During mid-cycle periods, the up-front costs of deep efficiency and electrification upgrades are difficult to finance, for the following key reasons:

- **Mortgage Lenders:** Lenders hold exclusive approval rights over — and may prohibit — the additional loan indebtedness required to fund efficiency upgrades, whether such debt is in the form of a subordinated, junior mortgage loan or a secured equipment loan.
- **Tax Equity Investors:** Investors in buildings funded by the Low-Income Housing Tax Credit have approval rights over any significant additional indebtedness taken on by the buildings.
- **Rent Restrictions:** Because of restrictions on rent, affordable housing properties usually have limited cash reserves, other than the minimum required for repairs and ordinary capital replacement. They typically do not have surplus revenue (after operating expenses and existing debt servicing) to qualify for additional debt to finance deep-energy retrofits.
- **Utility Allowances:** Many subsidized housing programs have a mechanism for ensuring that tenants' living expenses do not exceed a certain percentage of their incomes. This mechanism consists of a "gross rent" cap, which is the sum of the tenant's rent plus a utility allowance to pay their utilities. State regulations governing utility allowances provide protections for tenants and allow Affordable Multi-Family Housing building

owners to increase rents (subject to affordability caps on the total of monthly rent plus the utility allowance) to recoup the cost of upgrades that lower tenant utility costs.

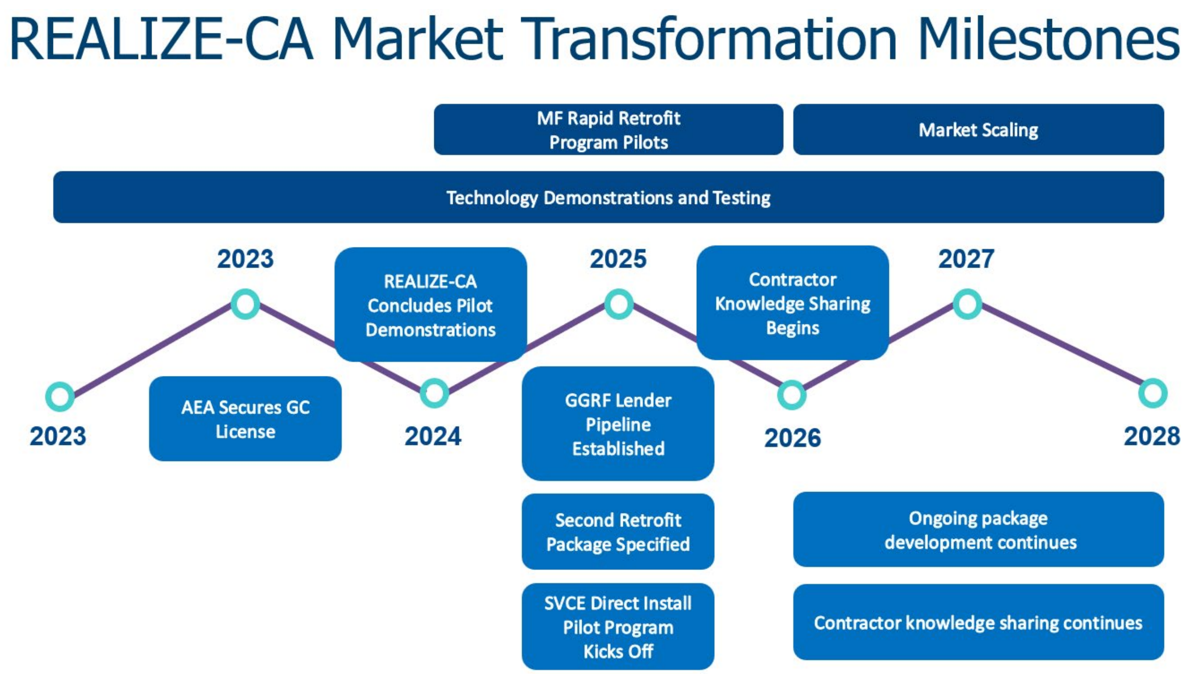
The project identified two potential solutions to these challenges, energy service agreements and inclusive utility investments, each of which is documented in two ancillary reports to this report:

- *Tariffed On-Bill to Finance Energy Efficiency and Decarbonization Retrofits for Multifamily Buildings in California* (RMI, 2023b)
- *Energy Service Agreements for Deep Efficiency and Electrification Retrofits of Affordable Multifamily Housing in California* (RMI, 2023a)

REALIZE-CA also provided input to the state treasurer's GoGreen Home Energy Financing program (Office of the California Treasurer 2024a) and encouraged interested building owners to explore products offered by participating lenders. The program helps provide lower capital costs for EE improvements and partners with several third-party lenders. A summary of products available through this program can be found in the GoGreen Home Energy Financing Chart (Office of the California Treasurer, 2024b).

Key project milestones, encompassing ongoing knowledge transfer activities with project partners and additional RMI programs, are represented in Figure 1.

Figure 1: Key Project Milestones



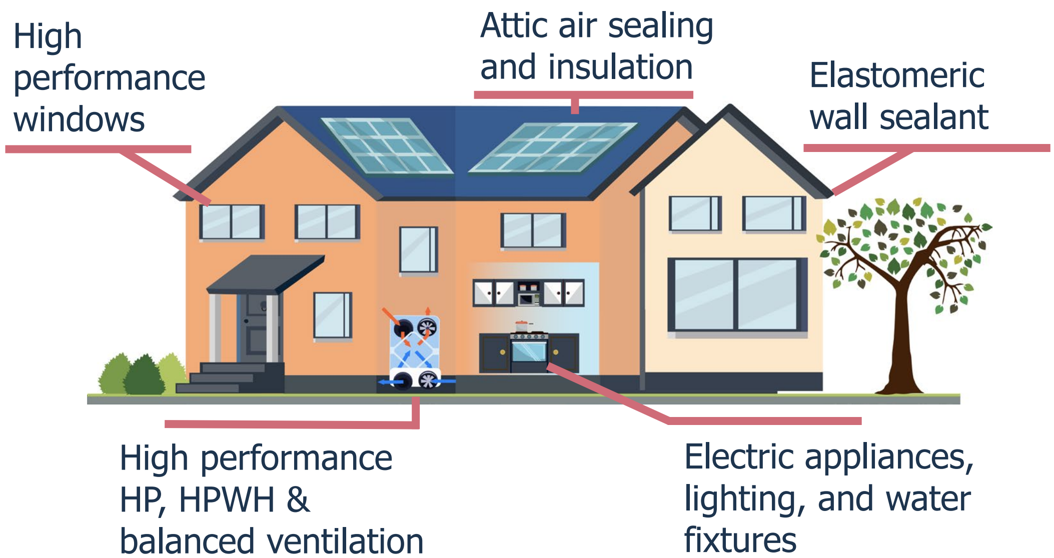
Source: REALIZE CA Market Platform Charter

CHAPTER 3: Results

The Package

The final REALIZE-CA retrofit package (Figure 2) was informed by technology demonstrations and features emerging and commercially available technologies for heating, ventilation, and air conditioning (HVAC), domestic hot water, and envelope upgrades. Newly installed electric appliances and equipment can also be paired with on-site renewable generation to achieve net-zero-energy annual operations.

Figure 2: REALIZE-CA Retrofit Package Measures

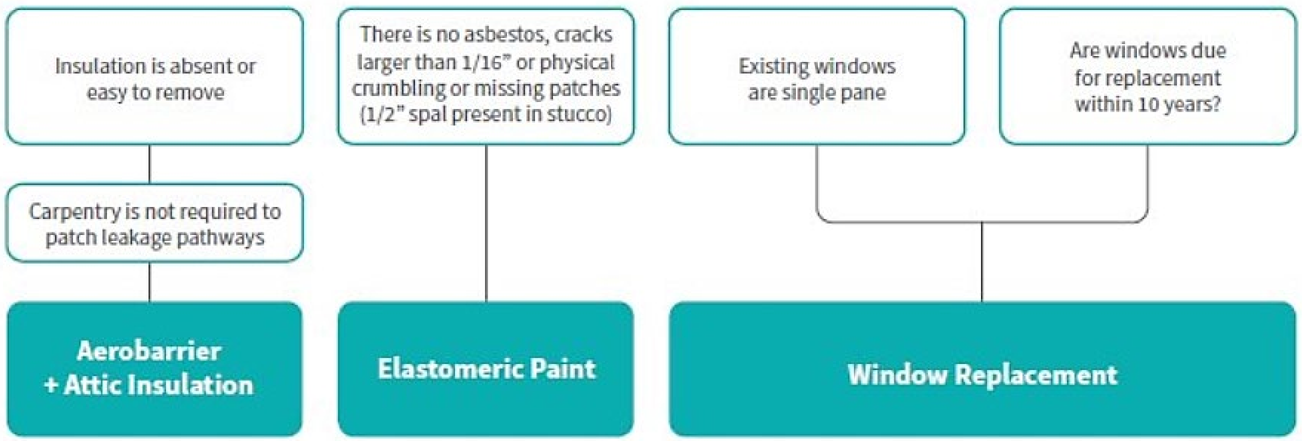


Source: REALIZE-CA Design & Installation Guide

Envelope

In most cases, the retrofit package includes new windows and attic air sealing and insulation, depending on existing conditions, as described in Figure 3. For stucco walls in good condition, an elastomeric sealant may be added to the package for added durability. Overcladding solutions such as insulated roof and wall panels are not included in the REALIZE-CA retrofit package but represent promising technologies for future research and development (see Appendix A, "Promising Technologies").

Figure 3: Envelope Measure Decision Tree



Source: REALIZE-CA Design & Installation Guide

Windows

Like the current standard weatherization upgrade, the typical retrofit candidate has existing single-paned windows, often sliding windows, to be replaced with double-paned windows to meet Title 24 performance specifications. An upgrade to a higher-performing triple or thin-triple-paned window was determined to have diminishing returns relative to the incremental cost above current-code minimum requirements. However, the REALIZE-CA retrofit package includes a higher-performing installation detail than current practice, along with expanded performance criteria to increase quality and resilience.

Attic AeroBarrier

AeroBarrier is an aerosolized elastomeric sealant that is released into an interior space while it is pressurized or depressurized so that the sealant is automatically drawn into leakage pathways until they are sealed. Compared with manual sealing in an attic application, AeroBarrier uses less material. The sealant is released into the attic space while a blower door depressurizes the conditioned area of the home; because the method is driven by creating a pressure differential, the sealant targets and seals cracks that may not be easily discovered or accessed by manual methods. REALIZE-CA pilot demonstrations successfully demonstrated that AeroBarrier could achieve whole-unit leakage reduction by 55 percent, compared to a 14-percent reduction from manual sealing with spray foam. This measure will be applied to all eligible projects if the existing attic is not insulated with R-30 blown-in insulation or R-38 batt insulation.

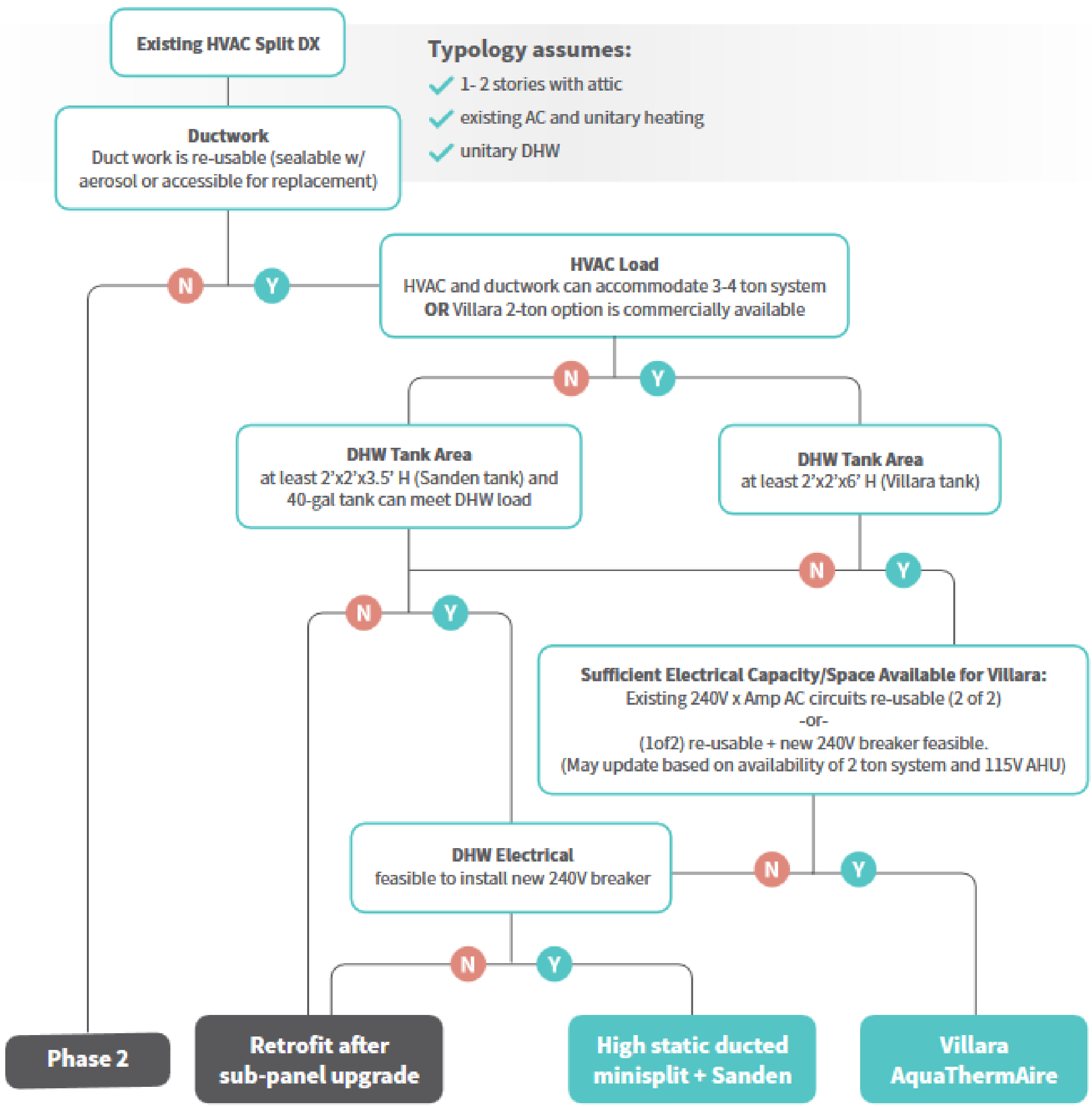
Attic Insulation

Provided that existing attics are not insulated with R-30 blown or R-38 batt, all retrofits will include insulation removal and new blow-in attic insulation to meet a final installed R value of R-44. Blown-in cellulose insulation will be used for typical projects.

Heating, Cooling, Ventilation, and Hot Water

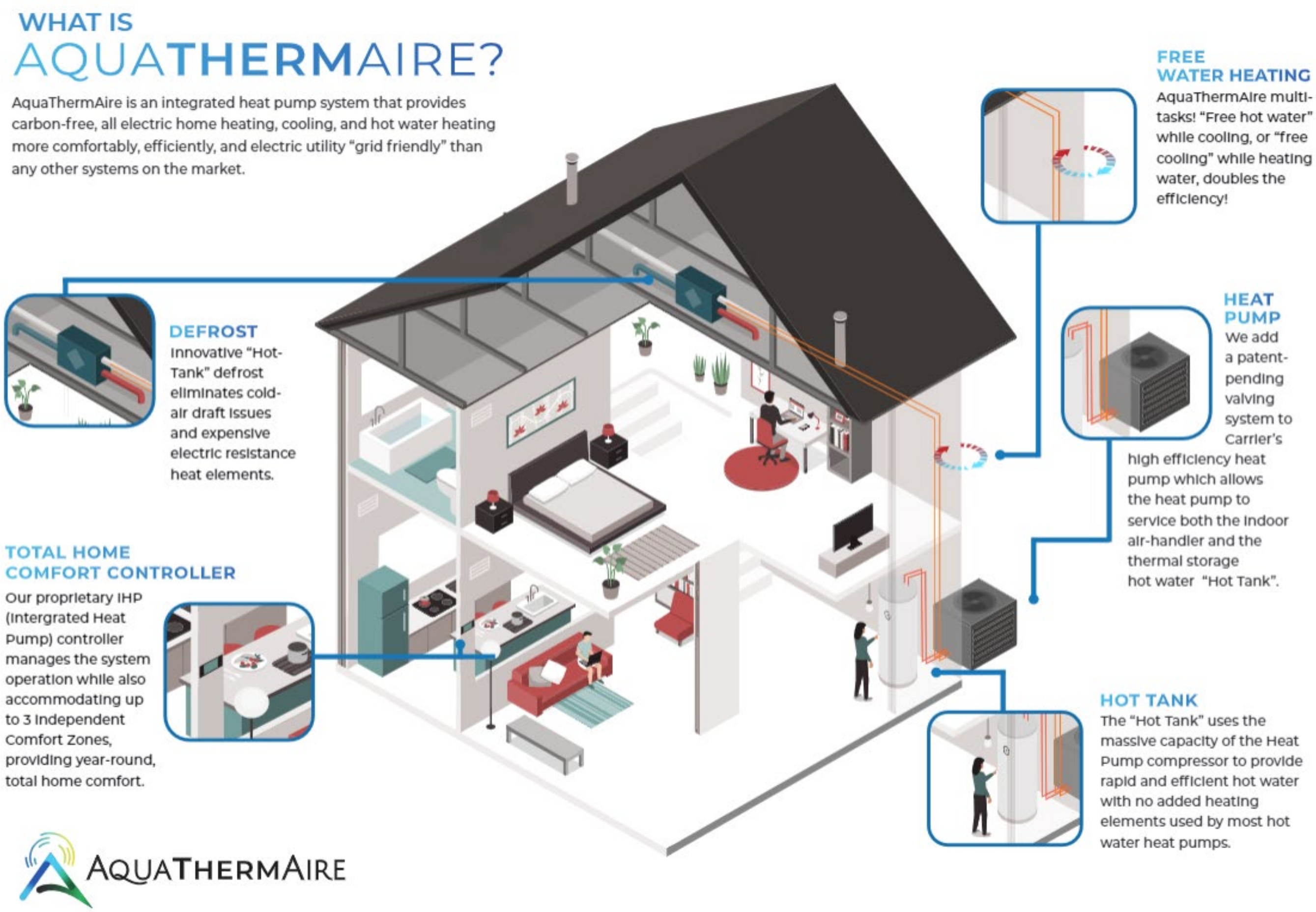
REALIZE-CA retrofit packages will serve only buildings with split direct expansion HVAC systems paired with unitary tank-style water heating systems. If specific conditions, as described in the decision tree (Figure 4) are met, these systems will be replaced with the Villara AQTA, a 3-in-1 multifunction mechanical system that provides space heating, cooling, and domestic hot water with one heat-pump compressor. More information about the AQTA system is included in Figure 5. If the Villara AQTA system is infeasible due to limited electrical capacity or available space, then a high-static ducted mini-split HVAC heat pump and a split heat-pump water heater are paired to serve as an alternative mechanical package. Buildings requiring ductless HVAC systems or central water heating retrofits are not eligible for REALIZE-CA retrofit packages, but they should be considered in future pilot demonstrations.

Figure 4: HVAC Decision Tree



Source: REALIZE CA Design & Installation Guide

Figure 5: Villara AquaThermAire (AQTA)



Source: REALIZE CA Design & Installation Guide

Energy and Emissions

At each REALIZE-CA demonstration, an all-electric retrofit package was installed and evaluated, representing a total of 345,002 square feet, located in disadvantaged communities within the Pacific Gas and Electric Company and Southern California Edison investor-owned utility service territories. Demonstration sites, representing 60 buildings and 371 individual apartments (shown in Table 3) were chosen based on how well the common existing conditions aligned with the low-rise multifamily typology that represents 3.2 million multifamily units statewide, or about 25 percent of California households (RMI and AEA, 2024). Aside from achieving efficiency and greenhouse gas (GHG) reduction mandates, retrofits also provide non-energy benefits to tenants, including improved indoor air quality and thermal and acoustic comfort.

Table 3: REALIZE-CA Demonstration Site Existing Conditions

Site Name	Corona Del Rey	Light Tree Three	Vera Cruz Village	King's View Manor
Property Ownership	National Core Inc.	Eden Housing	Self Help Enterprises	San Mar Properties
Year Built	1964	1966	1993	1990

Site Name	Corona Del Rey	Light Tree Three	Vera Cruz Village	King's View Manor
Climate Zone	Southern California, 10	Bay Area, 3	Central, 13	Central, 13
Square Feet	178,880	37,126	50,194	78,802
Building Typology	Townhomes, 2-story, 2 bedrooms	Townhomes, 2-story and loaded corridor; 4-story, mix of 2 and and 3 bedrooms	Townhomes, 1- and 2-story; mix of 2, 3 and 4 bedrooms	Loaded corridor, 2 story, mix of 1 and 2 bedrooms
Gas Heating	Forced air furnace	Wall furnaces	Rooftop packaged unit	Rooftop packaged unit
Existing Electric AC	Yes	No	Yes	Yes
Gas Water Heating	Central boiler, 80% efficient	Central boiler, 80% efficient	In-unit, tank-type, 60% efficient	Central boiler
Existing Insulation	No	No	Wall R-11 Attic R-19	Wall R-11 Attic R-13
Electric Upgrades Needed	Building: No Apt. sub-panel: Yes	Building: New service Apt. sub-panel: Yes	Building: No Apt. sub-panel: No	Building: No Apt. Sub-panel: No
Seismic Retrofit	Yes	Yes	No	No

Source: REALIZE-CA Demonstration Data, AEA

Overall, portfolio-wide savings (Table 4) achieved a 21-percent reduction in electricity usage for already electrified end uses (CEC required a minimum of 10 percent) and a 43-percent reduction in metric tons of carbon dioxide equivalent (MTCO2e) when comparing pre-existing conditions to post-EE retrofit conditions. These results include solar for sites with systems already under construction. Operational GHG emission impacts were calculated by applying the United States Environmental Protection Agency's conversion factors for MTCO2e per kilowatt hour at $0.000394 and MTCO2e per therm at $0.0053.

Table 4: Portfolio-wide Savings

Measurement	Portfolio Improvement (345,002 square feet)
British thermal unit (Btu)	6,604.51; 55%
Kilowatt-hours (kWh)	344,573; 21%
MTCO2e	423; 43%

Source: REALIZE-CA Demonstration Data, AEA

The primary savings are derived from a range of advanced HVAC and domestic hot water heat pump technologies, enhanced envelope measures (including prefabricated walls, attic insulation, and air leakage improvements), high-performing roofs, ENERGY STAR® appliances, and LED lighting replacements deployed at each site. Individual demonstration site energy use intensity (EUI) and emissions reduction results are shown below in Table 5. A comparison of the most effective packages deployed is discussed later in this report.

Table 5: 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						**55%**	**21%**	**43%**
**Corona Del Rey (Only 6 months)	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%
King's View Manor	51.0	38.7	solar in progress	265.8	168.3	24%	4%	17%

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

Retrofit Package Results

Package Variation

The project used both a per-site approach and a comparative technology approach to evaluate variations of whole-building retrofit packages deployed across multiple demonstrations, with the goal of recommending a standardized package for scale. While site-specific physical and capital needs primarily guided the equipment and measures selected, some sites featured deployment of multiple package variations as part of a comparative study, as shown in Table 6. For emerging technologies like exterior panelized retrofits or multifunctional heat pumps, cost and energy benchmarks established by conventional approaches served as important evaluation resources.

While Table 5 provides an overview of all-electric heating, cooling, and envelope technologies that vary widely by retrofit package, categories like lighting, appliances, mechanical ventilation, and domestic water heating remain relatively consistent regardless of the selected package:

- **Low-Flow Fixtures:** All units are equipped bathroom faucets and kitchen faucets limited to 1.5 gallons per minute (GPM), while showerheads are limited to 1.75 GPM.
- **LED Lighting:** LED replacements for all lighting, including occupancy sensors, were included in all common area spaces (i.e., common rooms, storage, restrooms, etc.).
- **Cooking:** Gas cooking ranges werew replaced with induction cooktops and electric resistance ovens. Tenants with electric stoves were encouraged to switch them to induction, when feasible.

- **Ventilation:** At a minimum, retrofit packages assume an exhaust-only ventilation strategy consisting of ENERGY STAR® multispeed bathroom exhaust fans that run continuously at low speed with high-speed boost, and a ducted ENERGY STAR® kitchen range exhaust. At one site, where the existing conditions demonstrated excessive moisture build-up and the lack of regular kitchen exhaust hood use, a constant low-speed kitchen exhaust hood was installed.

Table 6: Package Variation Across Demonstration Sites

Package Name	A	B	C	D	E	F	G	H
	New HVAC + no envelope upgrade	New HVAC + prefab wall panel (low R)	New HVAC + prefab wall panel (high R)	New HVAC+ site-built envelope retrofit	New HVAC + conven-tional envelope	New HVAC + prefab roof panel (AIOHP)	New HVAC + prefab roof panel (split HP)	New HVAC + storm window insert
Building Site	Corona Del Rey ROS	Corona Del Rey 205	Corona Del Rey 217	Light Tree 3	Vera Cruz ROS	Vera Cruz 619	Vera Cruz 615	King's View Manor
Apartment Count	152	4	4	57	41	4	4	106
HVAC								
Ducted					X	X	X	X
Ductless	X	X	X	X				
Packaged		X	X		X	X	X	X
Split	X			X			X	
Central Water Heating		X	X	X				X
Unitary Water Heating	X				X	X	X	
Envelope								
New Windows		X	X	X	X	X	X	X
Attic Insulation & Air Sealing					X			
Improved Wall Air Tightness		X	X	X		X	X	
Above-deck Roof Insulation		X	X	X		X	X	
Insulated Metal Panel Roof System						X	X	
Wall Gut-retrofit & Reclad				X				
Panelized EIFS Wall System		X	X					

Source: REALIZE-CA Demonstration Data, AEA

A detailed list of measures and specifications for each package follows:

1. **Package A. New 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. HVAC + Prefab wall panel (Low R-15)**
   - **Demonstration Site: Corona del Rey, Building 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 (High R-21)**
   - **Demonstration Site: Corona del Rey, Building 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 (AIOHP)**
   - **Demonstration Site: Vera Cruz, Building 619**
   - 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 HP)**
   - **Demonstration Site: Vera Cruz, Building 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
8. **Package H. New HVAC + Storm window insert**
   - **Demonstration Site: King's View Manor**
   - Heating and Cooling: Vertical, Wall AIO HP; COP 3.71, SEER 13.65
   - Duct Sealing/Insulation: New prefab duct soffit: pre- insulated & pre-sealed
   - Water Heating: Central, Low GWP HP on Prefabricated Skid
   - Windows: Prototype of Alpen Operable Triple Pane Slide Storm Window

Energy Performance by Package

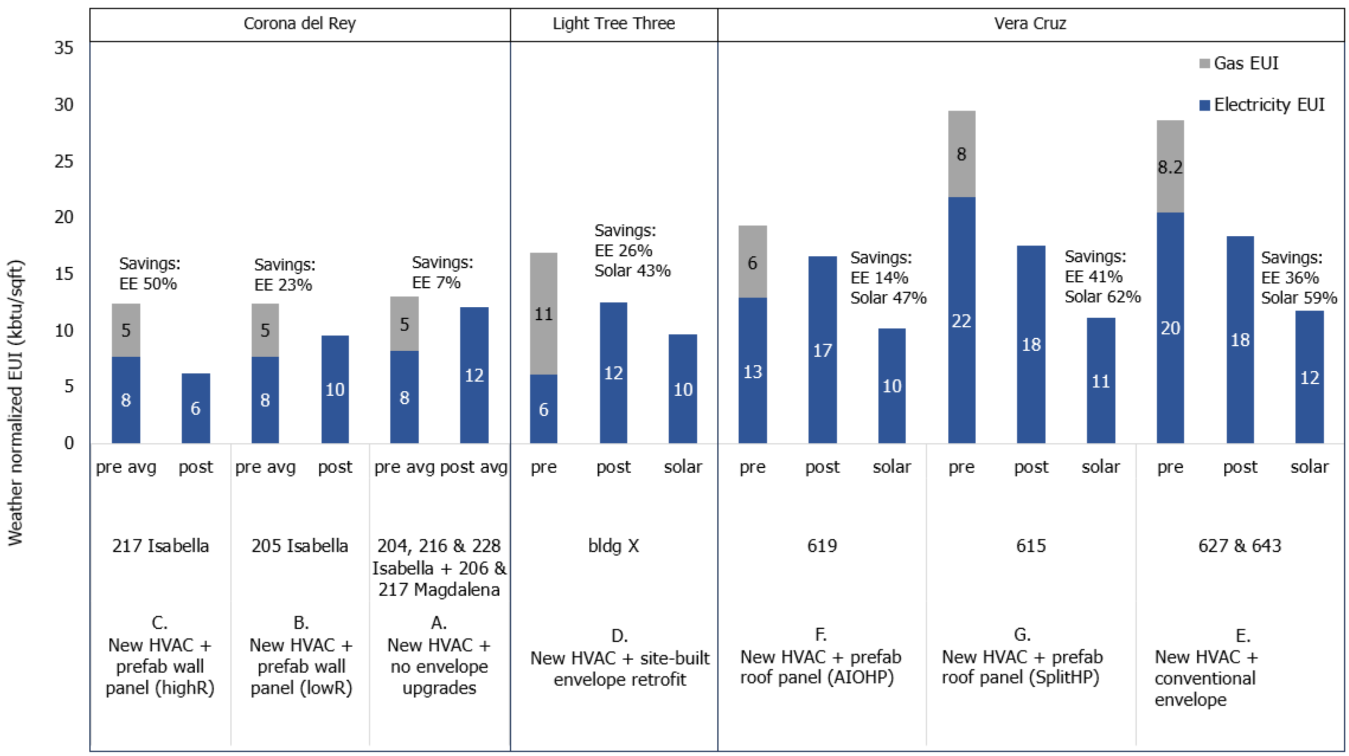
To better understand the effects of a whole-building retrofit across climate zone, the team weather normalized building-level utility data and evaluated EUI reductions between existing, post all-electric EE retrofits, and post-EE + solar retrofit time periods (Figure 6). Nonretrofitted and retrofitted periods were weather normalized using 10-year rolling averages of heating-degree and cooling-degree days from local weather stations.

King's View Manor site data were unavailable (tenants were unwilling to authorize their utility-data access), so all retrofit package results represent post-retrofit conditions for both the townhouse and the garden-style low-rise construction types. For sites with available data, electricity-utility data were accessed at the building level, while pre-retrofit gas data were limited and available only on a per-site basis, estimated per building. Building-level energy usage included the same end uses across retrofits, as the sum of residential end uses and owner-paid hot-water heating, if applicable. Occupancy data were difficult to obtain, so tenant behavioral differences across packages were unknown but could be deduced for buildings where the same package was demonstrated on different buildings.

Due to construction delays, retrofits completed at the Corona Del Rey project were limited to 6 months of post-retrofit summer data, so 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.

As reflected in Figure 6, EUI reductions between pre-retrofit and post-EE retrofits (not including PV solar) for all demonstrated options ranged from 7 percent to 50 percent. Both the highest- and the lowest-saving retrofits were demonstrated at the Corona Del Rey project: the highest savings were attributed to "Package B. New HVAC + prefab wall panel (high R) (50 percent)" and the lowest to "A. New HVAC + no envelope upgrade (7 percent)," which is an average across multiple buildings.

Figure 6: Summer, Weather Normalized EUI by Fuel Type



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

Comparing these two packages offers a full range of potential savings for an uninsulated existing building when considering both an equipment-only retrofit and a retrofit featuring equipment replacement and additional envelope measures (which could, in turn, include prefabricated walls, window replacements, and roof upgrades). The team could also attribute the higher savings of Package C (over Package B) to the addition of ceiling fans and slightly thicker wall insulation. When tenants of 217 Isabella Way were asked about ceiling-fan use, the team found that they used them almost daily before turning on zoned package terminal heat-pump units installed throughout the apartment. Ceiling fans, by promoting air circulation, reduce HVAC demand, leading to additional energy savings. A future study where ceiling fans are provided to residents of 205 Isabella Way would help disaggregate the impacts of increased R value in the walls.

Pairing electrification with solar also presents an opportunity for further energy reduction, and all REALIZE-CA demonstration sites have either installed or plan to install PV solar. Additionally, solar can ensure consistent electricity reductions, especially when fuel-switching measures could add electric load, post retrofit. Post-EE and solar results, combined, achieved between 23 percent and 38 percent more operational energy reductions than EE alone. Further reductions were also realized for Building 619 at Vera Cruz and Building X at Light Tree Three, where gas load was eliminated, although electric load increased after the EE retrofit.

Costs and Benefits Performance

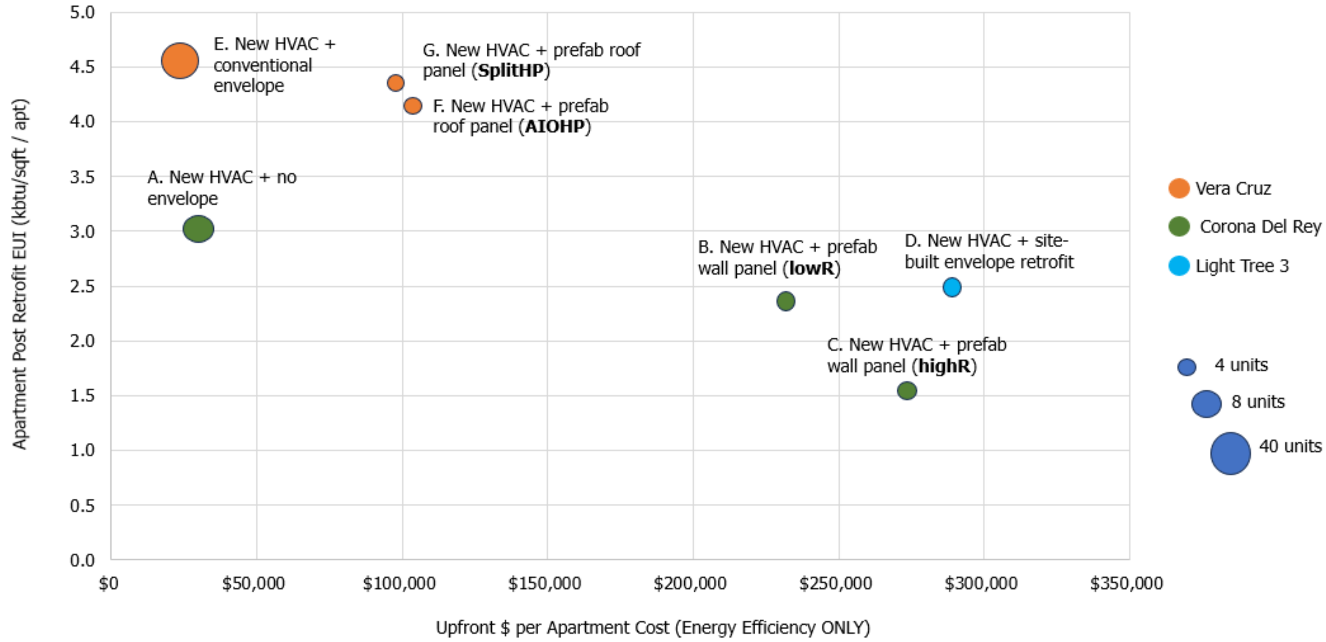
The following sections evaluate whether prefabricated or industrialized technologies offer greater energy savings (Figure 7) and utility cost reductions (Figure 9) compared with conventional retrofit solutions, while also assessing the benefit-to-installed-cost ratio of these technologies without solar. Specific envelope and HVAC sections discuss incremental cost differences and highlight areas for cost optimization.

Cost analysis further illustrates retrofit differences and is reported in two categories: upfront cost, based on prevailing wage rates, and utility bill savings per apartment per month. Upfront capital expenditures are represented without incentives and represent only hard costs associated with energy retrofit work, excluding solar and administrative expenses. Lifecycle cost is discussed for one retrofit, but not for all. Utility bill savings were calculated using an effective electric and gas utility rate derived from actual monthly electricity and gas bills, at the building level, associated with the post-retrofit. 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 EE pre- and post-retrofit. Utility cost savings reflect summer months and are presented as a utility cost savings estimate (per apartment per month). Almost all residents utilized California Alternate Rates for Energy (CARE) rates, which discount electricity bills by 30 percent to 35 percent and natural gas bills by 20 percent.

Whole-building Retrofit Upfront Costs Relative to Energy Savings

Figure 7 provides a retrofit-by-retrofit comparison of the 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 2-bedroom or 3- to 4-bedroom categories.

Figure 7: Summer, Post-EE Retrofit Only: Apartment EUI 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 retrofit B, with prefabricated wall panels to retrofit D with a site-built envelope, total costs per apartment were similar but largely driven by different measure costs. The site-built envelope retrofit's largest cost was associated with a demonstration of a Low GWP central water heating plant, while retrofit B cost was driven by envelope and interior finish measures. When drilling down into the 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.

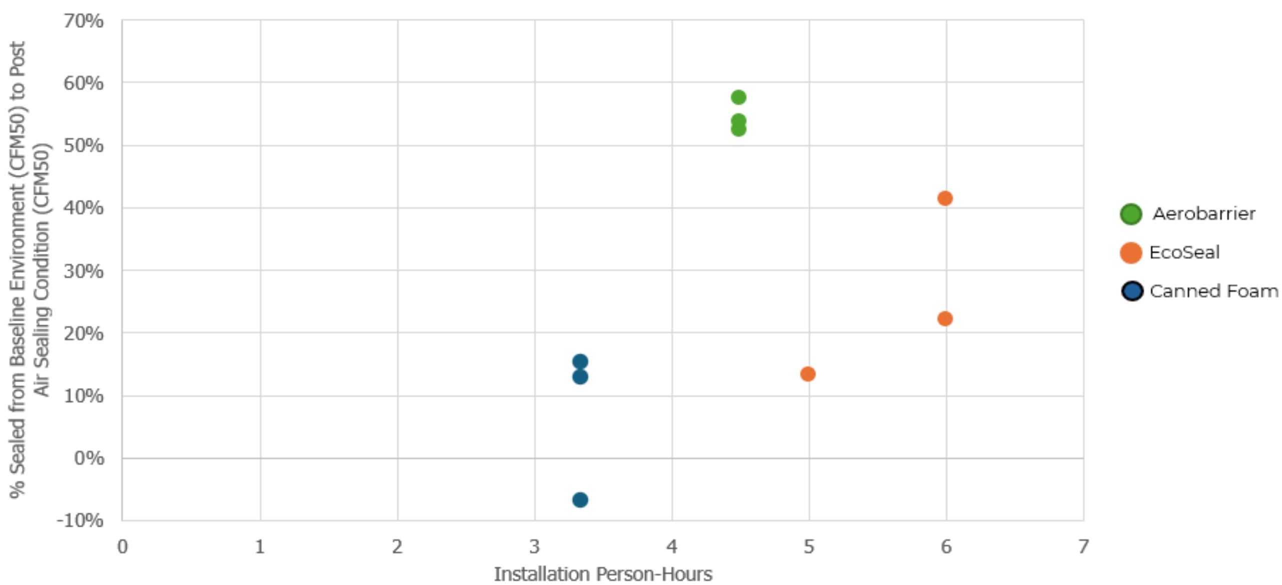
However, a more significant 38-percent EUI improvement was achieved when the wall R-value was increased to R-21. Attributing additional savings to the presence of ceiling fans also remained a consideration, and further disaggregation of these factors could be valuable for future research. Despite the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

Retrofits incorporating prefabricated roof retrofits offer notable EUI improvements compared with market-ready envelope measures, yet the higher costs suggest that targeting more affordable solutions could prompt broader adoption. IMP roof retrofits exhibit 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 of approximately $23,000 per apartment would make 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 the Western Cooling Efficiency Center at the University of California, Davis (UC Davis) (Figure 8), AeroBarrier demonstrates superior apartment leakage reductions (50 percent to 60 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 is 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

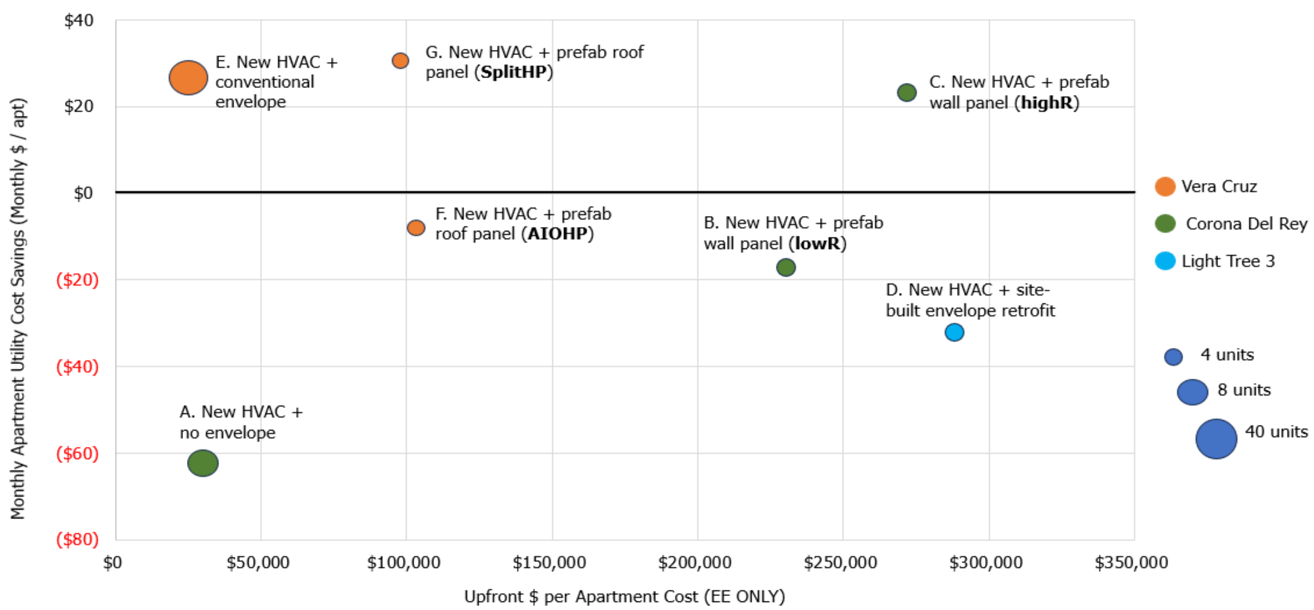


Source: REALIZE-CA Demonstration Data, AEA

Upfront Costs Relative to Utility Bill Savings

Despite California's mild climate, envelope retrofits can lower utility bills when compared with 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 retrofit A, without envelope upgrades, utility cost savings for all other retrofits were consistently higher (47 percent to 150 percent). However, Figure 9 shows that energy-bill savings of electrification (without solar) were insufficient to cover the full costs of electrification. Small returns are likely due to high electricity rates, but the team also saw inconsistent savings across the same package type. This is likely due to varying tenant behaviors. 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 (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

Attic insulation (R-38), air sealing, and ducted packaged terminal heat pump (PTHP) conventional retrofits (costing $20,000 per apartment) had the second-highest utility cost savings of $27.52 per month per apartment; but, after evaluating the 30-year net present value cash flows, payback was 30+ years. Even after incentives, the payback period was only reduced to 24 years. Pairing electrification with solar and/or monetizing non-energy benefits, like including a societal cost of carbon associated with operational carbon savings in the lifecycle cost analysis, is critical for improving the retrofit value proposition and closing the financial gap needed to make these more financially accessible and widespread in the future.

Envelope Costs and Installation Person-hours

Table 7 shows the incremental per-apartment installed cost associated with envelope measures, utilizing prefabricated envelope systems that deviate from envelope retrofits utilizing more traditional site-built retrofit options.

Table 7: Incremental First Cost per Apartment of Prefabricated Envelope Features

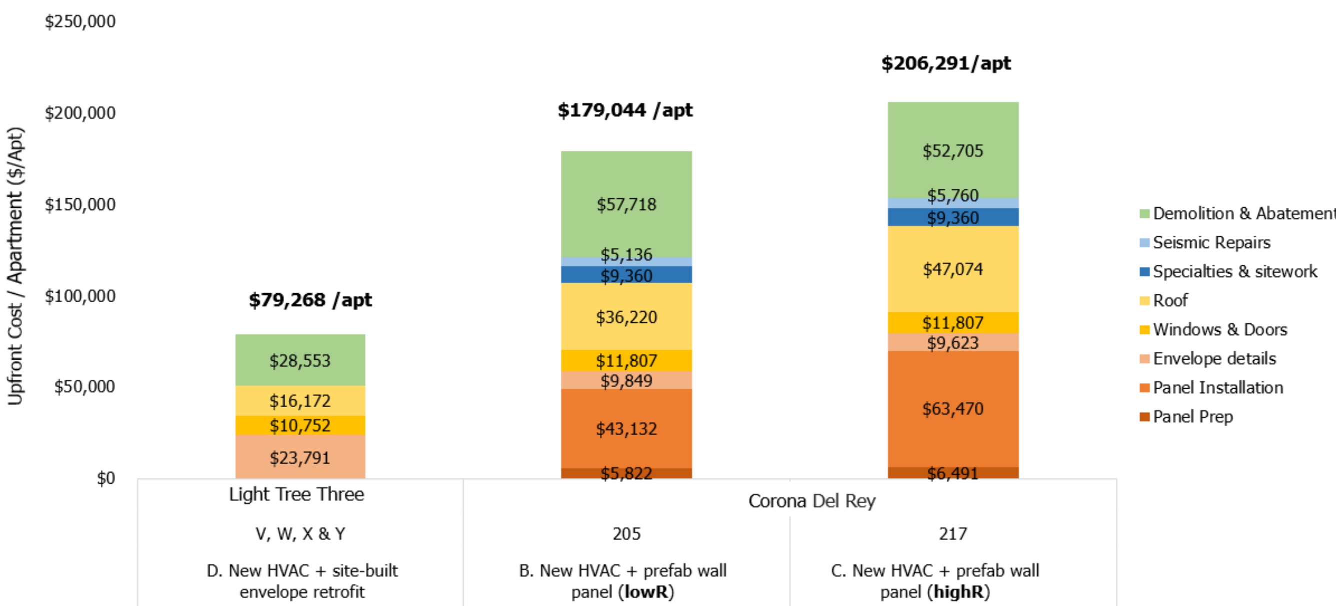
Site-built Design	Prefabricated Design	Incremental $/Apt First Cost Increase (+)
Attic insulation (R-38) + air sealing	Insulated roof panel (R-30) + sealing	+ $56,517 to $60,798

Site-built Design	Prefabricated Design	Incremental $/Apt First Cost Increase (+)
Wall cavity insulation (R-15), roof insulation (R-30)	Insulated wall panel (R-15), roof insulation (R-30)	+ $99,776
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 10 focuses on EIFS wall-panel systems, demonstrated at Corona Del Rey, compared with envelope retrofits utilizing traditional site-built retrofit options, demonstrated at Light Tree Three. The total envelope measure cost of the prefabricated panelized system was nearly 2.2 times to 2.6 times higher than the cost of the site-built option. As shown in Figure 10, almost a third (26 percent to 32 percent) of this cost was 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, there may be a tolerable cost premium for some developers. But, to enhance the viability of prefabricated wall retrofits in future projects, it will be critical for combined wall panelization and panel preparation costs to get closer to the site-built envelope detailing cost, requiring an 80-percent to a 165-percent cost compression.

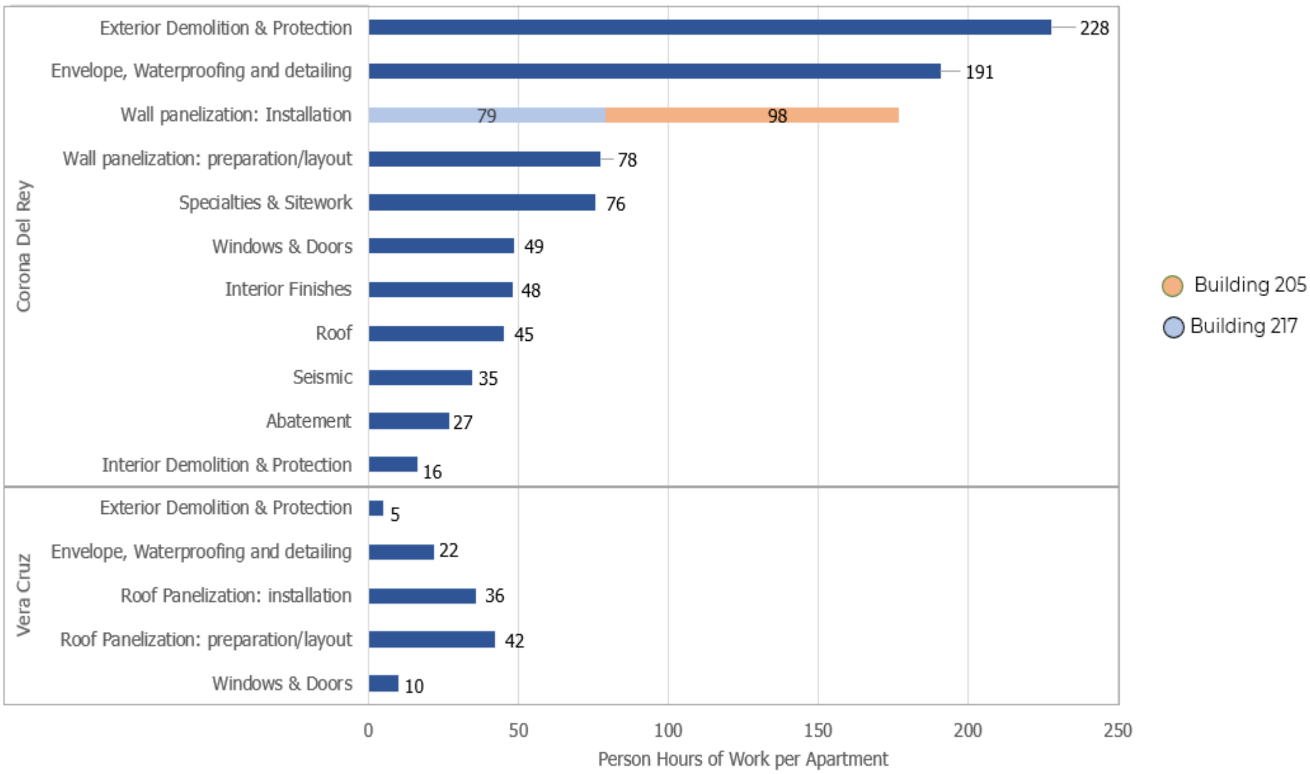
Figure 10: Installed Cost per Apartment Comparison: Site-built Versus Prefabricated Envelope Measures



Source: REALIZE-CA Demonstration Data, AEA

Upon further investigation of labor hours (Figure 11), we see that demolition and abatement were expensive, accounting for, conservatively, a third of the total person-hours of the job (30 percent). When looking at both relative costs and relative work, waterproofing and detailing work (20 percent of labor hours) was a lot more involved and required more coordination than anticipated. Streamlining the coordination of onsite trades and gaining experience with multiple installations could reduce the labor intensity for this scope.

Figure 11: Labor Hours per Apartment for Prefabricated Envelope Retrofits



Source: REALIZE-CA Demonstration Data, AEA

HVAC Costs and Labor Data

Figure 12 and Table 8 show per-apartment person-hours associated with construction and installed costs for HVAC equipment demonstrated across sites. Costs included electrical, heat-pump equipment, ducting, and other material or labor costs involved in prepping the site and installing and commissioning equipment.

Systems are categorized by either central air systems, consisting of a single indoor unit that serves the entire home, or zoned systems, requiring an individual indoor unit for each room. Results show that central air systems consistently cost less, even when comparing conventional to emerging technologies, primarily due to each apartment's central equipment installation. The addition of exhaust-only ventilation to mechanical equipment adds roughly 8 to 18 additional hours of person-hours per apartment labor and $3,296 to $9,999 per apartment of cost, depending on ducting or electrical needs.

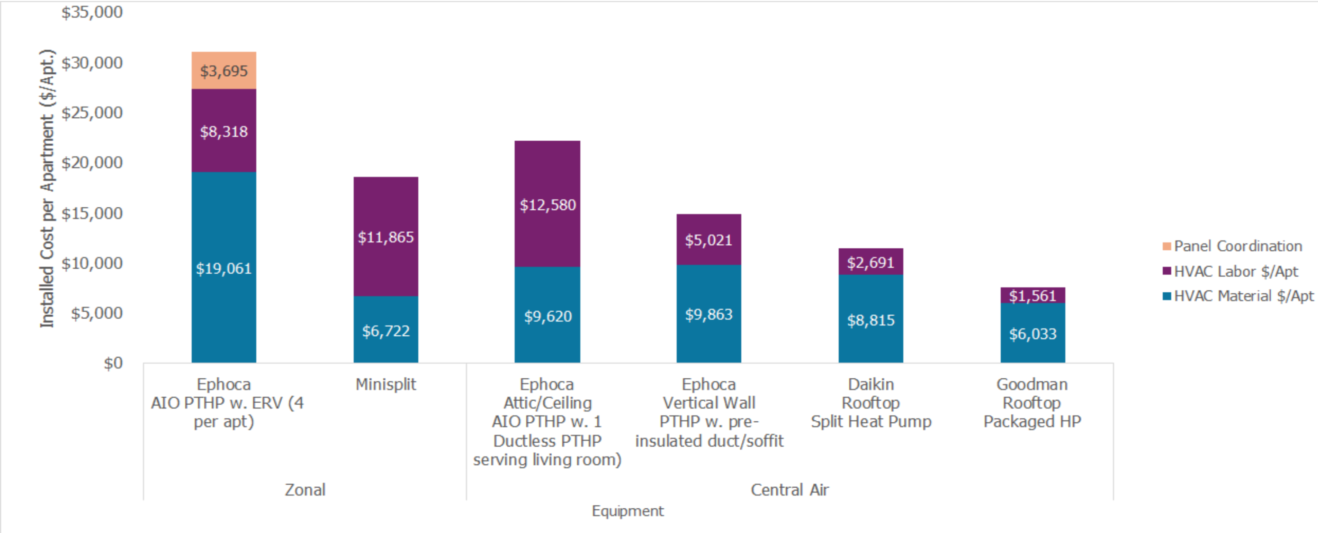
Table 8: HVAC Equipment: Labor Hours and Installed Cost per Apartment

HVAC Type	Equipment	Person-hours of Work	HVAC Material $/Apt	HVAC Labor $/Apt	Total $/Apt
Zonal, Ductless	Ephoca AIO PTHP w/ Energy Recovery Ventilators (ERV (4 per apartment)	26	$19,061	$8,318	$27,379
	Panel coordination	5	$1,841	$1,855	$3,695
	Mini-split	23	$6,722	$11,865	$18,587
Central Air, Ducted	Ephoca ceiling AIO PTHP w/ 1 ductless PTHP serving living room	91	$9,620	$12,580	$22,200
	Ephoca vertical wall PTHP w/ pre-insulated duct/soffit	95	$9,863	$5,021	$14,884
	DaikinSplit HP	27	$8,815	$2,691	$11,506
	Goodmanrooftop packaged HP	24	$6,033	$1,561	$7,594
Exhaust-only Ventilation	Bath exhaust and kitchen exhaust	8 to 18	$2,016 to $4371	$1280 to $4371	$3,296 to $9,999

*Reported range across multiple projects.
Source: REALIZE-CA Demonstration Data, AEA

The lowest labor costs and installation times were for equipment that contractors had previously installed or were familiar with, including systems like mini splits, rooftop packaged units, or split-system heat pumps, representing roughly 24 to 27 person-hours per apartment. However, the various (3) versions of Ephoca all-in-one heat pumps demonstrated were the first in the nation to be installed in a multifamily retrofit; unsurprisingly, the installation experienced higher costs. Each Ephoca system is an air-to-air multifunction heat pump that integrates heating, cooling, and ventilation into one product. The project evaluated the benefits of centralizing multiple mechanical systems into a single product, which could streamline labor, improve maintenance (via elimination of outdoor compressors), and enhance indoor air quality by integrating continuous filtered outdoor air into heating and cooling systems.

Figure 12: HVAC Equipment: Person-hours of Work and Installed Cost per Apartment



Source: REALIZE-CA Demonstration Data, AEA

Although the Ephoca ductless PTHP exhibited the highest material costs, even when the accessory ERV cost of $5,600 was removed, it offered the lowest installation times of the multifunction units and was comparable with conventional systems. At 26 person-hours per apartment, which removed the additional 5 hours of prefabricated wall panel coordination not performed at other sites, this was particularly impressive, given the contractor's lack of familiarity with the system and the benefit of the added functionality of air-side energy recovery ventilation over conventional systems like mini-splits (23 person-hours/apartment) or central, split heat pump (27 person-hours/apartment.) Reducing material costs by 15 percent could make this option more accessible as an alternative to mini-splits. One drawback of this system is its size, specifically the additional depth (12 feet) with the additional ERV attachment. Based on resident surveys, residents were frustrated by the equipment blocking placement of large furniture and complained about the loss of valuable square footage.

Centralized systems offer a significant cost advantage compared to individual room units, making them a more competitive option. Centrally ducted multifunction systems demonstrated substantial potential for reducing labor costs and installation times, especially as contractors gained familiarity with the technology. Initial installation durations took longer due to rework and, in some cases, custom site preparation, stemming from inefficient procurement and material coordination with manufacturers. However, as contractors' expertise with these systems grows, installation times are expected to decrease and should aim for a target of under 30 person-hours, aligning with the installation benchmarks of other centrally ducted systems.

Water Heating Cost

Table 9 shows per-apartment person-hours associated with construction and installed costs for heat pump water heating equipment demonstrated across sites. Costs include electrical, heat pump equipment, piping, insulation, recirculation pumps, and any other material or labor cost involved in prepping the site or installing and commissioning equipment.

Table 9 shows that central systems are typically cheaper than the sum of per-apartment systems required to achieve the same objectives. This cost and labor intensity advantage stems from the ability to distribute installation costs across a large number of units, leveraging economies of scale that individual systems cannot match. That is also true for an emerging product, the central prefabricated WaterDrop skid, which was the first installation for the contractor but cost 65 percent less than other central systems demonstrated. This is due, in large part, to lower labor costs and person-hours as a result of the pre-packaged system, which integrates all of the components into one skid. This ensured standard performance, even for contractors unfamiliar with heat-pump technology, since the main on-site work was to deliver and install the system (21 percent of person-hours) and make two primary connections to the skid: one to the main electrical service (32 percent of person-hours) and the other to existing hot, cold, and recirculation lines at the building (47 percent of person-hours). At this demonstration site, plumbing connection runs were long, given that the system was too large to re-use existing boiler rooms and required moving the water heating system outside. A site with shorter plumbing runs would reduce labor hours even more.

Table 9: Heat Pump Water Heating Equipment: Labor Hours and Cost per Apartment

Equipment	Person-hours per Apartment	Material $/Apt	Labor $/Apt	Total $/Apt
In-unit, Rheem	12 to 16	$3,846	$3,400	$7,246
Central, Sanden (1 per building, serving 4 apartments)	4.5	$6,339	$9,598	$15,998
Central, Prefabricated WaterDrop Skid (1 per building, serving 53 units)	2	$4,370	$816	$5,186
Low Flows	0.25 to 0.50	$115	$136	$251

Source: REALIZE-CA Demonstration Data, AEA

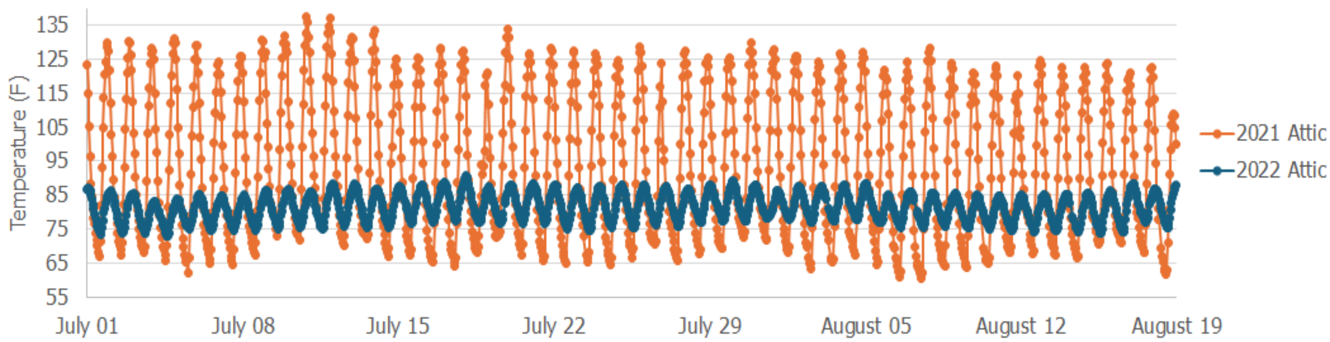
Thermal Comfort and Indoor Air Quality

To evaluate non-energy benefits across retrofits, thermal and air quality performance was measured using blower door air leakage testing, and 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 are 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 worse-case condition outdoor air quality (OAQ) summer days, post-retrofit.

Apartment leakage reductions were quantified using two tests. Whole-building blower door testing was conducted at Corona Del Rey by RDH Building Science, with measurements taken pre-retrofit, mid-construction, and post-retrofit. This enabled verification of improvements from wall panel installations and air sealing measures. At Vera Cruz, 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.

Figure 13: Attic Air Temperatures Pre- and Post-retrofit of IMP Roof



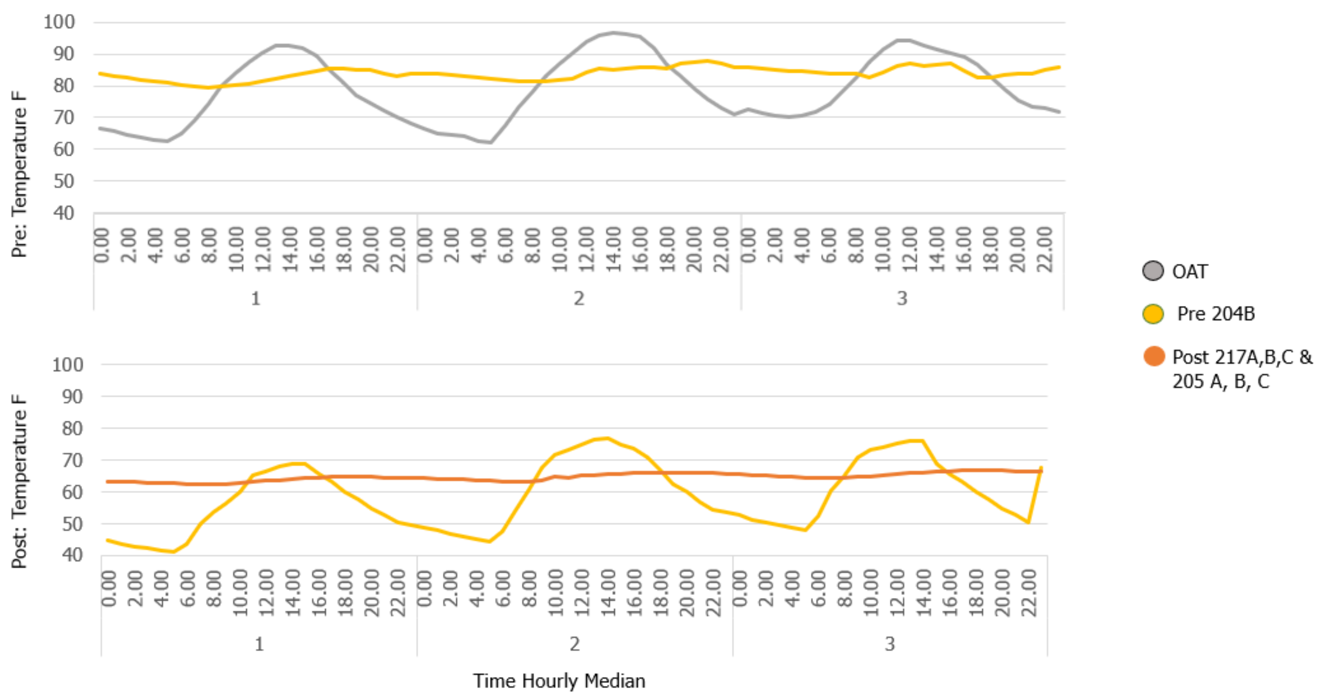
Source: REALIZE-CA Demonstration Data, AEA

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 13, pre-retrofit, attic temperatures showed a striking degree of overheating in the vented attic where the HVAC distribution was located, regularly swinging in 60 degrees Fahrenheit (°F) (33 degrees Celsisus [°C]) fluctuations daily. Attic temperatures measured after roof panel installation were dramatically lower and more stable, fluctuating between 10°F (6°C) and 15°F (8°C) daily. The benefits of this stability are twofold: improved thermal comfort, and reduced workload on mechanical systems by mitigating the impact of extreme temperature differences. As a result, HVAC equipment operated more efficiently, leading to lower energy consumption and the potential for increased service life.

Since the attic is directly adjacent to occupied spaces, these temperature measurements serve as a proxy for thermal comfort within the apartments. Additionally, the controlled temperature and reduced air leakage indicated that indoor air quality improvements were also 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 14: 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

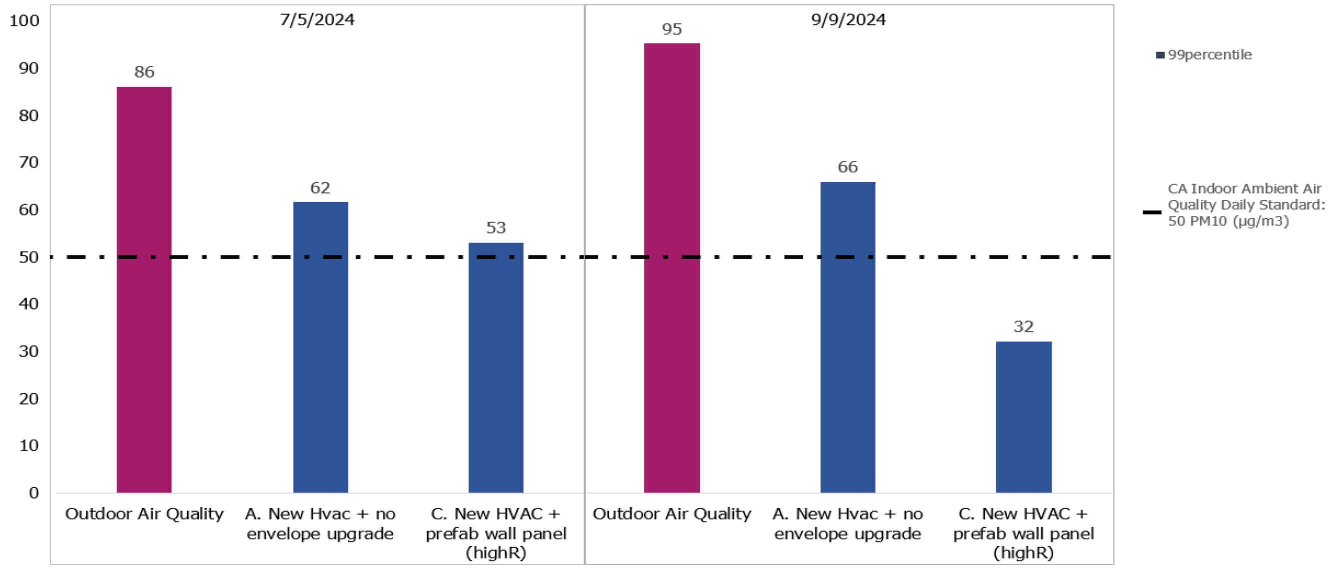


Source: REALIZE-CA Demonstration Data, AEA

Figure 14 shows average indoor apartment temperatures at Corona Del Rey, in response to outdoor air temperature, before and after the panelized wall retrofit. We see fluctuations in indoor air temperatures stabilize and decrease by 60 percent, from pre-retrofit fluctuations at 9.4°F (5.2°C) to 3.6°F (2°C) post-retrofit, implying that comfort in the apartments is also more stable.

Figure 15 demonstrates the protective benefits of Corona Del Rey retrofits in shielding residents from the top two highest summer days 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.

Figure 15: Post-retrofit Indoor Air Quality PM10 Concentrations During Worst-case Outdoor Air Quality Concentrations



μg/m³=micrograms per cubic meter
Source: REALIZE-CA Demonstration Data, AEA

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 impacts by envelope retrofits suggests that health and resilience benefits, such as reduced respiratory risks and enhanced resilience to climate-related air pollution events, are uniquely relevant, given California's frequent wildfire seasons and smog challenges.

Demonstration Site Challenges

California Housing Typology Limitations

As previously mentioned, the Energiesprong approach was not well-suited to the state's targeted multifamily housing inventory for several reasons, including architectural diversity, seismic concerns, and workforce challenges when specifying and deploying packages across climate zones that employed both emerging and commercially available technologies.

For example, California's light wood-framed building stock has limited structural capacity due to its age and now-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 demonstrated 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 opting to manage trades directly. This decision led to contracting inefficiencies, scope gaps, and schedule delays (for example, issues with mechanical penetrations and the procurement and installation of roof-vent installation that would likely have been addressed by a general contractor's oversight).

Additionally, building owners requested the use of their preferred vendors for some construction scope, which was coordinated with their respective property maintenance staffs instead of 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. The retrofit also included 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, insulated metal panels had to be installed by roofers certified for that product. However, the roofers were not familiar with the product and so were not equipped to, for example, verify structural attachments for submittal and permit reviews. They were also unable to complete basic accessory details correctly, such as gutters and downspouts, because of 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. Ensuring the ability for owners 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 confusing control or usability issues by creating specific operation guides for residents, 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 the demonstration of emerging technologies would not compromise either the safety or the functionality of building systems.

CHAPTER 4: Conclusion

California has laid the foundation for a strong residential retrofit industry that could transform construction statewide. The project team successfully deployed and compared various iterations of a standardized, or package, approach to scaling retrofits, using both conventional and industrialized components in multifamily housing. In doing so, the project team identified primary barriers to scale, sharing demonstration site findings with the CEC throughout the research project. As a result, the REALIZE approach has been included in the California Equitable Building Decarbonization program, which incentivizes standard package deployment and partnership with the trades while also providing cost coverage for the electrical and remediation measures often required in retrofits.

Overall, the project findings demonstrated that a strategic approach to selecting appropriate multifamily buildings is critical to scaling deployment of a standardized retrofit package utilizing prefab components. In addition, although some of the technologies deployed across the pilot demonstrations were not included in the final package recommendation, the project team recommends that additional research and development (R&D) be conducted in more appropriate climate zones (for example, cold weather climates in regions like the Northeast, where winter heating savings could present more favorable economics for panelized envelope solutions) and that future demonstrations leverage project learnings related to project delivery (especially regarding vertical project integration).

It's likely that scale, through a program like Equitable Building Decarbonization, will result in some installation cost compression, as contractors become more efficient and there are more of them installing heat pumps. That said, process innovation is still needed in project delivery integration. Specifically, vertically integrated administrators, or solution providers, could also achieve cost-compression through bulk procurement with certain manufacturers through a larger manufacturer consortium, although project team findings demonstrated that actual project savings were lower than the 50-percent savings envisioned nearly seven years ago, at the outset of this project.

Findings

- Scale can be achieved using currently available off-the-shelf technologies.
    - The specific technologies highlighted in the Netherlands' Energiesprong program (mechanical pods and prefab panelized wall systems) are not needed for standardized package deployment in the state's building retrofit market.
    - Products developed for California's specific market conditions did show strong promise, including AeroBarrier and the Villara Aquathermaire.

- Some degree of vertical integration of delivery entities can improve scale and cost compression.
    - Delivery entities should be nimble enough to leverage, train, and expand the existing regional workforce.
- Energy bill savings and incentives are insufficient to cover the full cost of multifamily retrofits in states with high electricity rates, like in California.
- Technology innovation is not the primary barrier to scale:
    - There is a shortage of contractors committed to residential retrofits and skilled workers capable of installing emerging technologies and even existing technologies that would be required.
- Scattered programs and insufficient funding make it difficult for contractors and building owners to participate in decarbonization programs.
- Monetizing non-energy benefits and leveraging non-energy funding to achieve a basic standard of livability (comfort, health, resilience) are critical for retrofits of pre-Title 24 housing, and they should be prioritized in future R&D.

Recommendations for Future Funding

- Monetizing non-energy benefits and leveraging non-energy funding to achieve a basic standard of livability (comfort, health, resilience) is critical for pre-Title 24 (California Building Code) buildings. This could include, but is not limited to:
    - **Multifamily retrofit pilots** quantifying indoor air and environmental quality during monitoring and verification post-retrofit, as measured by sensors/monitoring equipment installed in building envelopes (walls + windows).
    - **Multifamily retrofit pilots** quantifying building resilience benefits, as defined by the number of days tenants can shelter-in-place during an extreme weather event (for example, wildfires, extended periods of poor air quality, Check Before You Burn, "no burn" alert days).
    - **Multifamily retrofit pilots** quantifying productivity, as defined by attendance (sick days/call outs) for workers or students in regions plagued by poor air quality (for example, the South Coast Quality Management District).
- Address workforce shortages impacting the scale of residential retrofitting.
- Develop contractor training for labor signatories (union contractors) and non-union residential contractors, featuring package equipment curriculum and resources for workers interested in obtaining general contractor licenses.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
3D	three-dimensional
ABC	Advanced Building Construction Collaborative
ACH50	air changes per minute at 50 pascals
AEA	Association for Energy Affordability
AIO	all-in-one
AQTA	AquaThermAire
Btu	British thermal unit
°C	degrees Celsius
CARE	California Alternate Rates for Energy
CEC	California Energy Commission
CIAAQ	California indoor ambient air quality
COP	coefficient of performance
EE	energy efficiency
EIFS	exterior insulation and finish systems
EPIC	Electric Program Investment Charge
ERV	Energy Recovery Ventilators
EUI	energy use intensity
°F	degrees Fahrenheit
GHG	greenhouse gas
GPM	gallons per minute
GWP	global warming potential
HP	heat pump
HPSF	Heating Seasonal Performance Factor
HVAC	heating, ventilation, and air conditioning
IMP	insulated metal panel
kBtu	thousand British thermal units
kBtu/sqft	thousand British thermal units per square foot
kBtu/sf/yr	thousand British thermal units per square foot per year
kWh	kilowatt-hour
MGR	Market Guidance Report
MTCO2e	metric tons of carbon dioxide equivalent

Term	Definition
NREL	National Renewable Energy Laboratory
OAQ	outdoor air quality
PM	particulate matter
PM10	particulate matter with a diameter of 10 microns or smaller
PTHP	packaged terminal heat pump
PVC	polyvinyl chloride
R&D	research and development
REALIZE-CA	REALIZE California
RMI	Rocky Mountain Institute
ROS	rest of site
SEER	seasonal energy efficiency rating
SHGC	Solar Heat Gain Coefficient
SVCE	Silicon Valley Clean Energy
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
$\mu g/m^3$	micrograms per cubic meter

References

AEA, RMI, Integral Group, DBA, and UC Davis (Association for Energy Affordability, Rocky Mountain Intitute, Integral Group, David Baker Architects, and University of California, Davis). 2024. *REALIZE-CA Design & Installation Guide*. Accessed November 20, 2024. Available at https://rmi.org/wp-content/uploads/dlm_uploads/2024/11/rmi_realize_ca_design_installation_guide.pdf.

California Housing Partnership. April 2024. "Over 220,000 Unsubsidized Affordable Homes at Risk." Accessed on November 20, 2024. Available at https://chpc.net/wp-content/uploads/2024/04/Unsubsidized-At-Risk-Report_April-2024.pdf.

Lin W., B. Brunekreef, and U. Gehring. 2013. "Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children." *International Journal of Epidemiology*, 42(6):1724–37. Available at http://doi.org/10.1093/ije/dyt150.

Office of the California Treasurer. 2024a. *GoGreen Home Energy Financing*. Accessed November 20, 2024. Available at https://www.treasurer.ca.gov/caeatfa/cheef/reel/index.asp.

Office of the California Treasurer. 2024b. *GoGreen Home Energy Financing: Lending options for residential energy upgrades*. Accessed November 20, 2024. Available at https://www.treasurer.ca.gov/caeatfa/cheef/reel/resources/ggflender.pdf.

RMI (Rocky Mountain Institute). 2023a. *Energy Service Agreements for Deep Efficiency and Electrification Retrofits of Affordable Multifamily Housing in California*. Accessed November 20, 2024. Available at https://rmi.org/insight/energy-service-agreements-for-efficiency-and-electrification-retrofits-of-affordable-multifamily-housing-in-california/.

RMI. 2023b. *Tariffed On-Bill to Finance Energy Efficiency and Decarbonization Retrofits for Multifamily Buildings in California*. Accessed November 20, 2024. Available at https://rmi.org/insight/tariffed-on-bill-to-finance-energy-efficiency-and-decarbonization-retrofits-for-multifamily-buildings-in-california/.

Scavo, Jordan, Suzanne Korosec, Esteban Guerrero, Bill Pennington, and Pamela Doughman. 2016. *Low-Income Barriers Study, Part A: Overcoming Barriers to Energy Efficiency and Renewables for Low-income Customers and Small Business Contracting Opportunities in Disadvantaged Communities*. California Energy Commission. Publication Number: CEC-300-2016-009-CMF. Available at file:///C:/Users/chein/Downloads/TN214830_20161215T184655_SB_350_LowIncome_Barriers_Study_Part_A__Commission_Final_Report.pdf.

U.S. Census Bureau. 2024. "National, State, and County Housing Unit Totals: 2020-2024." Accessed on November 20, 2024. Available at https://www.census.gov/data/tables/time-series/demo/popest/2020s-total-housing-units.html.

Webster, Brett, Aven Satre-Meloy, Leslie Badger, Alison Donovan, Damon Lane, Kevin McGrath, Eric Wilson, Janet Reyna, Cheryn Metzger, Tyler Pilet, Martha Campbell, and Lucas Toffoli. 2024. *Accelerating Residential Building Decarbonization: Market Guidance* *to Scale Zero-Carbon-Aligned Buildings*. Advanced Building Construction Collaborative. Available at https://advancedbuildingconstruction.org/wp-content/uploads/2024/03/ABC_Industry-Guidance-Report_2023_v6.pdf.

Project Deliverables

- Task 1 - Convening
- Task 2 – Business Plan
- Task 3 – Building Typology Study, Emerging Tech Summary
- Task 4 – Commissioning Report
- Task 5 – Monitoring and Verification Plan
- Task 6 – Market Platform Charter
- Task 7 – Design & Installation Guide, Tech Transfer Plan
- Task 8 – Final Benefits Questionnaire, Final Presentation Deck

CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A: Promising Technologies

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APPENDIX A: Promising Technologies

Envelope

Insulated Metal Roof Panels

Product Description & Performance Specifications

Insulated metal panels (IMPs) are powder-coated galvanized steel extruded with EPS foam and then keyed together in 40” widths to create a self-aligning and water-tight array along an existing roof surface. Panels span from ridge to eaves, up to roughly a 50-foot maximum length. They can have ribbed, standing seam or flat profile and typically come up to 6” thick. To achieve our target R-30 roof insulation, the thicker 6” panels would be necessary (Figure A-1). Accessories such as gutter, rake, ridge and valley components, as well as clips for solar PV attachment, are typically provided by the same supplier.

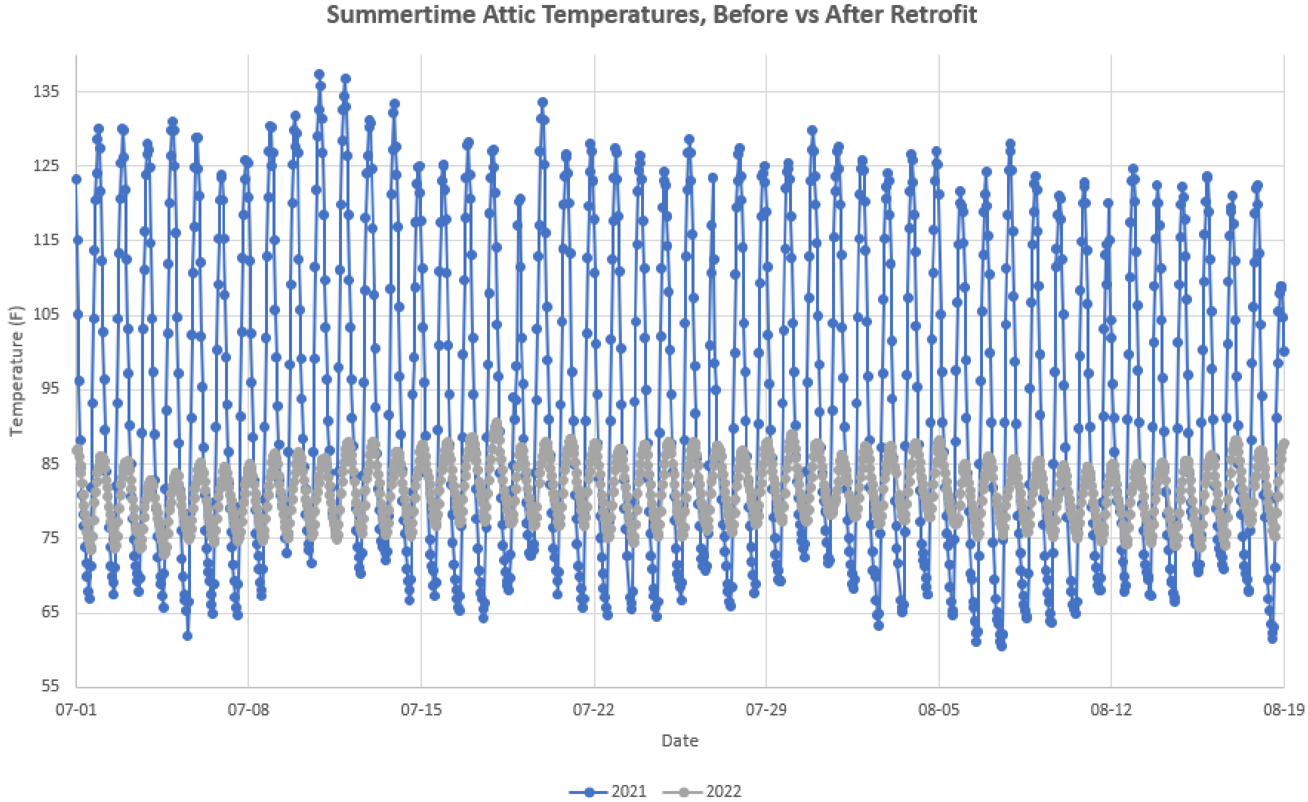
Figure A-1: A Generic Insulated Metal Panel

Source: REALIZE-CA Construction Set, David Baker Architects

Although IMPs are well-established, they are rarely used for existing wood-framed buildings, where non-planar, unlevel surfaces and the need to confirm or provide adequate structural attachment to the existing framing can complicate the installation. Although they can be installed in any configuration, they are best suited for uncomplicated roof lines. IMPs require a minimum slope of 1/2”:12”, so they are only viable for pitched roofs. On flat-roofs, REALIZE-CA would employ field-installed rigid insulation plus a single-ply membrane which is readily commercially available, commonly installed, and very cost-effective.

A pitched-roof retrofit using IMPs coverts the attic to a conditioned space by moving the thermal barrier from the existing location at interior ceiling to a new location at the plane of the roof sheathing. This may be an attractive option if the roof is already scheduled for replacement and there are ducts in the attic intended to be re-used. Moving the air barrier to the same location under the IMPs entails installing a new membrane underlayment onto the sheathing prior to placing IMPS. Attic temperatures measured before our IMP demonstration at Vera Cruz showed a striking degree of overheating in the vented attic where the HVAC distribution was located (Figure A-2). Attic temperatures measured after roof panel installation were dramatically lower and more stable.

Figure A-2: Attic Temperatures in July and August 2021 and 2022 before and after IMP Installation



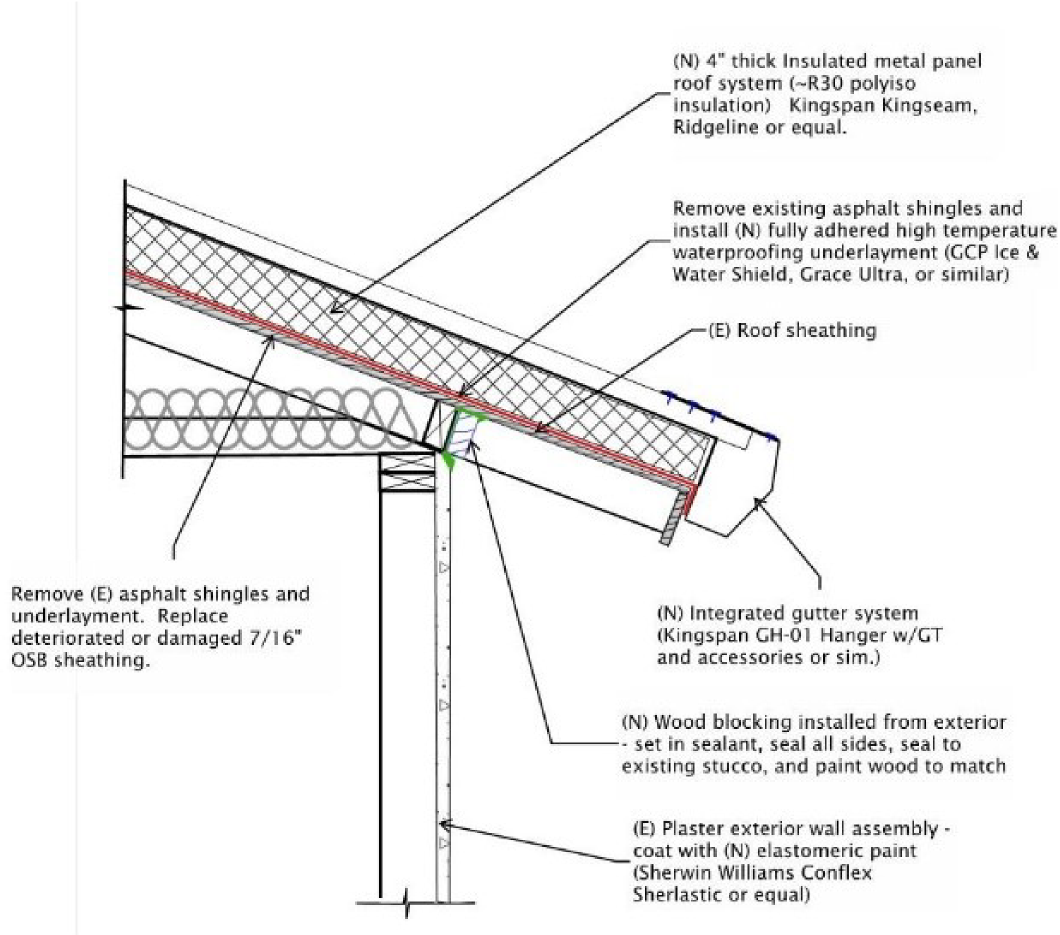
Source: REALIZE-CA Demonstration Data, AEA

Installation

The first step of a retrofit IMP installation is to identify the critical details for maintaining air barrier and thermal barrier continuity. At a minimum, this will include the transition from roof deck to wall at the roof eaves and rake/gable end. Existing wall, ridge and eave vents must be blocked out or removed and covered, and gable ends need to be insulated and air sealed. At Vera Cruz, other critical conditions included recessed porches, dormers, and a lower roof meeting an adjacent upper story wall, which all required new material to provide thermal continuity. Therefore a complete IMP roof installation necessarily involves multiple trades (Figure A-3 through Figure A-6).

Existing buildings may have other unique details that need to be negotiated. Where there is a second story adjoining an existing roof, there may be conflicts with existing windows or other features in adding thickness to the roof plane.

Figure A-3: Typical Air and Thermal Barrier Continuity Details at Eaves



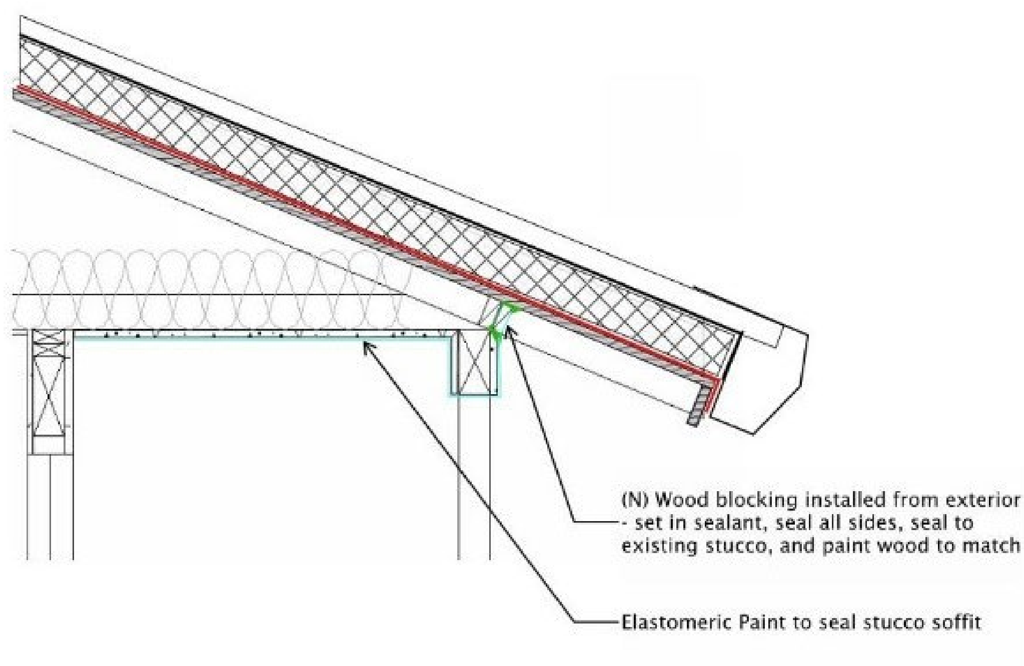


Figure A-4: Termination Detail at Adjacent Wall

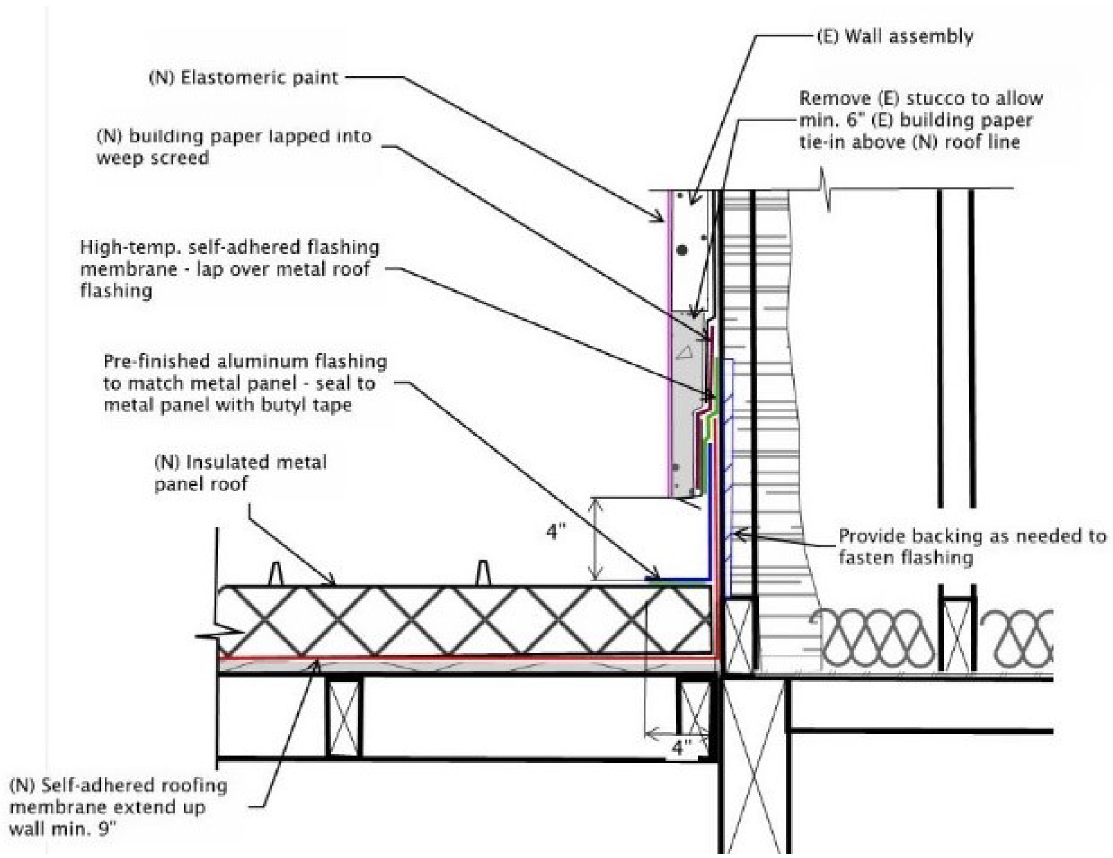


Figure A-5: Termination Detail at Roof Deck

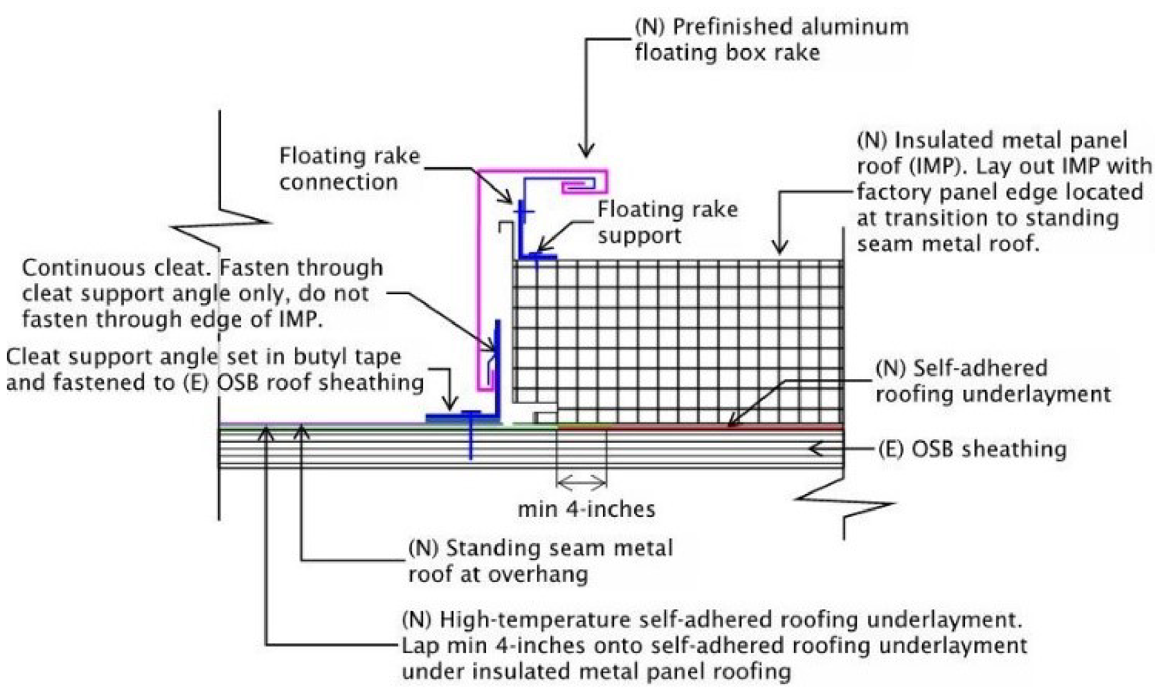
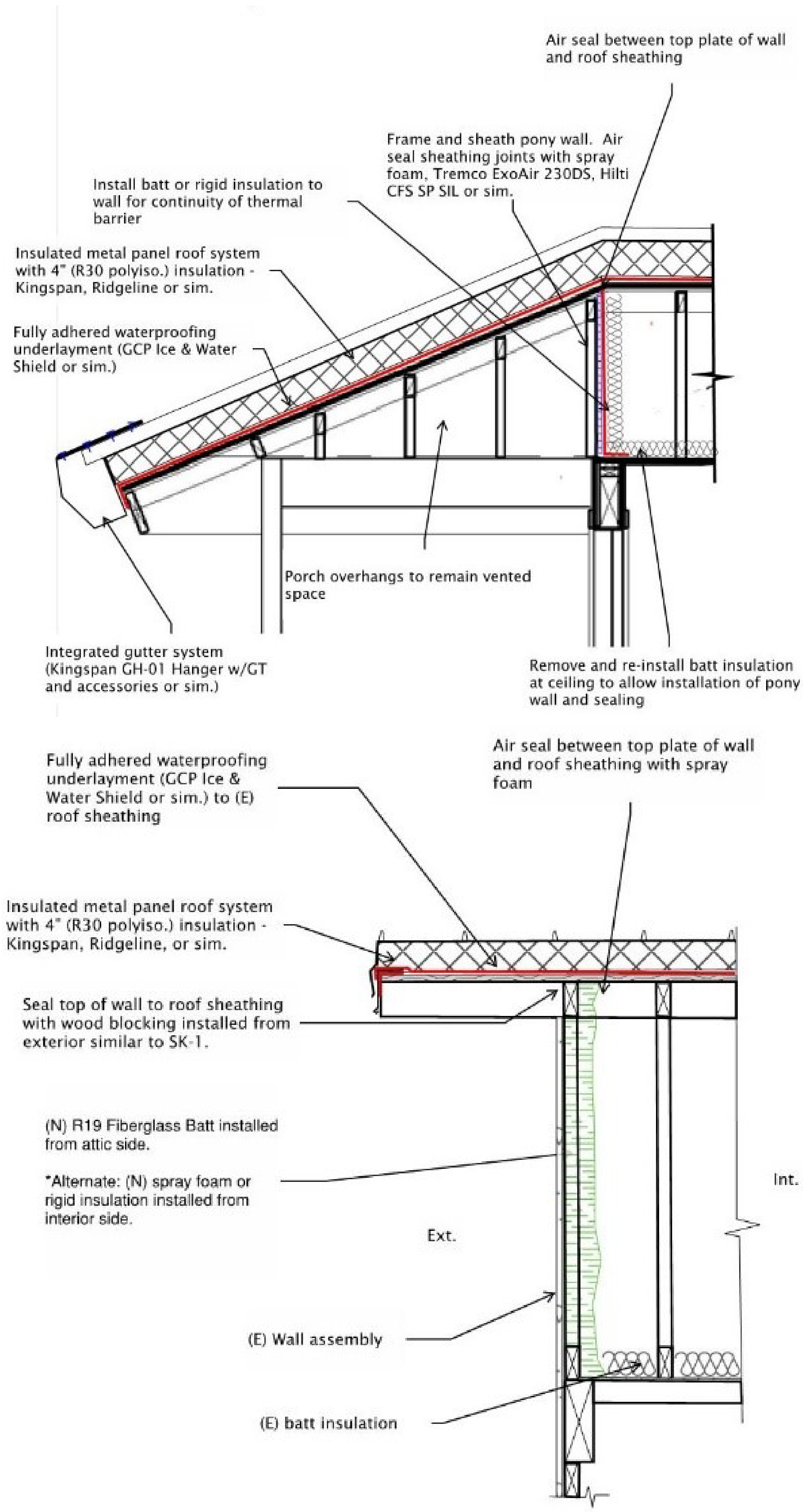


Figure A-6: Air and Thermal Barrier Continuity and Gable and Dormer Roof



Source: REALIZE-CA Demonstration Data, AEA

Availability & Commercialization

Insulated metal panels are not an emerging technology; they are a simple product produced by established manufacturers (Kingspan, Nucor, All Weather) and wide distribution throughout California.

Because a turn-key IMP roof retrofit involves multiple trades, it is best performed under a general contractor that ideally self-performs the roof installation. However, most IMP manufacturers require credentialled installers to install their products. In the current market, these installers typically do not have residential experience, let alone retrofits of wood-framed buildings in coordination with other trades. Market transformation would have to involve an incentive for small residential roof installers and general contractors to become trained in handling IMPs; or considerable incentives for existing panel installers to re-tool their services to deliver a full roof solution.

Among the steps our panel installers were unprepared to provide were structural calculations/ engineering for the light wood-framed building, demonstration of code compliance particularly when it came to panel attachment, and what methods of attachment were acceptable. They also stumbled on procuring and installing accessory components such as new roof vents compatible with new HVAC equipment and installing a roof gutter/downspout system that successfully negotiated roof lines that weren't perfectly level.

The commercialization of 3D scanning workflows would also help reduce errors in the field when it comes to planning around existing penetrations and understanding deviations in plane of the underlying surface for quick furring.

Compared to a standard asphalt shingle roof, an insulated metal panel roof is much more durable and long-lasting, reducing long-term risks and maintenance costs. However, at this point the life-cycle cost is still higher for a metal panel roof because of the cost of metal and relatively specialized labor. These are fundamental aspects of this solution that would have to be addressed before IMPs make sense at scale.

Panelized Insulated Cladding

Product Description & Performance Specifications

This product solution is an umbrella category that includes a range of potential rigid over-cladding products combining insulating and cladding layers in one. For existing affordable housing stock in California, the vast majority are low-rise, conventionally wood-framed buildings with substandard lateral support, and any over-cladding is limited by code to 4 pounds per square foot of added weight, without adding structural repairs. For our 2023 retrofit demonstration at Corona Del Rey, this narrowed our options considerably to panelized EIFS, namely Dryvit Fedderlite-M.

A number of existing conditions must be met in order for a panelized wall system such as Fedderlite-M to be feasible:

- Simple building geometry to limit demolition and thermal bridges
- Clean healthy stucco
- Grade level must be lower than top of first floor slab and the bottom edge of stucco not buried below grade.

Fedderlite-M is cut to precise dimensions, fitted with hanging rails embedded in EPS foam, and coated with EIFS finish in the factory. At the job site, panels are lifted and hung onto channels installed on the building to correspond with the rail locations. At panel joints, Tremco originally proposed using their Emseal product which is a prefabricated expanding foam with exterior silicone seals that would form a continuout air/water barrier. Tremco later decided that the Emseal product was incompatible with panel installation and the project team opted for typical panel to panel seals incorporating backer rod and sealant. Similar to EIFS in new construction, the exterior EIFS panels are a secondary water shedding barrier, and the primary air/water barrier is installed by sealing the existing stucco with a fluid-applied weather barrier (Tremco ExoAir 230). Due to inconsistencies in the existing stucco, the drainage gap behind EIFS panels varied from 0.25” to 1.5” which increased the risk of wind washing that would derate the thermal performance of the EIFS system. One strategy to address this risk is to provide air baffles behind the panels to limit air circulation and convection. Due to the limitations of the panel installation, it was not possible to install reticulated foam air baffles behind every EIFS panel. The team eventually decided to install air baffles at the perimeter of each building elevation. Over the course of construction, however, Dryvit-Tremco did not end up installing air baffles behind the EIFS panels.

Installation

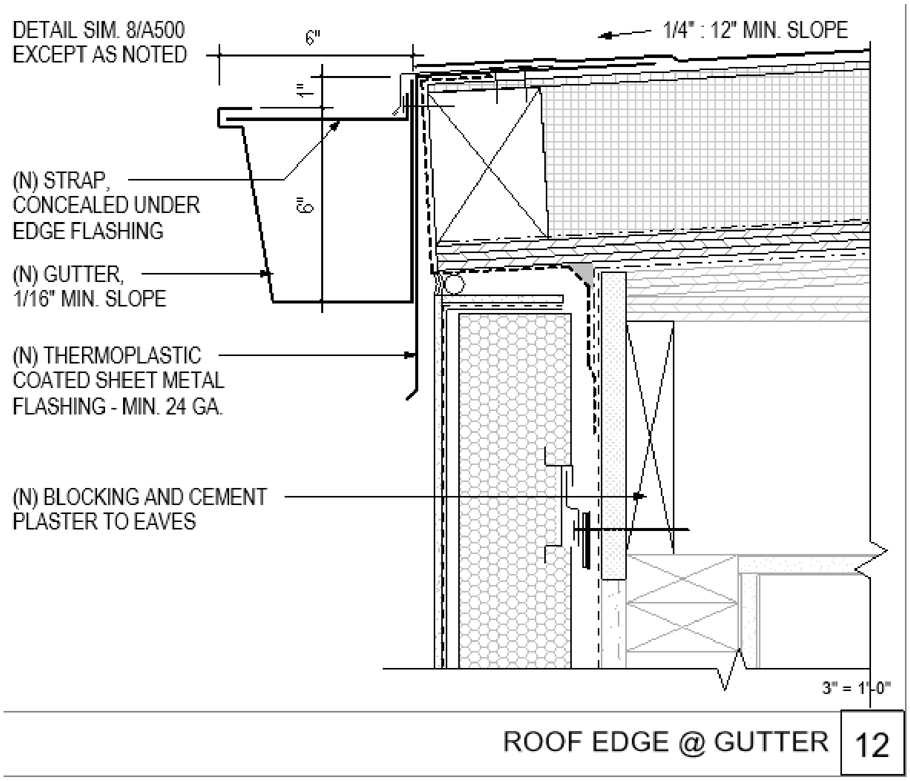
A successful panelized overcladding retrofit relies on prefabricated panels built from exacting measurements. To be handled without a crane, a typical panel has a maximum area of roughly 40 square feet, or approximate maximum dimensions of 5 feet x 8 feet. Along the length of a single facade, perhaps 50 to 75 feet, such as the front facade of Corona Del Rey, these panel dimensions result in 12 vertical seams, each of which cannot vary by more than +/- 0.25" without compromising the sealant joint between adjoining panels. Similarly, structural furring must be added wherever panels hang more than 0.625” from the wall. Therefore, the panel shop drawings must be based on a model that properly anticipates how panels with the assigned thickness join, lap, negotiate existing features, and site relative to the existing building plane. This model is ideally built from a wire-frame interpretation of a point cloud generated from a high-resolution building scan. Once the wireframe model successfully interprets panel thickness and joint seams, it should be able to directly generate shop drawings.

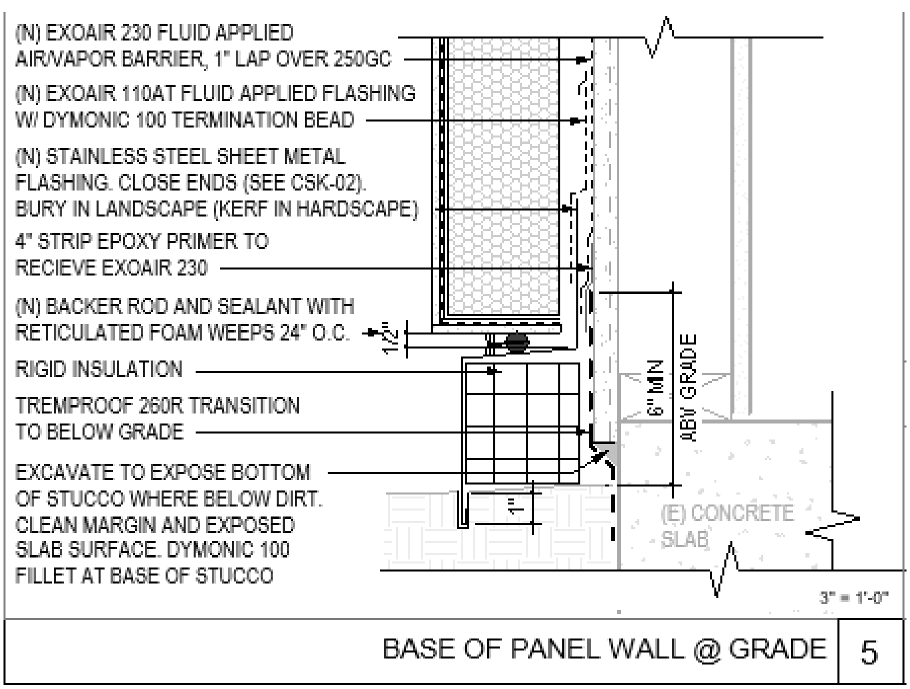
The model should include an "origin” point and horizontal datum that can be easily located on the building and establishes the start of the panelization sequence. It was discovered during our demonstration that lifting panels into place in order to mark their exact rail locations and installing the corresponding channels onto the existing building, loosely at first to provide some give while adjacent panels were installed, was the most efficient sequence for a severely out-of-plane building surface, even though it involved lifting and removing panels multiple times. Although this might suggest that smaller panels would create a more nimble process, having fewer pieces to puzzle together overall had the greatest benefit to speed and efficiency. On the other hand, in part because of worker safety rules, it required the same number of people to install a small panel as one big enough to require a crane, negating some of the labor cost benefit we assumed for the larger crane-installed panels.

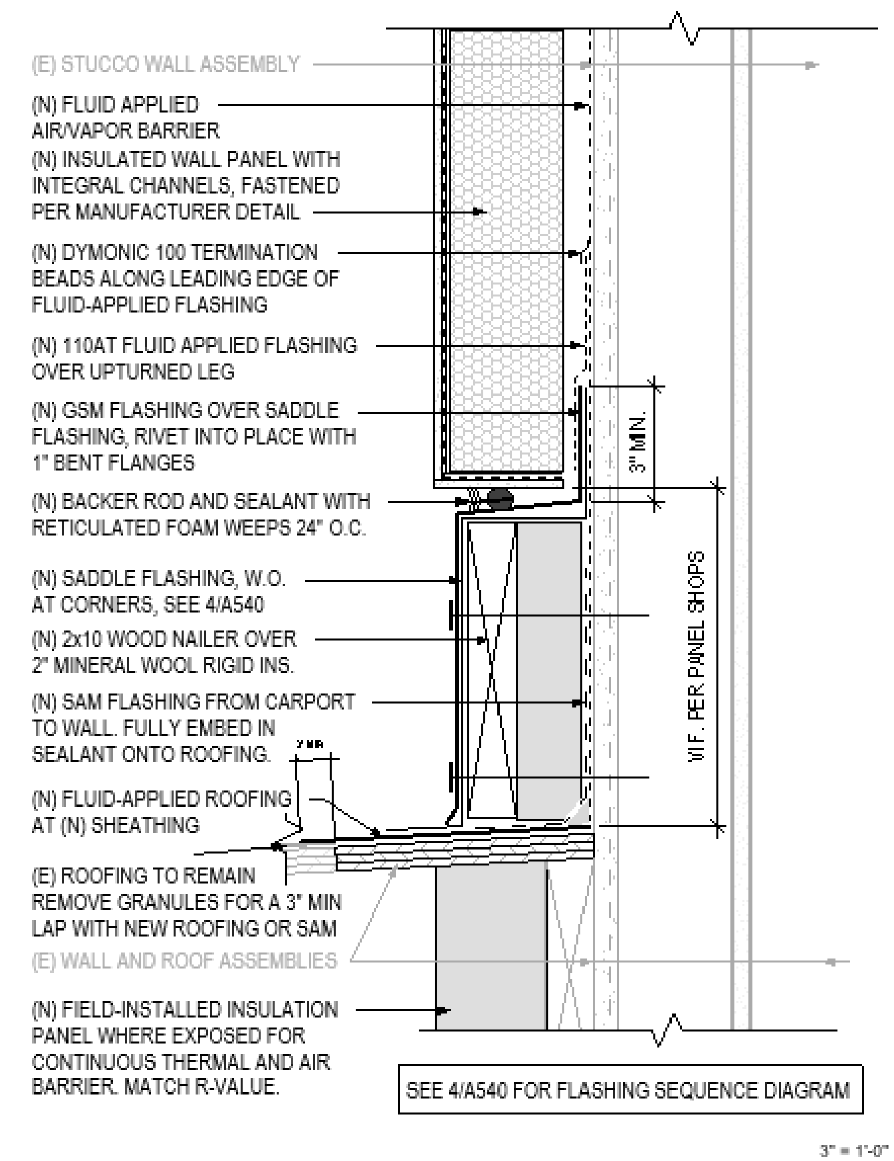
Critical details that required bespoke detailing, complex product specification and design included:

- Base of wall at grade. Fedderlite panels must maintain 6” minimum distance above grade. Assuming grade is within a few inches of top of slab, this necessitates either accepting a major thermal bridge at the base of wall or installing an independent piece of rigid insulation concealed under sheet metal flashing at the base of wall. If the existing stucco wall is buried within grade, cracks in the stucco may allow water to adsorb into the wall via capillary action. This is mitigated by installing a capillary break, which is to cut flush the very bottom surface of the existing stucco and coat it with a fluid-applied weather barrier material.
- Base of wall above a roof. Where wall panels are installed above a lower section of roof, the base of panel detail needed to allow enough space for roofing to turn up minimum 8-inches. This spacing is important to allow future reroofing without needing to removing the panels. Additional labor/cost needs to be factored in for areas with complex geometry such as saddle flashing where roofing stops in the middle of a wall.
- Top of wall to roof transition. Where existing roof overhangs are shorter than the added thickness of wall panels, additional carpentry is needed to extend the roof overhang to cantilever over and cover the top of wall panels. This resulted in a multi-stage installation sequence where the roofing vapor barrier was installed first, followed by wall panels, and then completed roof membrane.
- Replacement of demolished features. Even a building with relatively simple geometry like Corona Del Rey is likely to come with attached exterior features like balconies, attached garages, overhangs, entry awnings and fences that must be built around or replaced with an equivalent feature. At Corona Del Rey, the full wall panel retrofit necessarily included the construction of new post footings for the existing fence, and new entry trellises, which included the coordination of new post footings as well as knife-blade penetrations through the air/water barrier back to existing structure (Figure A-7).

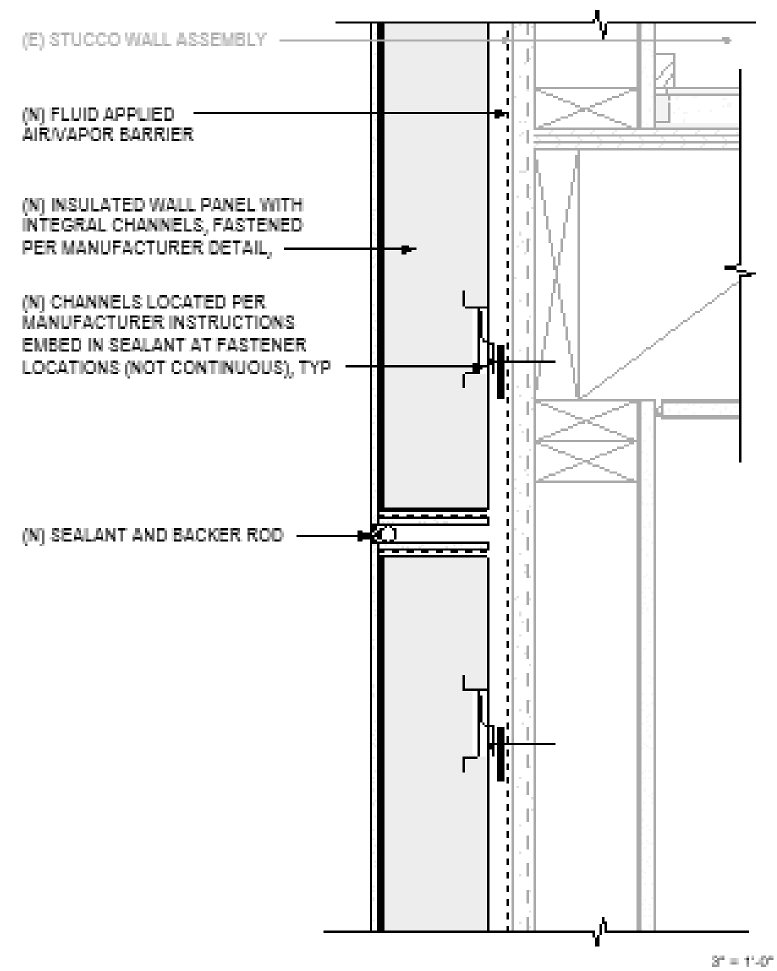
Figure A-7: Critical Panel Details at Corona Del Rey



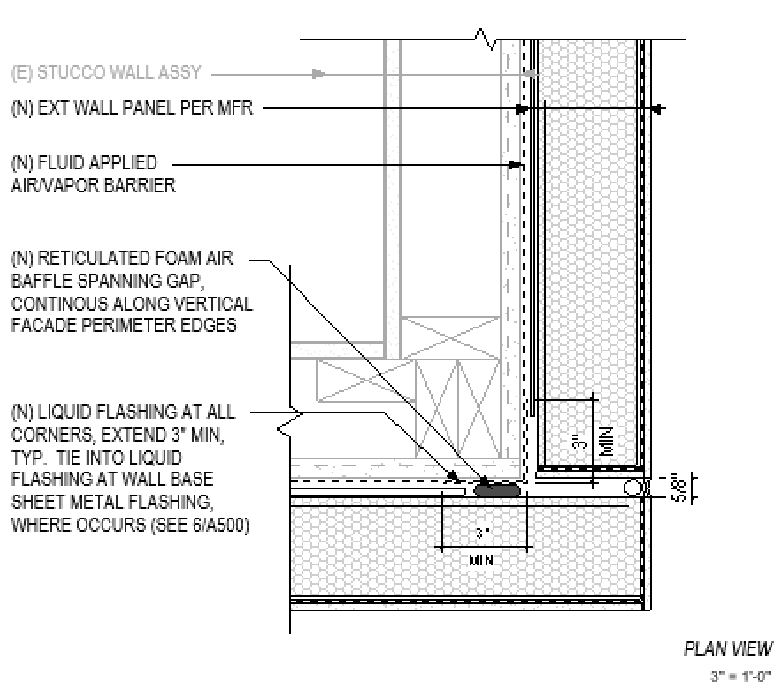




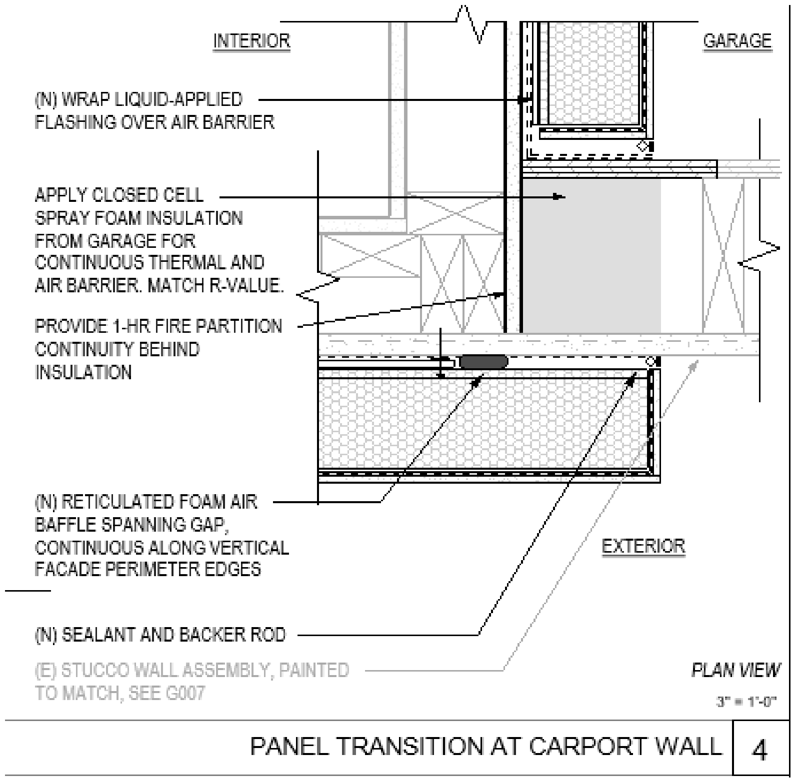
BASE OF PANEL @ LOW ROOF, TYP. | 6



HORIZONTAL PANEL JOINT, TYP. | 10



PANEL OUTSIDE CORNER | 2



Source: REALIZE-CA Demonstration Data, AEA

Availability & Commercialization

Status of panel manufacturing. To date, industrialized panel manufacturing and testing exists in Europe, China, and Canada, but no manufacturer has developed and marketed a scalable solution for panelized retrofits in the US. Other than Tremco/Dryvit, manufacturers Sto, Dextall, Nexii and mnmMOD have expressed interest in providing panelized retrofit solutions at scale in the US market, but most of these products are too heavy and unsuitable for California's affordable housing stock.

Commercialization of EIFS and alternatives. Panelized EIFS is widely commercialized in the United States from a limited number of large, established manufacturers who have focused offerings on both new construction and retrofit market. Retrofits of small wood-framed buildings are relatively rare; Corona Del Rey was the first deployment of Fedderlite and Revitalite on a low-rise multifamily building on the West Coast (Revitalite is a large format Fedderlite panel that has internal fiberglass internal framing and can support a window). These products are still a relatively expensive and heavy-handed solution for California building stock. Advances in more nimble solutions, such as high-performance insulated vinyl cladding and non-panelized products like spray-applied cork-based EIFS hold great promise with considerable investment in market transformation. A matrix comparing a range of products is included in Appendix A.

Table A-1: Matrix of Insulated Wall Panel Products

Manufacturer	DryVit/Tremco	DryVit/Tremco	Nexii	Sto	Sto	mnmMOD
Panel Model	Fedderlite (Retrofit)	Revitalite (Retrofit)	Nexii	StoPanel	StoLite Panel	mnmMOD Panel System
Available in the USA	Yes	Yes	Intended	Intended	Intended	Yes
Window Included	No (feasible with DryVit/Tremco Revitalite panel)	No (feasible with DryVit/Tremco Revitalite panel)	Integrated into panel	Windows must be field installed (not included in panel)	Windows must be field installed (not included in panel)	Included (optional)
Installation Time	~5 Days	~5 Days	< 1 week for entire building (predicted)	< 1 week for entire building (predicted)	< 1 week for entire building (predicted)	Not specified
Finishing Options	Including but not limited to: Textured Acrylic (HDP), Wood, Masonry, Stone, Metal Panels (variety of textures and colors)	Including but not limited to: Textured Acrylic (HDP), Wood, Masonry, Stone, Metal Panels (variety of textures and colors)	Able to design to owner/architect specifications.	Glazing, wood, masonry, stone, render in a variety of colors of textures.	Glazing, wood, masonry, stone, render in a variety of colors of textures.	Not specified
Seismic/Structural	No	Yes	No	No	No	Yes
Technological Readiness Level	TRL 7: System prototype demonstration in operational environment	TRL 7: System prototype demonstration in operational environment	TRL 2: Technology concept formulated	TRL 2: Technology concept formulated	TRL 2: Technology concept formulated	TRL 6: Technology demonstrated in relevant environment
Wall Panels						
Panel Thickness (inches)	2-12"	2-12"	Not specified	~5”	Not specified	3.5”
R-value	8-48	8-48	6 to 18 (predicted)	18 (predicted)	Not specified	14 (estimated).
R-Value per Inch of Thickness	4	4	Not specified	Not specified	Not specified	~4 for EPS foam product used in panel.
Cost/Square Foot ($)	$40-60	$40-60	$42.49	$39.47	$20-25 (installed)	$8.60
Weight/Square Foot (lbs)	2	2	Not specified.	8-20	1.5	3.5 (estimated, for standard panel)

Roof Panels						
Panel Thickness (inches)	2-12"	2-12"	18 (predicted)	~5″	~4-5″	6
R-value	8-48	8-48	30 (predicted). R72 Insulation specified.	30 (predicted)	Not specified	24 (estimated).
R-Value per Inch of Thickness	4	4	Not specified.	Not specified	Not specified	~4 for EPS foam product used in panel.
Cost / Square Foot ($)	$40-60	$40-60	$42.49	$65 (installed)	$20-25 (installed)	$11.88
Weight / Square Foot (lbs)	2	2	Not specified	8-20	1.5	3.5 (estimated, for standard panel)

Market transformation. There are three major areas for market transformation before panelized EIFS or a similar solution become viable for the REALIZE-CA program:

- Cost compression for panelized EIFS or cheaper alternatives
- Formation of nimble, vertically integrated delivery entities
- Commercialization of high-resolution 3D scan-to-shop drawing workflows

Similar to IMPs, a panelized overcladding retrofit will necessarily trigger work by multiple trades, including rough framing and thermal/moisture protection, site-built roofing and accessories, sheet metal, site work and concrete, and landscaping to restore what was disturbed. There may be coordination with MEP for integrating new penetrations, as we did at Corona Del Rey. In order to be incorporated into the REALIZE program, the formation of delivery entities that can deliver and warranty a full envelope solution for a non-profit property owner is essential. These entities must vertically integrate general contracting, panel manufacturing and delivery. Tremco, our partner for Corona Del Rey, and the parent company for Dryvit, Fibergrate (panel manufacturing) and Weatherproofing Technologies, Inc (a roofing and general contractor) was not nimble enough as an organization to deliver true vertical integration and efficient project delivery at Corona Del Rey. FunForm, a start-up on the east coast, presents a more promising model for developing a ground-up retrofit delivery entity more tailored to the specific California low-rise housing market.

Another setback at Corona Del Rey was that 3D scanning workflows were similarly not developed enough to achieve a true demonstration of the workflow. Although we were able to demonstrate the enormous time savings compared to hand-measurements meeting the necessary accuracy, the tools necessitated, the wireframe model did not provide a direct basis for shop fabrication. However, such tools are evolving rapidly and are absolutely essential to incorporating panelized retrofits into a REALIZE-CA package.

Additional research and development needed for digital scan-to-shop-drawing workflow to streamline production includes:

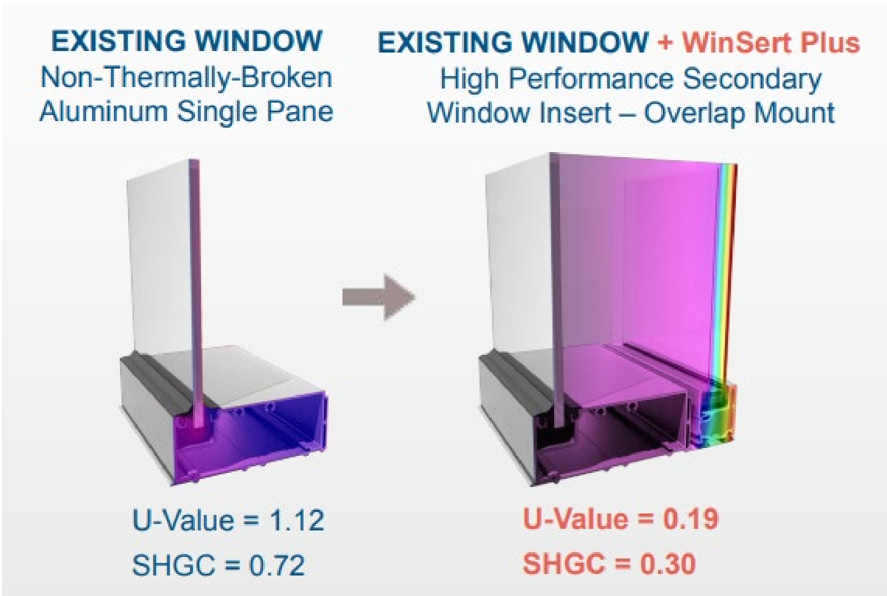
- Apparatus like drones or jigs to "fly" the camera to different vantage points in order to achieve high-resolution scans that have consistent accuracy across a facade. This technology is much farther along than when we conducted our scans in 2021.
- To our knowledge, platforms for converting scan point-clouds to a wireframe model that can resolve added thickness and panel joints exist in an early form, but do not yet correct for deviations in the planarity of the existing building, which are of particular importance to light, wood-framed construction.
- Based on current products in development, such as Signetron, or FunForm a parallel "architectural design" workflow is still needed to make aesthetic decisions about locating panel joints and finishes, to resolve special conditions, and to document design intent outside of the shop drawing workflow. Wood-framed buildings often present more complex geometry, which potentially leads to a higher degree of intervention and visualization by an architect. Ideally, the retrofit delivery entity could bypass an architectural consultant, and visualization or other drawings needed to document the project can be developed from a single model.

High Performance Window Inserts

Product Description & Performance Specifications

Storm window inserts are lightweight, high performing secondary windows mounted to the inside of an existing window. The REALIZE-CA King's View Manor demonstration featured an Alpen WinSert window insert specifically designed to be operable in order to maintain the use of the existing sliding windows (Figure A-8).

Figure A-8: Existing Compared to Single Pane Window + WinSert Plus



Source: REALIZE-CA Construction Set, David Baker Architects

By adding an additional insulating gap between the existing single-pane window and the Winsert, thermal performance of single-paned or double-paned window can be enhanced. Alpen's lab testing reports air leakage reduction, as well as a U-Factor improvement as low as 0.19 to 0.47, SHGC from 0.28 to 0.38, depending on the Winsert model. The REALIZE-CA team has yet to calculate reductions in heating, cooling or fan loads at the demonstration site, but reported no infiltration benefit after completing whole-unit air leakage testing. This may be a result of 1) the prototype design, which did not include a gasket material between the two new sliding panes, leaving an air pathway to the existing leaky window and 2) the existing leakiness of the existing window construction. After conducting surveys, tenants reported acoustic benefits and found the new window to be more aesthetically pleasing than their existing one.

After demonstration, it was determined this product is best paired with fixed, casement or awning windows where the existing window is in good condition and a full retrofit window replacement is prohibitive. Specifically, building conditions that make storm-window inserts appealing include historic buildings, siding with asbestos, high-rise or mid-rise buildings where scaffolding, boom lift equipment is required for replacement.

The REALIZE package would only include this product if achieving performance above conventional double-pane window specifications did not have diminishing returns relative to the incremental cost. Therefore, the installed cost of these products will need to be cost competitive, if not cheaper than a full window replacement to scale as a viable retrofit solution for affordable housing. Alpen's typical Winsert Lite and Winsert Plus products are non-operable and range from $40 to $50 per square foot, while the prototype was $10 per square foot more. This prototype was comparable in installed cost to the double pane window retrofits at other demonstration sites. Despite that, the team does not consider this product to be an appropriate alternative to a full retrofit window replacement.

Installation

The window inserts are designed to be lightweight and installed from the interior. Prior to installation, inserts are fabricated according to contractor measurements of each unique window type at the property. Inserts are brought to site, fitted to the window opening and drilled into the top of the window opening. Contractors reported 1 hour installation time per window, inclusive of measurement and installation. This is less than a double-pane vinyl "piggy-back" retrofit window, which requires waterproofing.

Availability & Commercialization

Storm windows are commercially available, but high performing products are relatively new to the market, and operable products are not typical, since the primary application is for historic commercial and institutional buildings.

Heating, Cooling, Ventilation & Hot Water

Ducted, Vertical Packaged Heat Pumps and Phenolic Ductwork

Product Description & Performance Specifications

The Ephoca series of ducted all in one heat pump ERV models paired with Thermaduct KoolDuct Soffit allows for high efficiency delivery of most major mechanical end uses from one system. The Ephoca Vertical AIO unit delivers space heating and cooling, and heat recovery ventilation from one unit, which does not require an outdoor unit as the compressor and fan coil are contained within the same box that can be installed indoors. The system could utilize prefabricated, insulated, airtight phenolic ductwork that is lightweight and factory-fabricated, delivered to the site in pieces up to 13 feet long and hung in place with clips. Its foil-faced surface is paintable and therefore can be textured and painted to match drywal once it is installed. The two paired together offer a high efficiency air-based space-conditioning and ventilation system with the potential for simplifying installation in smaller apartments where minimal new soffiting/ducting is needed.

Installation

The Ephoca Vertical AIO unit requires an indoor space that can accommodate that height and width of a refrigerator and the depth of a slim bookcase, and is located on an exterior wall inside the home. Because the unit provides balance ventilation (with heat recovery), it requires air pathways for fresh air intake and extract/exhaust air from and to the outside respectively. Clearances should be minded for install and maintenance capabilities. It is an air-based system requiring duct distribution, which is connected at the top of the unit

Thermaduct's KoolDuct Soffit distribution system is designed for easy and fast installation, with an estimated labor time reduction of 50 percent. The best application for this air distribution system is smaller apartments with relatively centralized and compact delivery pathways, and apartments without attics or accessible interstitial space to run traditional ductwork easily or at all. Because it is a soffit, regular or higher ceilings are necessary to accommodate the exposed soffit run. The system is airtight and made of insulative material, each of which enhances the distribution performance and efficiency. Clips are screwed into the ceiling and wall where the soffit is installed and fold down into the KoolDuct material to secure it in place. It is light enough that the system doesn't require hangers or straps, and can rely on the support of the clips. Special care should be taken where the Soffit must pass through walls, either interior or exterior (in this pairing, interior only), and structural members should be considered at the design stage.

Availability & Commercialization

The Ephoca Vertical AIO is commercially available but requires large lead time for large orders as production happens in Italy and they are not well-stocked in the United States. Only a few have been installed in California to date, but the product is available for purchase and utilizing in design. The KoolDuct Soffit is fully in the R&D stage and is not commercially available for purchased. This product has only been installed as a mockup in the manufacturer's shop and the first planned installation of the first demonstration component is to take place in mid-December 2023. The product remains in the R&D stage with more design work needed for standardized product and to determine how much customization will be needed in the design/fabrication process. It is a viable product and can be installed in buildings today, but requires more development before becoming widely commercially available.

Appliances and Fixtures

Kitswitch

Description

Modular interiors are a promising method of prefabricating individual complex components of a building - such as a kitchen – requiring coordination of multiple trades (casework, countertop and backsplash, hardware, appliances, fixtures, and MEP connections). The same benefits of standardization, quality control and cost compression apply to modular interiors as they do to factory-built whole-building (volumetric modular) construction but with much lower risk. The modular kitchen demonstrated at Kings View Manor assembled four independent, factory-built sections, each mounted on light-gauge steel and erected and joined on site. Each modular component includes integrated plumbing and electrical connections with shut-off valves, ensuring clean installation and removal without disturbing drywall or building systems. Because the modular components are adaptable to areas of any dimension, conversions and retrofits are a promising application of modular kitchens. A menu of appliance options ensures that the final product meets performance criteria.

Installation

As demonstrated at King's View Manor, once the modular components, with appliances and finishes, are selected from a limited menu of options, the kitchen installation takes two days, including demolition of the existing kitchen, with minimal disturbance beyond the area affected.

Commercialization

Modular kitchen and bathroom fabricators are not new, but the conventional value proposition is to create kitchens and baths as volumetric modular boxes, which get craned in to a new ground-up building. These have to be concrete buildings in order to sequence and transfer the mods into position. The supplier we used for our demonstration, KitSwitch, is a promising, woman-and-minority-owned small business based in San Francisco that is using a different model. It is part of the Autodesk Research Outsight Network, Net Zero Accelerator, and a Terner Center innovation grant recipient. They have recently commercialized the Kit-Kitchen, their first product offering, developed with the help of industry experts and in partnership with select casework manufacturers. To our knowledge there are no other providers delivering this type of product.

Environmental Impact

KitSwitch products promote all-electric, low-energy solutions as well as resource use reduction, re-use, and design for reconfigurability and disassembly, contributing to a favorable end-of-life for interior components, which make up a major share of a multifamily building's life-cycle impact.