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FINAL PROJECT REPORT

Low-GWP Mechanical Modules for Rapid Deployment Project

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PREFACE

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

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

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

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

The Low-GWP Mechanical Modules for Rapid Deployment Project is the final report for EPC-19-032 conducted by the Association for Energy Affordability, Lawrence Berkeley National Laboratory, the Smith Group, the Rocky Mountain Institute, and Emanant Systems. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

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

ABSTRACT

Alteration to a building's interior to accommodate replacement systems is often one of the greatest barriers to an electrification retrofit. This rework is often very time-consuming, disruptive, bespoke, and costly. Heating, ventilation, and air conditioning, and domestic hot water systems can pose particular challenges because the system components are often spread throughout the building and installed in inaccessible locations. Combining the systems that deliver these major mechanical end uses could offer advantages for retrofits to achieve building electrification. As heat pumps take an increasing size of the mechanical system market, more refrigerant is being used in buildings. This report shares learnings and outcomes from studying three combined mechanical systems that use low-global warming potential refrigerant, and evaluate their suitability for California's existing multifamily building market, especially affordable multifamily housing. Each product evaluated represents a type of combined mechanical system whose advantages and disadvantages were measured through design and demonstration research. The findings share what types of products suit the target building market and why, and how system design can be considered going forward. Combined mechanical system products whose configuration allows for reuse of existing system locations and infrastructure, and are developed with specific retrofit applications in mind, are most primed for market development and most likely to be successful retrofit solutions. Ultimately, the research seeks to identify possible solutions for existing buildings to reduce greenhouse gas emissions, utility costs, and retrofit costs and invasiveness, to support pursuit of California's legislative and climate goals.

Keywords: mechanical retrofits, multifamily retrofit, decarbonization retrofit, integrated heat recovery, heat pumps, low-GWP mechanical systems

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Executive Summary

One of the most substantial barriers to retrofitting a building for electrification is the amount of rework that must be done to a building's interior to accommodate the replacement systems. This rework is often very time-consuming, disruptive, bespoke, and costly. Heating, ventilation and air conditioning and domestic hot water systems can pose particular challenges because the system components are often spread throughout the building and installed in inaccessible locations such as under floors, behind walls, or above ceilings. There are opportunities for significant efficiency improvements and installation cost savings associated with combining the components of various major mechanical systems, that are traditionally housed separately, into a single multi-function machine.

The Low-GWP Mechanical Modules for Rapid Deployment project is an outgrowth and extension of an EPIC research project, EPC-17-040 known as REALIZE-CA, that sought to demonstrate the design and rapid delivery of affordable integrated zero net energy retrofit packages. REALIZE-CA studied whether the Dutch Energiesprong model—a delivery model pioneered and proven in the Netherlands, which rapidly delivers deep energy retrofits using industrialized and pre-fabricated technologies and approaches, such as pre-fabricated envelope panels, mechanical pods combining all major mechanical functions, integrated controls and renewables, to scale deep energy retrofits—could be adapted to the California multifamily retrofit market. Initial findings indicated that a market gap in California existed for the all-in-one mechanical solution offered through Energiesprong. This project aimed to address that market gap. The purpose of the project was to design, test, and field demonstrate a combined mechanical system that used low-global warming potential (GWP) refrigerant—a GWP of 750 or less—to scale multifamily building decarbonization retrofits and reduce the emissions of mechanical systems. It sought to benefit the California rate payers, by studying those systems' applicability, energy efficiency, cost reduction, and speed of installation to deliver benefits to ratepayers and support California's climate goals. Through this project's EPIC award, EPC-19-032, low-GWP combined mechanical systems of different form factors and combinations of mechanical functions were evaluated to compare their benefits and challenges.

In supporting California's clean energy and climate goals, this research project focused on evaluating and seeking to illuminate a solution, or solutions, for mechanical retrofits that are both rapidly deployable and scalable to achieve building decarbonization in the existing multifamily building sector, especially in affordable housing. As stakeholders such as practitioners, building owners, and manufacturers seek solutions to achieve emissions reduction in the residential sector, alignment between supply and demand of those solutions is needed to realize carbon and emissions reduction. Federal regulatory policy is driving toward low-GWP refrigerants, therefore, exploring ways to optimize the energy performance and installation efficiency of products using such refrigerants is necessary to prepare the market.

Project Purpose and Approach

The EPC-17-040 multifamily buildings typology research identified low-rise stick frame construction as the most common building type in that market, representing about 82 percent of the existing multifamily housing stock, according to the EPC-17-040 REALIZE-CA Building Typology Study. Therefore, research demonstration focused on this building type to study the benefits and challenges for the greatest impact, in approximately 3.4 million apartments across California.

This project approach studied, field demonstrated, and evaluated different types of low-GWP combined mechanical systems in four units across two affordable multifamily properties in two different climate zones. The mechanical systems evaluated through this project represented three different system types:

1. System Type #1: a fully-packaged low-GWP combined mechanical system that serves all four major mechanical end uses—space heating and cooling, domestic hot water, and ventilation with heat recovery—with all components housed in one box.
2. System Type #2: a partially-packaged low-GWP combined mechanical system that serves three major mechanical end uses—space heating and cooling, and domestic hot water—with mechanical components physically separate but connected by refrigerant lines for coordinated operation and heat recovery opportunities.
3. System Type #3: a more dispersed low-GWP combined mechanical approach with zonal equipment that serves three mechanical end uses—space heating and cooling, and ventilation with heat recovery—with opportunity for coordinated controls, and a separate low-GWP domestic hot water system that serves multiple apartments.

The Systemair Genius represented System Type #1, which the research team studied in a laboratory test chamber setting and ultimately did not install in the field (though an informal test site installation did occur in California Climate Zone 3). The Villara AquaThermAire represented System Type #2, which the team studied through installation and performance monitoring in two units of a multifamily building in California Climate Zone 12. System Type #3 was represented by the All-In-One Wall Mount package terminal heat pump with integrated energy recovery Ephoca ventilator and the SanCO2 central heat pump water heating system, which the team studied through installation and performance monitoring in two units of a multifamily building in California Climate Zone 10.

The goals of the project were to measure energy and cost performance, and installation efficiency in the field to understand whether low-GWP combined mechanical systems can be a rapidly deployable solution for scaling decarbonization retrofits in California's existing multifamily building sector. The technology demonstrations assessed the market applicability of these products for this target market, and synthesized recommendations for these and other future products. Ultimately, the study sought to find solutions that would achieve energy efficiency, energy affordability, reduced installation time, reduced resident disruption, lower environmental and carbon impact, and provide reliable mechanical solutions for building resiliency.

Key Results

At the outset of the project, the team had planned to exclusively study System Type #1; however, the first half of this research study revealed that this system type had the potential of introducing more challenges in multifamily retrofit applications than it would solve. The second half of this research study sought to identify which characteristics of the combined mechanical product class actually yield benefits and savings to reduce barriers to building electrification. Below are the high-level findings:

1. Form factor—shape, size, and packaging product—and system component layout are two of the strongest determinants of whether a combined mechanical system will work in a multifamily retrofit application, and combined mechanical systems come in a variety of form factors.
2. Benefits associated with the heat recovery capabilities that are often a key selling point for some combined mechanical systems can only be realized during periods of coincident space cooling and hot water demand. There is a low natural occurrence of coincident demand periods in many residential applications, measured at less than 5 percent of operating time according to demonstration testing. There are potential ways to improve the heat recovery capabilities of these systems, which are described in the Conclusion below.
3. Combined mechanical system products developed with specific retrofit applications are most primed for market development and most likely to be successful retrofit solutions; however, there are very few of them available right now. The Villara AquaThermAire is an example of a product designed for a specific application. It slots in easily in the typology for which it was designed, but would not be a good retrofit solution for an apartment with on-demand domestic hot water and room-by-room heating, ventilation and air conditioning, for example.
4. Combined mechanical systems that integrate ventilation are likely to encounter challenges with code compliance due to exhaust re-entrainment. Experiences from this project indicate that current relevant codes are unclear and approaches to code compliance are burdensome. The research team's measurements support exception 4 of American Society of Heating, Refrigerating, and Air-Conditioning Engineers 62.2, Section 6.8 that it is reasonable not to have 10 feet of separation between intake and extract airways.
5. There is currently no testing standard, system performance standard, or dedicated compliance pathway for combined mechanical systems. Using the existing standards, it was not clear how to test combined mechanical systems in this project. Lack of clear compliance pathways means that some of the performance benefits for combined system are not measured or quantified adequately.
6. System Type #1 (all-in-one-box solution) is not well-suited for existing multifamily retrofits. Mechanical pods that currently exist on the market demand too much contiguous space to accommodate the machine's footprint, its clearances, and

distribution connections, and do not fit in typical mechanical system locations in this residential market.

Additionally, Table A-1 located in Appendix A summarizes some of the high-level metrics that were the focal points of the study.

Through extensive product research, design, planning, and field demonstration, System Type #2 proved to be the most suitable and market-ready option for deployment in California's existing affordable multifamily building stock. The form factor of the System Type #2 product was specifically designed to accommodate installation in what is a very common existing mechanical space layout in California; whereby, an existing outdoor condensing unit sits on an outdoor pad adjacent to an outdoor-accessible mechanical closet that houses the existing air handler and tank-type water heater. The options for System Type #1 that are currently available on the market today require further product development to be viable options for the types of retrofit applications considered in this study. This product class could be more readily applicable to the single family and new construction multifamily markets, but only after necessary design modifications and component and wiring changes are made to meet United States efficiency and electrical standards. System Type #3 shows promise, particularly for buildings that do not have usable or existing ductwork and have central domestic water heating. There are additional technical challenges such as space constraints and addressing the resulting envelope penetrations that should be considered. Further research and development are needed in the following areas:

- Gain a better understanding of the potential benefits of the integrated heat recovery options available in these types of machines, and subsequent optimization of that functionality. This could include control strategies that increase simultaneous operation of heating and cooling functions, advanced scheduling for runtime optimization and load shifting, refrigerant cycle optimization and other such strategies.
- Market/Product development for: 1) more low-GWP combined heat pump systems that are space-flexible and use existing mechanical spaces, 2) retrofit solutions for mechanical, electrical and plumbing distribution that reduce installation time, cost, and invasiveness, and 3) user-friendly and optimized controls solutions for room-by-room combined systems that suit the multifamily rental market.
- Continued policy development for use of low-GWP refrigerants and natural refrigerants, like R290 propane.
- Codes and Standards development for reducing barriers to electrification by using plug-in shared circuit mechanical approaches and offering a testing protocol for combined mechanical systems.

Further development and demonstration of products of this equipment class will build upon the findings of this study to refine design and promote rapidly deployable, affordable, high performing mechanical retrofit solutions. Further development would support the target goals set out in this Agreement and further deliver on utility ratepayer benefits, which include: potential for both upfront and operational cost-savings, non-energy benefits such as safety and resiliency from access to cooling, better indoor air quality, and increased safety removing combustion from the home, the potential for use as a grid reliability tool through demand response and load shifting, and potential for a less disruptive full mechanical retrofit.

Knowledge Transfer and Next Steps

The research team developed several work products that support the knowledge transfer objectives of this Agreement: two technology briefs, one case study, and one webinar. The technology briefs focused on different form factors of combined mechanical systems and the prefabricated mechanical, electrical and plumbing distribution retrofit product, the SoffitDuct, respectively. The case study spotlighted one demonstration project and its equipment that offers promise for California's affordable multifamily retrofit market. The webinar summarizes benefits and challenges of the different types of combined mechanical equipment studied.

The research outcomes and findings from this study will help inform future development of existing and new low-GWP combined systems that leverage heat recovery benefits, are space-flexible, and designed to take advantage of existing mechanical system locations and layouts. The results lay the groundwork for future product development, advocacy to reduce existing barriers, and technology demonstrations. This paper reports on the system design, installation time, performance, and cost implications of low-GWP combined mechanical systems studied.

CHAPTER 1: Introduction

The Low-GWP Mechanical Modules for Rapid Deployment Project (LG-MM) is an outgrowth and extension of an EPIC research project led by Rocky Mountain Institute (RMI) and Association for Energy Affordability (AEA) (EPC-17-040). That project – REALIZE: Mass Deployment Model for ZNE Retrofits (REALIZE-CA) – sought to demonstrate the design and rapid delivery of affordable integrated zero-net energy retrofit packages in disadvantaged communities across California. The REALIZE-CA project, which drew inspiration from the Dutch Energiesprong model, aimed to develop and demonstrate an industrialized approach to deep carbon retrofits in California. The Energiesprong model was centered around the use of two primary technologies that did not exist in the United States market at the onset of this research project award, EPC-19-032: 1) pre-fabricated, unitized, high-performance envelope panels, and 2) compact, packaged, modularized, grid-interactive, multi-function mechanical systems that provide heating, cooling, ventilation, and domestic hot water. EPC-19-032 sought to evaluate and test three different low-GWP combined mechanical systems to address the supply-side market gap, contribute to research needs of this emerging type of mechanical product class, and evaluate applicability and demand for such products in existing multifamily buildings in California. In partnership with EPC-17-040, REALIZE-CA and EPC-19-036 (a research grant focused on prefabricated envelope panels), the three project teams worked together to demonstrate this industrialized retrofit approach on a multifamily building in California.

Twenty-five percent of greenhouse gas (GHG) emissions in California come from buildings.[1] Heating, ventilation and air conditioning (HVAC) and domestic hot water (DHW) account for 56 percent of energy consumption of a home in California's residential buildings.[2] HVAC and DHW systems serving affordable multifamily housing often remain installed up to or past the end of their useful life and exhibit deferred maintenance. Mechanical system retrofits are currently very costly and can be too slow to install, particularly when faced with the scale of demand needed. The invasiveness of business-as-usual mechanical systems and distribution retrofits is a barrier to this scale. And with the push to electrify buildings, useable electrical infrastructure and available capacity become retrofit barriers, too. In pursuit of achieving net zero carbon electricity by 2045[3] and 40 percent GHG emissions reduction below 1990 levels by 2030[4] set forth in Senate Bill (SB) 100 and SB 32, respectively, low-carbon mechanical retrofit solutions are a necessary part of the strategy to deliver on these policies' goals. Updated

[1] California Air Resources Board. 2025a. *Building Decarbonization*. Available at https://ww2.arb.ca.gov/our-work/programs/building-decarbonization#:~:text=Residential%20and%20commercial%20buildings%20are,neutrality%20by%202045%20or%20earlier.

[2] Energy Information Administration. 2009. *2009 Residential Energy Consumption Survey*. Available at https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/ca.pdf.

[3] California State Senate. 2018a. *Senate Bill 100: California Renewables Portfolio Standard Program: emissions of greenhouse gases*. Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100.

[4] California State Senate. 2016. *Senate Bill 32: California Global Warming Solutions Act of 2006: emissions limit.* Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB32.

statewide goals put forth in the California Air Resources Board 2022 Climate Change Scoping Plan call for even more aggressive GHG emissions reductions by 2030 (48 percent) and installation of 6 million heat pumps to achieve climate-friendly and climate-ready homes.[5] Additionally, the California Cooling Act put forth by SB 1013 calls for prohibiting certain specified chlorofluorocarbons and using low-GWP refrigerants in refrigerant technologies.[6] An all-electric, cost-effective, efficient, and rapidly deployable mechanical solution is needed. The LG-MM will support these statewide efforts to allow for California's existing multifamily buildings to be part of the solution.

There are currently a number of fabricators and original equipment manufacturers producing various types of mechanical pod products outside of the United States; however, at the start of this Agreement, none had any plans to export their products to the United States. This resistance was largely due to a perceived lack of demand. Additionally, many of the existing European Modules were designed and optimized for colder climates and building types that are quite different from those in California. None of the existing mechanical pods used low-GWP refrigerants (defined in this Agreement as less than 750). While demand for these products in Europe was significant enough for some of the larger manufacturers to invest in development, it has not been large enough for them to prioritize further product development, modifications, or investment in export efforts. Over the course of the nearly five years this Agreement ensued, coincident research and development occurred for combined heat pump systems and several additional products emerged or were slated for the United States market. Over the same time period, the direction of refrigerant regulation oriented towards low-GWP.

The goals of this project were to demonstrate a market for low-GWP combined mechanical systems for multifamily retrofits, provide recommendations for product development, ensure those recommendations align with California's GHG emissions reduction goals and contribute to their achievement, move selected combined mechanical system products from technology readiness level (TRL) 4 to 7, and achieve or exceed the defined performance metrics. Table 1 summarizes the performance metrics, target performance, and field-measured performance metrics defined for this project.

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[5] California Air Resources Board. 2022. *2022 Scoping Plan for Achieving Carbon Neutrality (2022 Scoping Plan)*. December 2022. Available at https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents.

[6] California State Senate. 2018b. *Senate Bill 1013: Fluorinated refrigerants*. Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB1013#:~:text=(a)%20The%20Legislature%20finds%20and,as%20appropriate%20in%20the%20state.

Table 1: EPC-19-032 Performance Metrics

Performance Metric[7]	Baseline Performance[8]	Target Performance	Field - Measured Performance	Metric Significance
Heating Seasonal Performance Factor (HSPF)	8.2	9.6	Seasonal COP (heating)	high
Seasonal Energy Efficiency Rating (SEER)	14.0	18	Seasonal COP (cooling)	high
Uniform Energy Factor (UEF)	NEEA Tier 3 (2.6 CCF/UEFnc)[9]	3.6 UEF	Water Heating COP	high
First Hour Rating (FHR)	54	55	Field-measured FHR	medium
Cost	$37,000 (installed cost estimate for individual components)	$22,200 (40% cost reduction)	Installed Cost	medium
Technology Readiness Level (TRL)	4	7	Actual Assessed	scope

COP = coefficient of performance
Source Information: AEA, Emanant Systems, Lawrence Berkeley National Laboratory (LBNL), RMI, Smith Group

A commercially-available combined mechanical system—the Clivet ELFOPack—was used as the reference point for current leading mechanical pod technology. The target performance metrics were defined in the Grant Funding Opportunity 19-301 manual and based on market research and initial conversations with relevant HVAC and water heating manufacturers, were deemed achievable by the project team at the outset of the project. The cost reduction metric listed in Table 2 was based on the project team's collective experience delivering conventional decarbonization retrofits with competing technologies. This experience was used in combination with manufacturer input to determine a rough price point at which the market would be inclined to adopt such a technology.

[7] While all of the tests indicated above can be performed in LBNL's HVAC chambers, the Project Team may decide to limit the number or type of tests to only those deemed most informative and critical to the project's success. For example, following the federal test procedures for validating SEER and HSPF values may require two to three weeks of testing. While those tests are critical for product certification and commercialization, they may not be necessary at this early stage of product development, and shorter-term testing will still yield valuable insights into system performance efficiency.

[8] The Clivet ELFOPack can be considered a baseline technology, but because it is not currently in the U.S. market and its European-tested performance values are different from the U.S. test methods for HSPF, SEER, UEF, and FHR, then Title 20 and code minimum baseline assumptions are used for this table.

[9] UEFnc is the Northern California Uniform Energy Factor, which now is referred to as the cool climate efficiency as defined by the Northwest Energy Efficiency Alliance (NEEA) published Specification for Residential Water Heaters Advanced Water Heating Specification (formerly known as the Northern Climate Specification).

For the purposes of this project, the primary target market is existing affordable multifamily retrofit applications, because the need for innovation around HVAC and DHW retrofits is so great. However, one of the key findings of the project was that many of these products are better suited for new construction applications, where there is no need to integrate with existing distribution systems. As such, there are a wide variety of stakeholders for which the results of this research may be relevant and useful. The building design community, particularly architects and mechanical, electrical, and plumbing (MEP) engineers designing spaces and specifying equipment, builders, installation contractors, developers and owners, and energy consultants will all be able to use this research to better understand use cases, applications, challenges, and benefits of low-GWP combined mechanical systems. Policy makers can also use the results of this research to help shape the prospects of electricity and emissions reductions.

The ultimate beneficiaries of this research, though, are the utility ratepayers themselves. Ratepayer benefits include the potential for both upfront and operational cost-savings, non-energy benefits such as safety and resiliency from access to cooling, better indoor air quality, and increased safety associated with removing combustion from the home, the potential for use as a grid reliability tool through demand response and load shifting, and potential for a less disruptive full mechanical retrofit. Table 2 summarizes the quantified ratepayer benefits from the demonstrations; however, these benefits go beyond what is measured here. Unfortunately, the monitored data for the Corona Del Rey site does not include the heating season, so the gas savings from electrifying space heating are not included and the reported savings are, therefore, not representative of actual total annual savings.

Table 2: Summary of Measured Ratepayer Benefits

Measurement Sector	Time-frame[10]	Energy Savings (kBtu)	Greenhouse Gas Emissions Reduction - Combustion ($MTCO_2e$)	Greenhouse Gas Emissions Reduction - Refrigerant ($MTCO_2e$)	Air Emission NO_x Reductions (lb/ timeframe)	Adjusted Utility Bill Impact - Savings ($)
Bear Creek Demo, Measured - Apt 1	12 months	52,298	2.81	9.61	2.48	$893.04
Bear Creek Demo, Measured - Apt 2	12 months	27,527	1.39	9.61	1.55	$146.43
Corona Del Rey Demo, Measured - Apt A	8 months	11,704	0.87	3.50	0.59	$356.89
Corona Del Rey Demo, Measured - Apt B	8 months	5,460	0.44	3.50	0.59	$(259.86)

[10] Because only eight months of utility data, on which the energy and cost savings are based, was available for the Corona Del Rey demonstration units (Apt A & B), the timeframe was specified for each demonstration unit evaluated.

Measurement Sector	Time-frame[10]	Energy Savings (kBtu)	Greenhouse Gas Emissions Reduction - Combustion ($MTCO_2e$)	Greenhouse Gas Emissions Reduction - Refrigerant ($MTCO_2e$)	Air Emission NO_x Reductions (lb/ timeframe)	Adjusted Utility Bill Impact - Savings ($)
Measured - Total Demos		96,989	5.5	26.2	5.2	$1,136.50
Total Market[11]	Annualized[12]	41B	2M	10M	2M	$464M

B = billion; kBtu = thousand British thermal units; lb/timeframe = rate at which nitrogen oxides (NOx) are emitted or reduced, measured in pounds (lb) over a specific period of time; M = million; $MTCO_2e$ = metric tons of carbon dioxide equivalent.
Source Information: AEA

The results of this research largely inform what is (and is not) viable and constructable in California's existing multifamily building target market. The results also lay the groundwork for future research, development, and demonstration (RD&D) to continue development of this class of systems, infrastructural components that support the use of these products, and the broader use of low-GWP refrigerants. Further development is needed to achieve suitable commercial-ready products to scale electrification retrofits in the existing multifamily market and further reduce barriers to using those products as a retrofit solution. The following sections describe the approach taken to conduct this research, the objectives and outcomes of the research, and overall summary of findings.

[11] Based on the CEC 2009 California Residential Appliance Saturation Study data, there are more than 1.6 million apartments with natural gas space and water heating. Based on the assumptions listed above, if all of these households installed an LG-MM, it could result in the following statewide ratepayer benefits. The total market assumed 100 percent of apartments because this research evaluated different combined mechanical systems of various form factors, which is necessary to address the multitude of building typologies and mechanical system install locations that make up the addressable market.

[12] The Corona Del Rey measured savings were scaled up by 25 percent to arrive at an annualized total market savings value. This is a conservative estimate given that energy and GHG emissions savings from electrifying existing gas space heating is not included. The four demonstration units (using the scaled Corona Del Rey values) were averaged and applied to the total market number of apartment units.

CHAPTER 2: Project Approach

The research team approached the study and evaluation of low-GWP combined mechanical systems for California's multifamily retrofits by first identifying the target building typology within the broader multifamily market. The team referenced the building typology study conducted through EPC-17-040, REALIZE-CA. The most common multifamily building typology is low-rise—which occupies 82 percent of the existing multifamily building market in California[13]—and was selected as a target archetype for mechanical solution development. This target selection helped guide the system design process and demonstration site procurement.

The project direction evolved over time with three different approaches. The initial approach was to design, fabricate, and to lab-test and field-demonstrate a newly developed low-GWP combined mechanical system. Early on, the research team identified an existing European product that already had a number of the desired features and characteristics the team identified during the extensive conceptual design process. As such, the approach shifted to work with this European manufacturer, Systemair, to modify their existing all-in-one mechanical system, called the Genius, to be low-GWP and meet the needs of the team's target building market.

For the first 2.5 years of the project, the team collaborated closely with Systemair to modify the existing R410A version of the Genius to run on R32, make electrical modifications necessary for it to comply with UL Solutions requirements, and identify other modifications that would help the product better address the needs of the multifamily housing market in California and the broader United States. To inform these design modifications, the team tested the R410A Genius at Lawrence Berkeley National Laboratory (LBNL). The lab testing revealed significant operational and performance issues with the Genius. Concurrently, there were also significant supply chain and production partner challenges abroad. And finally, the extensive demonstration planning and design process revealed functional challenges associated with this system type's form factor that would present major obstacles in retrofit applications. This led the team to once again pivot, this time to a broader study of low-GWP combined mechanical systems with varying degrees of integration, and away from a focus on a single manufacturer and product.

The final project approach sought to evaluate and demonstrate a number of newly emerging low-GWP multifunction products. Based on market research, equipment lab testing, and installation planning, the team determined that both the type and arrangement of mechanical functions combined into a single machine impact in which the system's could fit into existing mechanical spaces, its functionality, energy performance, and total cost. Therefore, form

[13] Reyna, J., E. Wilson, A. Parker, A. Satre-Meloy, A. Egerter, C. Bianchi, M. Praprost, A. Speake, L. Liu, R. Horsey, M. Dahlhausen, C. CaraDonna, and S. Rothgeb. 2022. *U.S. Building Stock Characterization Study: A National Typology for Decarbonizing U.S. Buildings*. Golden, CO: National Renewable Energy Laboratory. Report Number: NREL/TP-5500-83063. Available at https://www.nrel.gov/docs/fy22osti/83063.pdf.

factor became a focal point while assessing these systems for multifamily retrofit application viability.

Demonstration Products

General System Types

The research team evaluated three types of packaged mechanical systems:

1. System Type #1: a fully packaged low-GWP combined mechanical system that serves all four major mechanical end uses—space heating and cooling, domestic hot water, and ventilation with heat recovery—with all components housed in one box.
2. System Type #2: a partially-packaged low-GWP combined mechanical system that serves three major mechanical end uses—space heating and cooling, and domestic hot water—with mechanical components physically separate but connected by refrigerant lines for coordinated operation and heat recovery opportunities.
3. System Type #3: a more dispersed low-GWP combined mechanical approach with zonal equipment that serves three mechanical end uses—space heating and cooling, and ventilation with heat recovery—with opportunity for coordinated controls, and a separate low-GWP domestic hot water system that serves multiple apartments.

The team selected three specific products that were representative of each system type. These systems were evaluated in either the lab or a field setting to learn about the specific products and about the product class more generally.

Specific Demonstration Products

System Type #1: Systemair Genius

The R32 Systemair Genius represented System Type #1 and is a combined mechanical system that provides space heating, space cooling, domestic hot water, and heat recovery ventilation. The system is contained within one large refrigerator-sized box, runs on R32 refrigerant, and is composed of three modular parts: the base module contains the 40-gallon hot water storage tank and water pump, and the electrical components and control board; the middle module contains the heat pump with the compressor and refrigerant circuit; and the top module contains the heat recovery ventilator, which is an enthalpy flywheel.

Supportive Distribution: Thermaduct SoffitDuct

One of the most potentially impactful innovations that emerged from the System Type #1 research effort was the Thermaduct KoolDuct Soffit product, called the SoffitDuct. The SoffitDuct is a lightweight, prefabricated, pre-insulated, multi-channel, phenolic soffit duct solution housing the supply and exhaust airstreams, as well as an additional compartment for all the necessary electrical and plumbing distribution. It offers an innovative solution to one of the biggest challenges associated with integrating combined mechanical systems into existing buildings, and with HVAC and water heating system retrofits in general: the invasiveness and labor-intensity of MEP distribution retrofits. The SoffitDuct has the potential to improve distribution system performance, speed of installation, and labor intensity, while minimizing the invasiveness of the retrofit.

System Type #2: Villara AquaThermAire

The Villara AquaThermAire (AQTA) represented System Type #2. It is a 3-in-1 multifunction heat pump that provides space heating, space cooling, and domestic hot water in a semi-packaged form factor that uses R454b refrigerant. The system is comprised of an off-the-shelf air handler and standard efficiency outdoor condenser/compressor unit, with a proprietary refrigerant management system that enables the single heat pump to serve both the air handler and the domestic hot water tank. The unique hot water tank was designed and manufactured by Villara and integrates a wrap-around refrigerant coil that heats the water in the tank, which then transfers that heat to potable DHW water lines that are suspended in the tank. The tank is not pressurized and has no backup electric resistance heating element or electrical connection and was specifically designed with retrofit applications in mind. The system can also perform thermal heat recovery when operating in simultaneous space cooling and domestic water heating mode. The AQTA also has a unique approach to managing the heat pump's defrost cycle, whereby it uses the heat stored in the hot tank as opposed to the standard method of using the heat from the conditioned air. This facilitates much shorter defrost cycles that are typically only two to three minutes. And most importantly, it prevents the most common complaint associated with defrost: blowing cold air into a heated space.

System Type #3: Ephoca All-In-One Wall Mount + ERV with Integrated Controls and SanCO2 CHPWH

System Type #3 was represented by the R32 Ephoca All-In-One Wall Mount (AIO WM) + energy recovery ventilator (ERV) unit, integrated HVAC controls, and a SanCO2 central heat pump water heating system (CHPWH). The Ephoca AIO WM+ERV unit is a modular 3-in-1 multifunction packaged terminal heat pump that is installed as a zoned HVAC system that delivers space heating, space cooling, and energy recovery ventilation. The equipment comes in 120 volts or 240 volts, and can be hardwired or plug-in (both voltage options). The ERV is a modular component that can be installed with the AIO WM unit initially or be added after the fact as a standalone ventilation retrofit. The SanCO2 CHPWH system is a central DHW solution that provides hot water to multiple apartments using an inverter-driven heat pump, paired with one or more 119-gallon hot water storage tanks and runs on R744 refrigerant. The HVAC and DHW components of this packaged approach are not fully integrated, as the HVAC is unitary and the DHW is centralized. However, the HVAC units include advanced controls that enable the individual zonal AIO WM units to operate in a coordinated and centralized fashion, and further coordinate their operation with ceiling fans in each room.

Demonstration Sites and Data Collection

The research team tested the low-GWP combined mechanical systems in two multifamily buildings in two different climate zones in California and collected data through system monitoring at each property for at least nine months. In addition to data collection through the design, planning, and project costing stages, the team collected empirical data through measurement and verification (M&V) in both the lab and field settings. Table 3 summarizes the lab testing and field demonstration components of this project.

Table 3: Summary of Technology Demonstrations

Evaluation Location Name	Location	Climate Zone	Type of Evaluation	Number of Evaluations	Product Evaluated
LBNL Lab	Berkeley, California	3	Lab Testing	2	R410A Systemair Genius R32 Systemair Genius
Bear Creek Apartments	Planada, California	12	Field Demonstration	2	R454b Villara AQTA Integrated Ventilation Controls AQTA Load Shifting[14]
Corona Del Rey Apartments	Corona, California	10	Field Demonstration	2	R32 Ephoca AIO WM+ ERV Integrated Controls Thermaduct SoffitDuct R744 SanCO2 CHPWH

Source Information: AEA

With the evolution of the project approach, changes in product demonstrations followed. The R32 Systemair Genius was the initial basis of design for all field demonstrations. The Systemair Genius was tested in a laboratory testing chamber at LBNL and because of major issues identified during testing, the team determined that it was too risky to install the system in an occupied home. Instead, the more functional R410A Genius was installed in the home of a project volunteer as an informal demonstration outside the scope of the project, which provided the team with some additional practical installation learnings. Reference the Functional Testing Reports – Part I and II (in Project Deliverables) of this study for more detailed information. The lab testing and preliminary demonstration design process resulted in a comprehensive set of modification recommendations to Systemair.

Despite the decision not to move forward with the installation of the R32 Genius unit at Corona Del Rey Apartments, the research team decided to design and demonstrate the SoffitDuct that was intended to be connected to it. Though not connected to anything, the SoffitDuct field installation demonstration allowed the research team to collect data on design challenges, pricing, and installation time before and during the installation that ultimately helped inform product development with Thermaduct, the manufacturer.

[14] UC Davis Western Cooling Efficiency Center (WCEC) conducted load shift testing with the AQTA through EPC-20-025. The research team collaborated with WCEC on this field demonstration and benefited from additional data monitoring and learnings from their load shifting research.

The Ephoca AIO WM+ERV, integrated controls, and SanCO2 CHPWH package were installed in two other apartments at Corona Del Rey. The team collected data and learnings through the extensive design and planning phase of the project in coordination with the EPC-17-040 REALIZE-CA and EPC-19-036 teams sharing the same demonstration buildings. Data collection continued through installation and post-retrofit M&V and included pricing, change order details, and installation time. One Ephoca AIO WM+ERV unit received an extensive performance monitoring package to measure functionality and performance of the individual components and the system as a whole. Detailed airflow and ventilation effectiveness testing was performed on one of the Ephoca AIO WM+ERV units in the field. The results of that field testing led the manufacturer to develop an updated version of the ERV, which was ultimately tested in both the manufacturer's enthalpy chamber (and the results were shared with the team) and one room of the demonstration site.

The Villara AQTA was installed in two apartments at Bear Creek Apartments. The design and planning phases were relatively short due to the project timeline but included a series of in-depth ventilation solution charettes. The research team collected data on installation time and pricing during the retrofit and implemented extensive post-retrofit M&V. Both AQTA systems received in-depth performance monitoring setups as a result of collaboration with the University of California Davis (UC Davis) Western Cooling Efficiency Center (WCEC) EPC-20-025 project team, who shared the demonstration site to study load flexibility opportunities and test their load shifting algorithm during their EPIC award (EPC-20-025). This collaboration allowed for expanding system monitoring from one system to two and provided additional learning from their load shifting experiment results. The R410A version of the AQTA was tested in the UC Davis WCEC laboratory through another EPIC-funded study.

Data and general information were collected throughout all stages of the project, including initial product design, product manufacturing, subsequent modifications, retrofit design, installation, and post-retrofit operations. Some of the data collected included time and costs associated with fabrication, delivery, and installation, as well as in-depth functional and energy performance metrics. Reference the *Monitoring Plan* and the *Evaluation, Measurement, and Verification Reports* (in Project Deliverables) for a full list of data collected and how that data was used to evaluate performance, respectively. The research team used all data collected to address the research objectives, which were initially outlined as follows:

- Demonstrate to manufacturers that there is a market for mechanical modules using a refrigerant less than 750 GWP for multifamily retrofits.
- Provide recommendations to optimize existing products, or products in development, for California
- Guide product development to align with California's GHG reduction goals (for example, use of low GWP refrigerant)
- Move selected combined mechanical system products from TRL 4 to 7
- Achieve or exceed the defined set of performance metrics (see Table 1: EPC-19-032 Performance Metrics in Chapter 1).

Some objectives were added and/or changed. The primary focus of this research became: 1) assessing the ease and relative feasibility of designing and installing the various system types, and 2) evaluating the pros and cons of various form factors and varying degrees of integration.

The Project Team and Partners

The research team was led by AEA and included Emanant Systems, LBNL, RMI, and Smith Group. All five organizations have many years of EPIC-funded research and demonstration experience, as well as extensive knowledge and experience with heat pump-based mechanical systems. Emanant Systems and Smith Group both brought deep experience with system design and co-led the design process. LBNL provided lab facilities and industry-leading expertise in system performance and functionality testing. AEA brought extensive retrofit project implementation experience, specifically heat pump-based mechanical retrofits, as well as building owner contacts and demonstration site recruitment expertise. AEA, LBNL, and Emanant Systems all brought extensive M&V and data collection experience to the field monitoring activities undertaken at each of the demonstration sites. RMI brought extensive market research work, technical expertise, and connections with parallel research initiatives that were helpful in supporting market assessment and development.

The Team recruited a technical advisory committee (TAC) made up of industry experts, manufacturers, building developers, and thought leaders. The TAC was initially consulted during the planning stages through technical advisory meetings held in 2021 and 2022, with subsequent one-on-one follow ups with individual TAC members with specific needs-based expertise.

The research team collaborated with at least one other EPIC-funded team on both demonstration sites. The Team worked closely with UC Davis WCEC on the Bear Creek demonstration site where they were conducting a parallel research effort as part of a CalFlexHub grant, EPC-20-025. The Team also partnered with two other research teams (of which AEA and RMI were a part) led by RMI at Corona Del Rey where both EPC-17-040 and EPC-19-036 were conducted. Additional team members from those grants that were heavily involved in coordination of LG-MM project demonstration activities were David Baker Architects, RDH Building Science, and Introba, Inc.

Each of the manufacturers of the demonstration equipment—Systemair, Villara, Ephoca, and Thermaduct—were integral partners that were highly engaged throughout the project. The Team maintained close coordination with Systemair representatives from both Canada and Germany through monthly planning meetings. Similarly, the Team worked closely with Thermaduct to inform and assist with the design, iteration, fabrication and installation of the KoolDuct SoffitDuct product. The Team also closely engaged with Villara, helping inform the system modifications necessary to run on low-GWP refrigerant, and worked side-by-side with them during the installation and post-installation monitoring phases and throughout the equipment troubleshooting process (reference the Demonstration Execution and Preliminary Monitoring Report and the Evaluation, Measurement, and Verification Report (in Project Deliverables) for more information on equipment issues and troubleshooting). The Team worked closely with Ephoca USA and their engineering team in Italy, through fabrication, installation, and testing of the ERV modules.

Lastly and perhaps most importantly, the property owners, property management, maintenance staff and participating tenants were all critical partners in the demonstration and data collection phase of the project. At both demonstration sites, property management and maintenance facilitated the installations and the many equipment troubleshooting visits needed throughout the project. The participating tenants were exceptionally willing, gracious, patient, and informative project partners, confirming learnings from the field, sharing their personal insights and experience interacting with the equipment, and helping to identifying equipment issues for the team to address.

Each of the project partners contributed at various stages of the project, which can be broken down into six distinct phases:

1. Design
2. Equipment Lab Testing
3. Field Demonstration Project Planning (Design & Iteration)
4. Field Demonstration Installation (Planning & Implementation)
5. Field Data Collection (Equipment Troubleshooting & Data Analysis)
6. Reporting

Each of the deliverables and project milestones were completed within the project term; the list of work products is included in the List of Project Deliverables section. The six phases were comprised of multiple milestones, which included: core team design brainstorming exercises focused on technology development needs, manufacturer partner engagement, equipment modification design work, lab testing (two iterations), project pivot from demonstrating one technology to re-focusing on form factors of different combined technologies, demonstration scoping and iterative design, demonstration installation, field testing and feedback to manufacturers, data collection, technology transfer activities, data analysis and synthesis of results. The manufacturing partner engagement and project pivot to focus on form factors were two notable milestones that changed the course of the project in ways that broadened and strengthened the usefulness of the research results. All activities led to the findings and results reported in Chapter 3.

CHAPTER 3: Results

Summary of Technologies and Research Outcomes

As discussed, the LG-MM project aimed to evaluate low-GWP combined mechanical systems of different form factors and configurations. The research objectives stated in the Agreement's Scope of Work were applied to the evaluation of the three different system types previously described. The team distilled the following high-level findings and research outcomes from 4.5 years of RD&D.

The high-level findings from the Project are:

1. Form factor and system component layout are two of the strongest determinants of whether a combined mechanical system will work in a multifamily retrofit application, and combined mechanical systems come in a variety of form factors.
2. Benefits associated with the heat recovery capabilities that are often a key selling point for some combined mechanical systems can only be realized during periods of coincident space cooling and hot water demand. There is a low occurrence of coincident demand periods in many residential applications. There are potential ways to improve the heat recovery capabilities of these systems, which are described in the Conclusion below.
3. Combined mechanical system products developed with specific retrofit applications in mind are most primed for market development and most likely to be successful retrofit solutions; however, there are very few of them available right now. The Villara AQTA is an example of a product designed for a specific application. It slots in easily in the typology for which it was designed but would not be a good retrofit solution for an apartment with on-demand DHW and room-by-room HVAC, for example.
4. Combined mechanical systems that integrate ventilation are likely to encounter challenges with code compliance due to exhaust re-entrainment. Experiences from this project indicate that current relevant codes are unclear and approaches to code compliance are burdensome. The research team's measurements support exception 4 of American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 62.2, Section 6.8 that it is reasonable not to have 10 feet of separation between intake and extract airways.
5. There is currently no testing standard, system performance standard, or dedicated compliance pathway for combined mechanical systems. Using the existing standards, it was not clear how to test combined mechanical systems in this project. Lack of clear compliance pathways means that some of the performance benefits for combined system are not measured or quantified adequately.

6. System Type #1 (all-in-one-box solution) is not well-suited for existing multifamily retrofits. Mechanical pods that currently exist on the market demand too much contiguous space to accommodate the machine's footprint, its clearances, and distribution connections, and it does not fit in typical mechanical system locations in this residential market.

The following research outcomes support and further specify the findings above:

- System Type #1, like the Systemair Genius, is not well-suited for existing multifamily retrofits, but may work well in single family and new construction multifamily buildings. Some of the challenges with using them in retrofit applications include:
    - They can rarely be installed in existing mechanical rooms/spaces.
    - The form factor and the fact that all distribution connections need to come together at the machine often results in the need for equipment to be located outside.
        - Most existing products in this classification are designed for indoor installations only; systems would need to be redesigned with outdoor rated enclosures, or additional mechanical spaces would need to be built to house the machine.
        - Numerous distribution system connection points, each having clearance requirements that must be met, means the space required to house the machine is significantly larger than its compact footprint would initially imply.
        - Transitions at the internal/external interface for all distribution components must be detailed and careful attention to waterproofing details must be considered.
        - Reusing existing distribution infrastructure is rarely possible.
    - Specific to the Systemair Genius
        - Product development is needed to re-organize where distribution connections are made. Meeting the code-requirement of 10 feet of clearance between intake and exhaust air poses a design challenge.
        - Product development is needed to right-size system components. There is a trade-off between a system's physical size, and its capacity and efficiency. Therefore, the focus on fitting all mechanical components into a single box came at the expense of several key performance criteria. The Systemair Genius does not meet federal minimum efficiency standards and can therefore not be installed in California as it exists today.
- System Type #2, like the Villara AQTA, has the most potential for widespread adoption in multifamily retrofit applications for the following reasons:
    - Ease of Installation: Requires the least amount of re-work and has the highest potential for installation cost and time reductions.

    - Ease of Operation: From the end user standpoint, these systems most closely resemble conventional systems and are, therefore, less susceptible to user error.
    - Highest Efficiency Potential: Improved energy recovery benefits through the incorporation of variable speed compressors and air handlers, and relatively simple control improvements have the potential to increase operating efficiency significantly.
- System Type #3, like the Ephoca AIO WM+ERV and central SanCO2 system, have some advantages from a form factor perspective, but also have a number of challenges associated with the efficiency, electrical capacity and distribution, and user experience.
    - Advantage of room-by-room design is modularity and zonal control, which can have efficiency benefits, provided users only turn units on when they are in the space that unit serves.
    - Disadvantages of room-by-room design include:
        - More usable space required than other system types.
        - More electrical capacity required, which is one of the biggest barriers to electrification.[15]
        - Requires a dedicated outlet, and in some cases, depending on the building department, a dedicated circuit. In either case, electrical infrastructure changes are required, which can be time- and cost-prohibitive.
        - There is often an inability to control the systems from one central location, and even where a solution exists (specifically, with Ephoca's web-based application), it is often not well-suited for multifamily rental applications.
    - Specific to the Ephoca AIO WM+ERV
        - Each unit requires two envelope penetrations, and because it is a room-by-room system, many envelope penetrations are needed. Each penetration must be detailed and demands careful attention to air sealing and waterproofing to avoid energy waste and potential damage to the structure.
        - Location of the intake and exhaust terminations does not meet current ASHRAE 62.2-2010 Section 6.8 code, which requires 10 feet of separation between the two terminations, and exception must be pursued.[16]
        - Compact design is at odds with efficiency.
        - Results of two rounds of field airflow testing on the Ephoca ERV module led the manufacturer to develop an updated version of the product.

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[15] Plug-in application potentially relives the electrical capacity burden, but there is dependency on whether electrical infrastructure already exists in the right location and on whether the local building department will accept this application for a permanent HVAC system.

[16] ASHRAE 62.2-2010 Section 6.8.

- Further research and assessment of more system types and products within each type is needed; however, based on the products assessed in this study, the system configurations that hold the greatest promise for multifamily retrofit applications are:
    - Partially packaged combined systems that leverage heat recovery benefits and can fit into existing system locations, like System Type #2.
        - There is a need for market development of combined systems that fit the form factor of conventional systems: looks at space available, existing infrastructure, and routing pathways to inform a system that combines end uses to leverage the benefits of doing so.
        - There is a need for technical and market development for design and control strategies that optimize for coincident demand resulting in heat recovery benefits.

The significance of these research outcomes is measured in the size of the potential market to which low-GWP combined mechanical systems are applicable, and the benefits they can bring to those markets. This summary is useful in identifying where further combined mechanical system research and development investment is needed. It is also useful in defining what and where these systems are applicable and where they fall short, measured through real-world demonstrations in occupied multifamily apartments. The results are significant because they support decarbonization retrofit solution pathways and shed light on the pain points and challenges that must be addressed.

Project Outcomes

The extensive data collected through this project led to, and support, the high-level findings and research outcomes outlined. The *Evaluation, Measurement and Verification Reports, Part I and Part II* (in Project Deliverables) cover the additional data analysis and quantitative findings in more detail. Through this research, the team sought to evaluate the suitability of the three systems based on their installation cost, ease and speed of installation, operational efficiency, and change in TRL. These metrics were compared across demonstration system type and with conventional systems, which consisted of a high-performance HVAC heat pump, new ductwork, a heat pump water heater, and exhaust-only ventilation upgrades.[17] Assessment of these metrics help indicate whether the goals of the Agreement were met and also the potential for these products as viable decarbonization retrofit solutions.

The team compared the installation time of the products demonstrated in the field to each other, and to a conventional retrofit, shown in Table 4. This comparison evaluates the ease and speed of installation in an effort to understand whether these products offered scalable mechanical retrofit solutions.

[17] This package of conventional mechanical retrofits was studied through one of the EPC-17-040 REALIZE-CA demonstration projects. Data comes from a real retrofit project conducted by some of the same team members.

Table 4: Installation Time (in Hours) Per Product Demonstrated as Compared to Conventional Equipment

Person-Hours per Install per Apartment	Apt 1	Apt 2
Goal	n/a	
Conventional	59	
Split Ducted HVAC Heat Pump	27	
HVAC Ductwork (attic)	8	
Unitary Tank-Type HPWH	8	
Exhaust-Only Ventilation	16	
Bear Creek: Villara AquaThermAire	44	86
Villara AquaThermAire	44	66
AQTA Ventilation	n/a	20
Corona Del Rey: Ephoca AIO WM+ERV & SanCO2 CHPWH	65	61
Ephoca AIO WM + ERV	23	21
Integrated Controls + Thermal Comfort	10	8
Exhaust Fans	8	8
SanCO2 CHPWH	24[18]	
Corona Del Rey: Thermaduct SoffitDuct	40	

HPWH = heat pump water heater
Source Information: AEA

A major caveat in quantifying installation time for a demonstration of emerging technology is the unknown amount of time associated with workforce learning. The first install of a new product will take longer to install than when done at scale. For example, the contractor for Bear Creek installed the two AQTA's with the same team a month apart. The Apt 2 AQTA was installed first and was the first installation for this crew. The same crew installed the Apt 1 AQTA one month later with a very similar setup. The second AQTA installation took nearly 50 percent less time and demonstrates the potential for efficiency gains that come with experience. Despite the learning curve caveat present, the installation time of both combined mechanical retrofits took similar or less time than the conventional retrofit.

The team also compared the installation cost of the products demonstrated in the field to each other, and to a conventional retrofit, shown in Table 5. This comparison evaluates current market viability from a financial lens, quantified originally as a goal of 40 percent reduction in total installed cost. If the cost of combined mechanical system retrofits is similar to, or less expensive than, conventional mechanical retrofits, their viability and scalability will have greater promise. Even if the upfront cost were greater compared with conventional costs, other benefits may be worth the higher value.

[18] SanCO2 CHPWH hours are estimated based on the Team's experience with these types of retrofits. Measured data was not available for this particular install. Also, this is a central system, and therefore, serves multiple apartments.

Table 5: Installation Cost Per Demonstration Product Priced as Compared to Conventional Equipment

Total Installed Cost Per Apartment	Material	Labor	Installed
Goal		$ 22,200	
Conventional - Measured[19]	$14,325	$7,071	$21,396
Split Ducted HVAC Heat Pump	$8,815	$2,691	$11,506
HVAC Ductwork (attic)	$1,129	$300	$1,429
Unitary Tank-Type HPWH	$3,355	$3,400	$6,755
Exhaust-Only Ventilation	$1,026	$680	$1,706
Corona Del Rey: Systemair Genius	$32,807	$33,534	$66,342
R32 Systemair Genius	$15,184	$11,738	$26,922
Pod Shed Enclosure	$10,667	$11,341	$22,009
Thermaduct SoffitDuct	$3,758	$5,970	$9,728
Electrical *(plumbing not included)*	$1,189	$2,042	$3,231
Heat Recovery Ventilator Damper - Bathroom	$1,497	$2,068	$3,565
Thermostat	$512	$375	$887
Bear Creek: Villara AquaThermAire	$19,868	$10,239	$30,107
Villara AquaThermAire	$16,406	$4,735	$21,141
AQTA Ventilation + Thermal Comfort	$3,462	$5,504	$8,966
Corona Del Rey: Ephoca AIO WM+ERV & SanCO2 CHPWH	$27,777	$23,836	$51,613
Ephoca AIO WM + ERV	$17,575	$5,072	$22,647
Ephoca AIO WM Ancillaries[20] *(needed for install)*	$2,376	$7,756	$10,132
Integrated Controls + Thermal Comfort	$3,485	$8,870	$12,355
SanCO2 CHPWH *(per apartment)*	$4,341	$2,138	$6,479

Source Information: AEA

Though the research team decided not to install the Systemair Genius, it got far enough into the design and planning process to price the entire installation. The Systemair Genius was by far the most expensive installation due to the amount of additional infrastructure needed and risk pricing for labor. Considerable cost compression for the system and efficiency gains in labor would be needed to be even remotely competitive. Even still, the extra infrastructure needed would likely still prove too expensive to achieve upfront cost parity. The room-by-room Ephoca AIO WM+ERVs and SanCO2 CHPWH demonstrated in place of the Systemair Genius was still far more expensive than the conventional approach, though they differ in: centralized

[19] The combined cost of conventional equipment installation included in the Agreement's original Scope of Work was $37,000; however, costs of electrification have come down since the start of this Agreement in 2020 as electrification retrofits have increased in the market. To reflect a more modern comparison, Table 5 uses the costs of conventional installations from an actual project rather than the cost estimate from the original performance metrics (see Table 1).

[20] Ephoca AIO WM ancillaries include existing equipment removal, running electrical and condensate, and waterproofing and other envelope integration measures.

versus room-by-room HVAC, ducted versus ductless HVAC, central versus unitary DHW, and of course, energy recovery versus exhaust-only ventilation. Heat/energy recovery ventilation is a major component that was included in both Corona Del Rey packages and missing from the conventional and Bear Creek packages. Additionally, the value of room-by-room HVAC control regarded by residents at Corona Del Rey in the post-retrofit survey is unquantified. Of note is the similarity in cost of the Villara AQTA and conventional mechanical retrofit. Excluding a ventilation and thermal comfort upgrade, the AQTA equipment was $3,107 more expensive than the similarly configured conventional approach; however, the AQTA labor was $1,656 cheaper. Villara priced the AQTA installation and is uniquely positioned as both the manufacturer and installation contractor, and so the pricing is likely more "commercial" than that of the other emerging products. Still, conversations with Villara indicated further room for cost compression on both material and labor when installed at scale. This data indicates that cost compression for both material and labor are needed to achieve cost-parity or -reduction compared to conventional approaches, but this is possible for some products.

Next, the team compared the performance of each system to understand system energy efficiency. The energy efficiency performance goals for this Agreement were focused on lab testing measurements, which were only collected on the R410A and R32 Systemair Genius systems. Table 6 summarizes those metrics, showing that the Systemair Genius did not meet the stated efficiency goals or even the federal minimum efficiency standards—see Table 1 in Chapter 1 for baseline and target efficiencies.

Table 6: Systemair Genius Lab Efficiency Testing Results

Metric	Condition	Systemair Genius - R410a	Systemair Genius - R32	Federal Minimum Efficiency Standard
SEER	no draw	4.00	unable to test	14.0
	continuous 1.0 gpm	7.48	unable to test	
	continuous 1.7 gpm	8.15	unable to test	
EER		2.59	2.98	11.0
HSPF	no draw	3.50	unable to test	8.0
	continuous 1.0 gpm	3.50	unable to test	
	continuous 1.7 gpm	3.50	unable to test	
UEF		0.72	unable to test	0.9134
FHR		37	unable to test	45[21]

EER = energy efficiency ratio; gpm = gallons per minute
Source Information: LBNL

[21] There is no Federal Minimum Efficiency Standard for FHR. An FHR of 45 gallons is the minimum standard for the Energy Star Program, which is an optional Federal program. Though not required for compliance, the team used this as a reference metric when assessing the lab-tested equipment.

The equipment demonstrated in the field did not undergo lab testing, and for this reason, seasonal COP per mode of operation became the efficiency metric for field applications. Table 7 summarizes the performance of the demonstration equipment when operating in occupied apartments.

Table 7: Seasonal Coefficient of Performance Measured in Field Demonstrations

Seasonal COP per Mode of Operation	Apt 1	Apt 2
Villara AquaThermAire		
Space Heating	2.68	2.55
Space Cooling	2.63	2.33
Water Heating	2.11	2.01
Simultaneous Cooling+DHW	1.52	1.22
Ephoca AIO WM + ERV		
Space Heating	None Measured[22]	
Space Cooling	2.30	
SanCO2 CHPWH	3-4[23]	

Source Information: AEA, LBNL, UC Davis WCEC

Overall, the equipment COPs measured in the field were lower than the team expected and lower than the equipment's respective ratings, where rated COP was provided. This is often the case when measuring efficiency in the field versus a laboratory setting. Calculating COP per mode of operation in combined mechanical systems was also challenging as each mode had to be disaggregated despite using a common source of thermal energy. This was particularly challenging for the Villara AQTA's water heating functionality since hot water demand and hot water production are often not coincident. As a result, the COP values for AQTA water heating are conservative. Similarly, the COP of simultaneous mode reports the efficiency of space cooling during simultaneous operation with hot water production and denotes hot water production during this time as completely free. Therefore, it does not properly demonstrate the higher efficiency of that mode.

Lastly, the Agreement focused on assessment of the market for low-GWP combined mechanical systems, and so evaluated both the market and commercial readiness of the equipment itself. The metric of evaluation is TRL, which United States Department of Energy (U.S. DOE) adapted from NASA to define nine stages of technological development for

[22] No space heating events were captured from the monitored Ephoca AIO WM-ERV unit during the monitoring period mid-April through early-January. The resident did not use this particular room's equipment in space heating during the monitoring period, which is out of the research team's control.

[23] Data quality from this demonstration was not good enough to solve for system COP. COP of 3 to 4 is what the research team has seen on other SanCO2 CHPWH monitoring projects.

commercial availability.[24] Table 8 below shows the Agreement's TRL goal and the research team's TRL assessment for each major product tested and/or demonstrated.

Table 8: Assessed Technology Readiness Level of the Demonstration Equipment at the Start (2020) and End (2025) of the Agreement

Technology Readiness Level	TRL - Start	TRL - End
Goal	4	7
R32 Systemair Genius	4	5
Thermaduct SoffitDuct	2	6
Villara AqthaThermAire	5	8
AQTA Ventilation + Controls + Thermal Comfort	2	6
Ephoca AIO WM+ERV[25]	3	8
Integrated Controls + Thermal Comfort	2	6
SanCO2 CHPWH	9	9

Source Information: AEA

The research team took an evolved approach that yielded multiple products for TRL assessment rather than just one. The products were at different levels of commercial viability at the outset of this project, ranging from conceptual design to already commercially available. This project helped demonstrate interest and present the case for market potential. By the end of the project, several new low-GWP combined mechanical products and ancillary components were either developed or significantly improved.

The team leveraged findings from research to inform coordination, engagement, and recommendations to manufacturing partners and provided recommendations to Systemair about the technical needs of the Genius equipment for the United States and California markets. The lab testing and preliminary demonstration design process resulted in a comprehensive set of recommendations to Systemair for modifications that included controls and integration opportunities, heat pump sizing and capacity-related changes, and design concepts for replacing the hot water storage tank with a phase change material battery to increase usable space in the enclosure for a larger compressor and air coil. The team provided feedback to Villara about the need for using low-GWP refrigerant, integrated ventilation solutions, and needs for controls updates. They also provided feedback to Ephoca about the ERV module and design guidance from in-field airflow testing, which ultimately supported redesign efforts. More detail can be found in Appendix C: Summary of Project Impact on Product Development.

[24] United States Department of Energy. 2015. *Technology Readiness Assessment Guide*. Report Number: DOE G 413.3-4A. Approved September 15, 2011, Change 1 (Admin Change) October 22, 2015. pp 9-10. Available at https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04a-admchg1/@@images/file.

[25] The Ephoca AIO WM+ERV was assessed as a whole system, rather than the componentry. This results in the TRL focusing on the new component, which is the ERV module. The Ephoca AIO WM on its own has a TRL of 9 at the start and end of the Agreement.

Though the team believes that further product development and/or evaluation is needed from the manufacturers to achieve commercial-readiness and scalability, each product boasts potential for its applicable market. Continued collaboration on development could support this outcome. In addition to continuing the work summarized above, this development could include manufacturer consideration of building typology in their product design. EPC-17-040 REALIZE-CA's Building Typology study lays out the prevalence and characteristics of California's existing multifamily buildings, which can be used as a reference or for design guidance in developing products well-suited for retrofits in this target market.

Technical, Market and Policy Barriers

The research team identified a number of technical, market and policy challenges that present barriers to widespread adoption of low-GWP combined mechanical systems. The following sub-sections detail each of the main barriers the team encountered, which should be used as a guide for what must be addressed for these products to be viable and scalable in California's affordable multifamily retrofit market.

Technical Barriers and Challenges

Technical and Market Barrier: Space Constraints in Affordable Multifamily Housing

Available space for mechanical equipment is often very limited in multifamily affordable housing, which presents a major technical challenge and market barrier for System Type #1, which has a larger contiguous footprint, especially when equipment clearances are considered. Interior or exterior mechanical closets are somewhat common (present at both the Corona del Rey and Bear Creek demonstration sites) but are often sized for smaller conventional equipment. In rare cases, units are located over garage or storage space, which is likely the best-case scenario. Form factors that differ significantly from conventional mechanical equipment are not able to make use of existing mechanical spaces and therefore require sacrificing other valuable space for the new equipment at the expense of the resident. The lack of an outdoor rated enclosure significantly limits siting options for this equipment.

At the Corona Del Rey site, the Systemair Genius could not be installed outside or in the existing mechanical equipment space; the 3′ x 3′ x 7′ unit is larger than what fits inside most mechanical closets. As a result, a large 10′ X 3′ mechanical shed had to be custom built in the outdoor patio space between two apartments, costing the project an additional $22,008 and depriving those two households of a significant portion of their outdoor leisure space. At the same time, the closet that housed the old furnace was sealed off and became an empty cavity in the wall. Theoretically, this could have been repurposed as storage for the resident; however, the project budget could not support that benefit.

Similarly, the packaged Ephoca AIO WM+ERV unit demands specific installation location parameters such as being installed on an exterior wall, located within 3′ of an outlet (for plug-in models), and within arm's reach in order to use its onboard controls. The location requirements for this equipment often necessitate taking away otherwise usable space from the resident. One of the most common pieces of feedback from the resident surveys at Corona Del Rey was that the Ephoca AIO WM+ERV units were too large and made locating furniture a challenge.

Adding the ERV module to the Ephoca AIO WM units also doubles the depth (from 6” to 12”), which ends up protruding significantly into the space and inviting the possibility that residents use it as a shelf, potentially covering up the return air grille as shown in Figure 1.

Figure 1: The Packaged Ephoca AIO WM+ERV Takes up Valuable, Usable Space in Affordable Multifamily Application

Credit: Emanant Systems

Contrary to the space constraints and lost space value at Corona Del Rey, the Villara AQTA system was very easy to install at the Bear Creek project. The AQTA was installed in the exact same location as the mechanical equipment it replaced and the ductwork, electrical circuits, and plumbing were all reused. The return air duct was upsized to 16” to accommodate the different airflow requirements and there were some initial space constraint challenges associated with tying the existing plumbing in with the new, taller domestic hot water tank. However, those challenges were minor and overall, the design and installation were easy, and space was 100 percent effectively reused without any forfeit from the tenant. The flexible design of the AQTA can allow for locating components in places like a mechanical closet or an attic or crawlspace, and its form mimics conventional equipment to take advantage of spaces designed around conventional equipment.

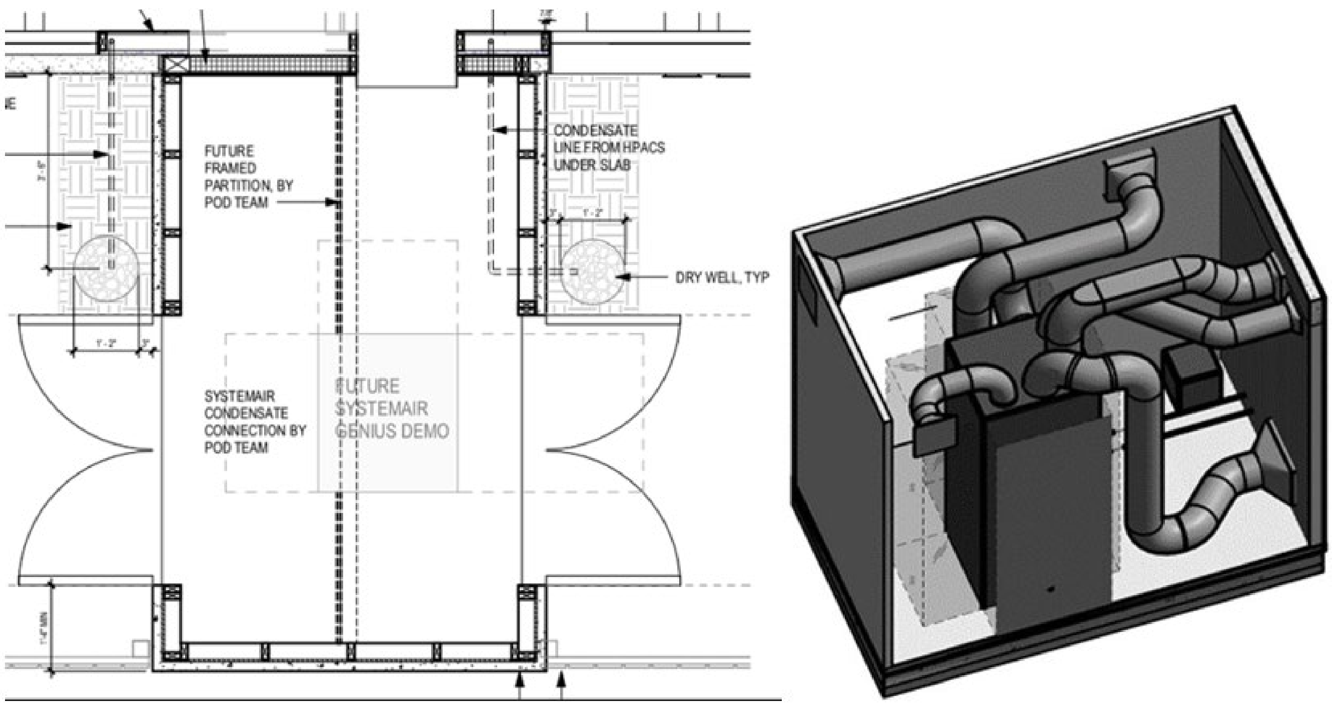
Technical Design Challenges from All-in-One-Box MEP Distribution

System Type #1 poses a major technical design challenge for routing HVAC distribution, and depending on the layout of the equipment, electrical and plumbing connections as well. The all-in-one-box solution necessitates all MEP distribution elements terminate at a single location, which creates space and routing related design challenges. Depending on the layout of the duct connections on the equipment itself, it can be very difficult to efficiently route ductwork.

Complying with code that requires 10ft of clearance between fresh air inlet and exhaust outlet exacerbates these challenges.[26]

At the Corona Del Rey project, this was addressed during system design. Orienting the equipment such that plumbing and electrical runs were direct, HVAC ductwork was optimized, and equipment clearances were maintained, were all at odds with one another. The design optimization exercise resulted in a "ductwork medusa" as shown in Figure 2 below. More space was demanded to accommodate this web of ductwork and ensure it met the re-entrainment standards defined by code.

Figure 2: Mechanical Pod Shed Design Showing Larger Space Needed for Clearances and Connections (left) and "Ductwork Medusa" Created by MEP Connections Being Made at One Piece of Equipment (right)



Credit: Introba, Smith Group

Invasiveness of Retrofitting MEP Distribution

In addition to the space and routing challenges with connecting MEP distribution to System Type #1, technical challenges arise from re-routing MEP distribution to one single location that is different from where mechanical equipment existed before. MEP distribution, like plumbing lines and HVAC ductwork, can be a source of inefficiency when not well-insulated or -sealed.

To address these issues the team employed the use of a pre-fabricated phenolic soffit designed specifically for use with the Systemair Genius equipment at the Corona Del Rey demonstration site.[27] The Thermaduct SoffitDuct is an insulated, air-tight soffit-duct that was

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[26] ASHRAE 62.2-2010 Section 6.8

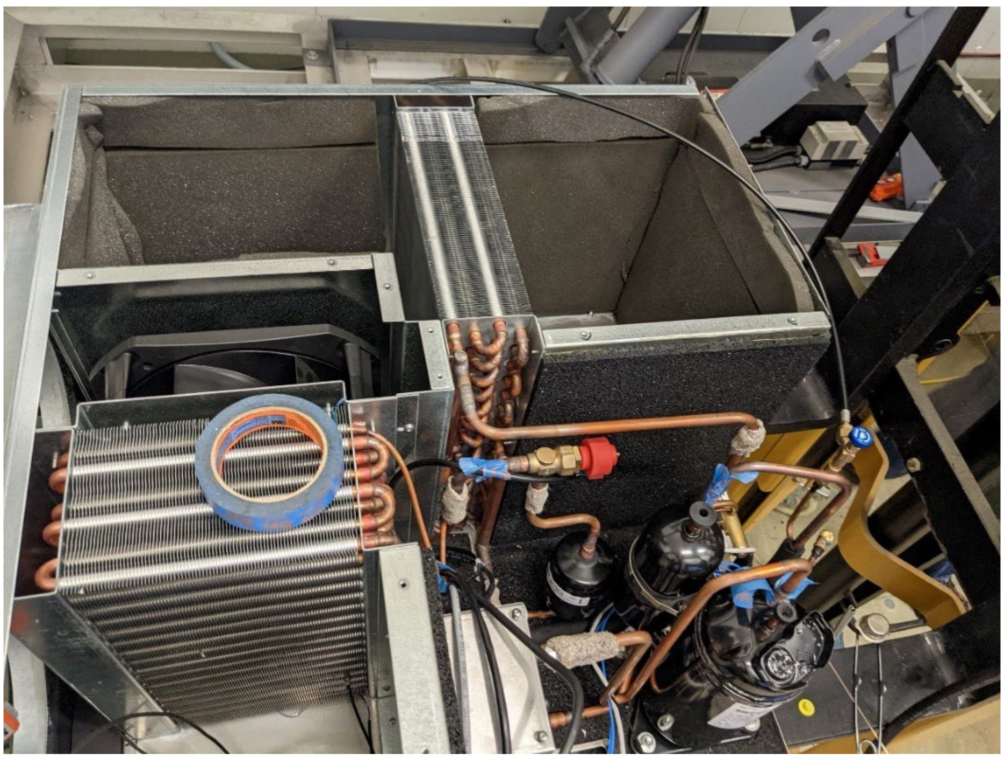
[27] Though the Systemair Genius equipment could not be installed, the KoolDuct Soffit pre-fabricated product was still designed, fabricated, and installed for demonstration purposes.

designed with four discreet channels, one for the space conditioning supply, a second for ventilation supply, a third for extract air, and a fourth for the plumbing and electrical lines. The SoffitDuct has the potential to greatly reduce labor time and cost. The installation contractor at the Corona Del Rey demonstration commented that the product was very easy to work with and install. The product also offers performance benefits. Reference the Technology Brief: SoffitDuct for more information on the product and its demonstration.

Impact Compact Design Has on Efficiency

Compact heat pump system design and system efficiency can be at odds with one another. Higher efficiency heat pumps require larger heat exchangers and other vapor compression related components. Careful design of heat pump equipment in combined mechanical systems is critical when combining multiple end uses into one system, particularly into one box. Figure 3 shows how tightly the heat pump componentry is packed into the Systemair Genius's heat pump module, a contributing factor to its low efficiency.

Figure 3: Compact Heat Pump Module of the Systemair Genius



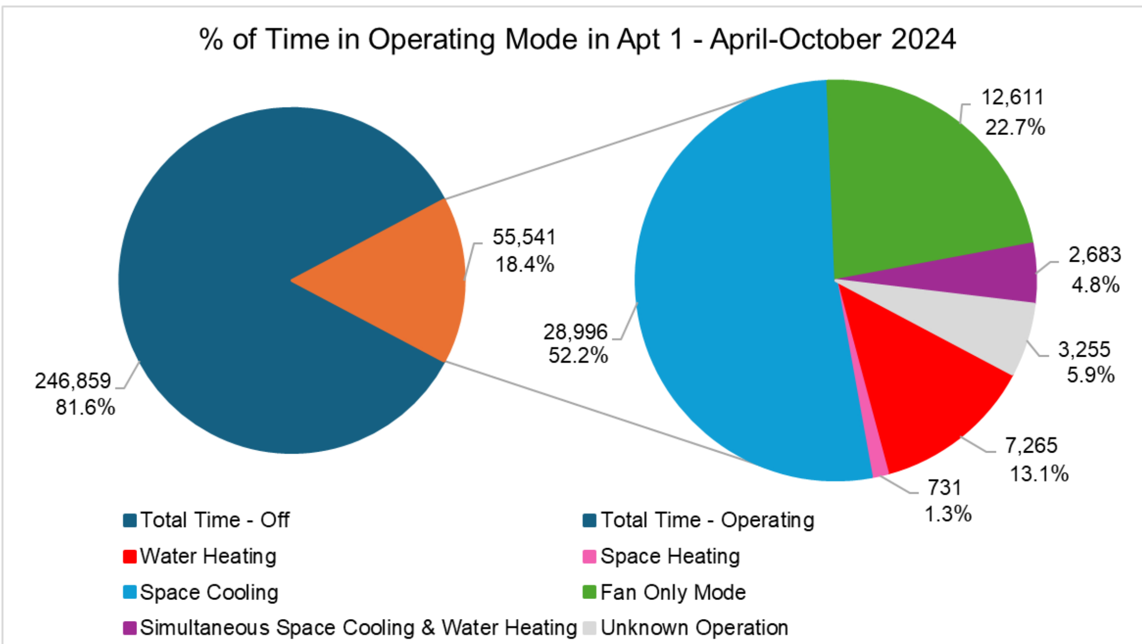
Credit: AEA

This compromise in efficiency in exchange for a smaller physical footprint was observed in the Systemair Genius through lab testing at LBNL and of the Ephoca AIO WM+ERV through performance monitoring at the Corona Del Rey demonstration site. In both cases, compact design and limited surface area for heat transfer were noted as contributors to the rated and measured efficiencies. Systemair informed the team that the Genius was originally designed specifically for Passive House certified homes with very low loads and therefore optimized for compactness over efficiency.

Low Occurrence of Coincident Cooling and Water Heating Demand

One of the selling points of a combined mechanical system is the potential efficiency benefits associated with heat recovery during simultaneous mode operation. There is some heat recovery potential with coincident space conditioning and ventilation, but significantly greater potential when there is coincident cooling and water heating demand. While the simultaneous occurrence of space conditioning and ventilation is high, especially when the ventilation is designed to run continuously, space cooling and hot water demand are not reliably coincident in most residential situations. Operation of the AQTA at the Bear Creek project demonstrated very little coincident space cooling and water heating demand—or simultaneous mode operation, as shown in Figure 4.

Figure 4: Percent of Time Per Operating Mode of Bear Creek's Apt 1 AQTA from April to October 2024



Source Information: AEA

Over the entire cooling season, less than 5 percent of the AQTA's operation was in simultaneous mode where heat recovery could occur. That figure was even lower in the second demonstration apartment. The benefits of heat recovery cannot be fully realized without coincident demand. Therefore, manufacturers should consider developing control algorithms that optimize hot water charging schedules in ways that increase the frequency at which the systems operate in simultaneous cooling and water heating modes.

Introduction of Potential Envelope Inefficiencies with Room-by-Room Solutions

Room-by-room combined HVAC solutions, such as the Ephoca AIO WM+ERV system, present energy and cost savings opportunities.[28] There are, however, some drawbacks to this HVAC configuration the most prominent of which are the number of envelope penetrations required

[28] Post-retrofit resident survey conducted at Corona Del Rey on October 11, 2024, and November 6, 2024.

to accommodate them. The energy efficiency impact of these penetrations was quantified at the Corona Del Rey demonstration through a series of blower door tests. Whole-building pressurization and depressurization blower door tests revealed significant air leakage in the new high-performance envelope in and around the HVAC penetrations. To control for this, both types of blower door tests were conducted again after taping all HVAC penetrations to mimic an uninterrupted envelope and eliminate the air leakage at that interface. The results of these comparative air leakage tests are shown in Table 9.

Table 9: Whole-Building Air Leakage Testing Results With and Without HVAC Penetrations at Corona Del Rey

Post-Retrofit Air Leakage - ACH50	Depressurization	Pressurization
No Tape @ HVAC	3.41	4.76
Tape @ HVAC	1.89 / -80%	2.83 / -69%

ACH50 = air changes per minute at 50 pascals
Source Information: UC Davis WCEC

The energy inefficiency of a leaky envelope is not inherent to room-by-room combined HVAC equipment; however, it can be the outcome of a poor installation. In this case, the Ephoca AIO WM+ERV was missing the foam gaskets that line the air pathway openings into the machine to make them flush with the wall penetration connection, as shown in Figure 5. This issue was unique to this installation because it was the first installation of the ERV module.

Figure 5: HVAC-Envelope Interface Shown During the Installation of the ERV Module at Corona Del Rey

Credit: AEA

The team does not anticipate missing foam gaskets in other installations; however, it highlights the importance of air sealing with this type of equipment. Careful attention to the HVAC-envelope interface is needed to achieve a successful installation and realize the efficiencies possible of the HVAC and envelope when using room-by-room equipment.

Market and Policy Barriers

Complexity of System Controls and Operation

Combined systems often have more complex controls and operating sequences than dedicated systems. This can make maintenance, troubleshooting, and system operation more complex. Affordable multifamily housing sites are less likely to have on-site staff with the training and capacity to maintain and service this type of equipment, and residents may be confused by system operation. In apartments at Corona del Rey with the Ephoca AIO units, residents reported being confused about when to use the wall-mounted thermostats versus the controls on the unit. Some residents also reported being confused by air coming out of the unit when heating and cooling were turned off. The airflow was ventilation air, but because it was unexpected, they disabled the ventilation out of fear that their utility bills would increase. This barrier was addressed by providing tenant education materials alongside the demonstration site installations. Due to timing constraints, follow-up was limited so it was difficult to determine what impact the educational materials might have had.

Refrigerant Regulations

The purpose of this project was to demonstrate low-GWP combined mechanical equipment. For the systems studied, R-32 was the most readily available refrigerant that could meet the low GWP requirements. R-32 is an A2L refrigerant, meaning it is mildly flammable. At the time of the demonstration site installations, A2L refrigerants were not permitted in the California Mechanical Code. The California Mechanical Code references the Underwriters Laboratories (now UL Solutions) (UL) standards governing heating and cooling equipment, specifically UL 60335-2-40, which is in the process of being updated to permit A2L refrigerants under certain conditions and applications. For the Corona del Rey site, where the demonstration units were being installed as part of a larger retrofit scope requiring mechanical drawings to be approved by the city, the engineer of record would not sign the drawings showing the R-32 equipment. The project team attempted to make an alternative means and method request from the city to no avail. The problem was addressed by purchasing R-410a versions of the Ephoca AIO WM units for permitting and inspection, and then subsequently replacing them with the low-GWP units for the temporary demonstration.[29]

For the Bear Creek site, the AQTA equipment utilized R454b refrigerant, also an A2L refrigerant. The AQTA demonstration was treated as a temporary demonstration to avoid permitting altogether as part of the Permit Status Plan. This path was pursued because of the risk and uncertainty around permitting for both the use of an A2L refrigerant and the combined mechanical system itself. The AQTA demonstration equipment was removed at the end of the monitoring period and replaced with the original existing equipment.

[29] The research team ultimately did not need to pursue this work around because of the California Mechanical Code change that went into effect on January 1, 2023, which allowed room air conditioning units and packaged terminal air conditioners to use refrigerant from the A2L class. Therefore, the R32 Ephoca AIO WM units were specified on the plans as a plan change and installed for the apartments’ permanent systems.

Lack of a Combined Product Test Standard

Lab testing of the SystemAir Genius unit employed current U.S. DOE test procedures for residential air conditioners/heat pumps and the test procedures for heat pump water heaters. However, the unit is designed to provide multiple mechanical services simultaneously (space conditioning, ventilation, and water heating) using the same heat pump. The lab testing attempted to isolate the functions to execute the tests as they are intended to be performed, but due to the integrated nature of the controls this proved challenging, and ultimately had an impact on the test results. A more relevant test procedure would account for the multi-functional nature of the machine, and measure efficiency of providing the multiple mechanical functions at once. Such standards exist in Europe but have yet to be adopted in the United States.

Local Electrical Codes Regarding Through-Wall Heat Pumps

The team discovered during permitting of the Ephoca AIO WM units that local building jurisdictions vary in their acceptance of allowing these units to be powered by a plug and outlet versus being hardwired on a dedicated circuit. The latter requires substantially more electrical work that could be disruptive, time-consuming, and costly, especially if the installation is not tied to a larger retrofit scope where sheetrock is being removed. In the case of the Corona Del Rey demonstration, the building department permitted the units to be plugged in; however, the wall outlet used was still on a dedicated circuit. Uncertainty from jurisdiction to jurisdiction remains a barrier to realizing the potential benefit the plug-in solution would bring at scale.

Knowledge Sharing and Transfer

The project team pursued a variety of activities to convey the learnings and recommendations from this research to a broader audience. These activities include two technology briefs, a case study of one of the demonstration sites, and multiple presentations including a recorded webinar.

Two technology briefs were developed to highlight the potential benefits and applications of the technologies demonstrated under this research. One technology brief focuses on multifunction heat pump systems, describing what they are and potential advantages for multifamily retrofits, as well as the specific technologies demonstrated through this award. The second technology brief describes the Thermaduct SoffitDuct technology demonstrated through this project, which could be applied to any forced air system.

The project team members presented a webinar describing the different types of low-GWP combined mechanical systems, and their challenges, benefits, and applications in Fall 2024 as part of the Energy and Environmental Building Alliance’s (EEBA) Webinar Series. This webinar is available on project team members’ websites, EEBA’s website, and as a podcast on the Better Homes, Better Future podcast accessible on podcast streaming platforms like Spotify.

A case study showcases the Bear Creek demonstration site where two of the Villara AquaThermAire systems were installed and monitored for 16 months.

The research findings and results will also be shared in public industry forums at conferences and other public engagements. Led by UC Davis WCEC, with whom the team collaborated closely with on the Bear Creek demonstration site, the team co-authored a paper focused on the shared demonstration project and findings thus far, published by the American Council for an Energy Efficient Economy (ACEEE). WCEC presented on the paper at the ACEEE Summer Study conference in Summer 2024. Participation in EEBA's webinar series in Fall 2024 was the first formal presentation from the project team members directly of this nature. The team also co-hosted a booth at the CEC EPIC Symposium technology showcase and video submission, both with Villara and WCEC focusing on the Bear Creek AQTA demonstrations.

Knowledge sharing has been occurring through informal engagement as well. Project team members participated in demonstration project debrief meetings with other grant-funded research teams studying and demonstrating combined mechanical systems. They are also engaged in national discussions through U.S. DOE's Advanced Building Construction (ABC) Initiative and shared learnings with ABC stakeholders. Early project learnings and efforts were shared within the Canadian-led Human Nest Project, which was active from 2021 to 2023 and had a combined mechanical system sub-group. And finally, the Team remains engaged with participating manufacturers: Systemair, Villara, and Ephoca to inform future product development.

CHAPTER 4: Conclusion

The ultimate purpose of this research was to identify scalable decarbonization solutions that reduce energy usage, emissions, installation costs, and utility costs to help achieve California's energy and climate goals, support its economy, and benefit its utility ratepayers. The energy and emissions reduction goals put forward by the State through SB 100[30] and SB 32,[31] and further updated in the 2022 Climate Change Scoping Plan,[32] signal demand for a mechanical retrofit solution that has the ability to increase market adoption of heat pump technologies. The combined mechanical system shows promise for being one such solution. Furthermore, use of low-GWP refrigerants support these goals and are now demanded by regulation through the United States Environmental Protection Agency's American Innovation and Manufacturing Act[33] and California Cooling Act, SB 1013.[34]

This project sought to identify and study low-GWP combined mechanical systems with the greatest potential to help increase adoption of decarbonization retrofits in California's affordable multifamily housing market. Benefits and challenges were identified through lab testing and field demonstrations of three different types of combined mechanical systems. These benefits and challenges helped determine which solutions are most viable for this market: combined systems that leverage heat recovery benefits, are space-flexible, and able to use existing mechanical installation locations. These learnings and the observations that led to them are the basis of the team's recommendations to manufacturers for designing combined mechanical systems for this market.

In addition to state climate goals, the development of low-GWP combined systems as a mechanical retrofit solution also supports state economic objectives. Economic support and benefit come in two main forms: 1) new workforce and upskilling of existing workforce to handle new technologies, and 2) product development opportunities for local equipment manufacturers. Development of skills to work with combined systems and low-GWP refrigerants, and to coordinate with other trades in ways that have not been needed before, will support the success of these products as retrofit solutions while also leading to increased need for skilled labor. The potential for a less invasive and disruptive retrofit will help bolster

[30] California State Senate. 2018a. *Senate Bill 100: California Renewables Portfolio Standard Program: emissions of greenhouse gases*. Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100.

[31] California State Senate. 2016. *Senate Bill 32: California Global Warming Solutions Act of 2006: emissions limit*. Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB32.

[32] California Air Resources Board. 2022. *2022 Scoping Plan for Achieving Carbon Neutrality (2022 Scoping Plan)*. December 2022. Available at https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents.

[33] United States Environmental Protection Agency. 2025. *American Innovation and Manufacturing (AIM) Act of 2020*. Available at https://www.epa.gov/climate-hfcs-reduction/background-hfcs-and-aim-act.

[34] California State Senate. 2018b. *Senate Bill 1013: Fluorinated refrigerants.* Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB1013#:~:text=(a)%20The%20Legislature%20finds%20and,as%20appropriate%20in%20the%20state.

demand for these systems and associated products (like the Thermaduct SoffitDuct). As a result, local manufacturers like Villara will also have opportunities to expand their workforce and facilities as demand for these products increases.

This research demonstrated that, while further combined mechanical system product development and refinement is needed, these systems have the potential for both upfront and operational cost savings for utility ratepayers. Deeper savings are possible if some of the suggested areas of development are pursued. These systems also have strong potential to be used as effective grid reliability tools provided connected demand response and load shifting capabilities are added. Additionally, because these solutions allow for the removal of multiple gas combustion appliances at one time, guarantee access to cooling, and typically include integrated mechanical ventilation, they have the potential to rapidly provide safer, healthier and more resilient indoor environments and reduce the negative health impacts associated with poor indoor air quality.

Low-GWP combined mechanical systems can address a large market sector, made up of 4.3 million existing multifamily buildings.[35] The space-flexible combined systems suit the affordable multifamily retrofit market best. Other form factors of combined equipment, like the all-in-one box pod approach, can be useful in other markets like new construction and single-family homes, which make up the remaining 9.1 million residential units in California.[36] Further development is needed for both product classes and more product offerings are needed to meet the needs of California's wide range of building typologies. Advantages exist in having multiple end-uses with one grid connection, but utilities engaged in demand response programs and in figuring out how to use connectivity and load shifting for grid reliability will need to determine whether new approaches or strategies are needed to interface with multifunction heat pump systems.

All of the lessons learned and described in the research outcomes in Chapter 3 support industry development needs for manufacturers, design practitioners, and building owners. Listed below are several areas in which investment in further development will be particularly impactful.

Future Research:

- Support further technical and market development for space-flexible combined systems that are designed for specific retrofit applications. Encourage manufacturers to consider building typology in their product design.
- Support further technical research in the optimization of heat recovery and load shifting capabilities of combined mechanical systems. Development should focus on balancing the optimization of systems for time of use and maximizing heat recovery. Some examples include: more strategic setpoint deadbands (adjusting setpoint dynamically to

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[35] Webster, Brett, Aven Satre-Meloy, Leslie Badger, Alison Donovan, Damon Lane, Kevin McGrath, Eric Wilson, Janet Reyna, Cheryn Metzger, Tyler Pilet, Martha Campbell, & Lucas Toffoli. 2024. *Accelerating Residential Building Decarbonization: Market Guidance to Scale Zero Carbon-Aligned Buildings*. Advanced Building Construction Collaborative. Available at: https://advancedbuildingconstruction.org/market-guidance-report/.

[36] Ibid.

allow for heat recovery when it is optimal to do so); and physical system design (having a pre-heat tank, sizing of components, etc.).

- Support product development of distribution solutions, like the SoffitDuct, to reduce labor and invasiveness of MEP retrofits.
- Support product development for room-by-room multifunction systems, with a focus on form factor and optimized control solutions that are user-friendly and suit the multifamily rental market. Some examples include: optimizing size and/or installation location so that the system does not displace obvious furniture locations; and controls that are centralized and are tied to the equipment rather than the user.

Advocacy/Regulatory:

- Advocate for communication between manufacturers, CEC, and U.S. DOE to determine the best and most applicable route for evaluating combined mechanical systems, whether it is through California Title 20, Energy Star, or U.S. DOE federal standards.
- Support RD&D of emerging technologies that use R290 and other natural refrigerants.
- Advocate for plug-in permanent mechanical systems to use shared circuits.
- Advocate for making the testing process for re-entrainment compliance under ASHRAE 62.2-2010 Section 6.8 more clear for manufacturers.

At least 7.6 million households in California alone could be candidates for an electrification retrofit using a low-GWP combined mechanical system.[37] Manufacturers, design practitioners, and contractors can leverage the lessons learned from this project to help meet that demand. Though the policy landscape is supporting the use of these systems in California through legislation for energy and emissions reductions goals, this report summarizes a number of barriers that still exist and must be addressed to realize the full market potential of these types of products. Addressing those barriers and designing with specific building typologies in mind can promote low-GWP combined mechanical systems as a major solution for delivering ratepayer benefits, bolstering the economy, contributing to State energy and climate goals, and addressing the global climate crisis.

[37] Ibid.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
A2L	a class of low-GWP refrigerants that are mildly flammable, such as R-32
ABC	Advanced Building Construction Collaborative
ACEEE	American Council for and Energy Efficient Environment
ACH50	air changes per minute at 50 pascals
AEA	Association for Energy Affordability
AIO WM	all-in-one wall mount
AQTA	AquaThermAire
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
B	billion
CEC	California Energy Commission
CHPWH	central heat pump water heating system
COP	coefficient of performance
DHW	domestic hot water
EEBA	Energy and Environmental Building Alliance
EER	energy efficiency ratio
EPIC	Electric Program Investment Charge
ERV	energy recovery ventilator
FHR	first hour rating
GHG	greenhouse gas
gpm	gallons per minute
GWP	global warming potential
HSPF	heating season performance factor
HPWH	heat pump water heater
HVAC	heating, air conditioning, and ventilation
kBtu	thousand British thermal units
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
lb/timeframe	rate at which nitrogen oxides (NOx) are emitted or reduced, measured in pounds (lb) over a specific period of time
LG-MM	Low-GWP Mechanical Module

Term	Definition
M	million
M&V	measurement and verification
MEP	mechanical, electrical, and plumbing
$MTCO_2e$	metric tons of carbon dioxide equivalent
NEEA	Northwest Energy Efficiency Alliance
NREL	National Renewable Energy Laboratory
RD&D	Research, Development, and Demonstration
REALIZE-CA	REALIZE California
NO_x	nitrous oxides
RMI	Rocky Mountain Institute
SB	Senate Bill
SEER	seasonal energy efficiency rating
TAC	Technical Advisory Committee
TRL	technology readiness level
UC Davis	University of California, Davis
UEF	uniform energy factor
UEFnc	Northern California uniform energy factor
UL	Underwriters Laboratories (now UL Solutions)
U.S.	United States
U.S. DOE	United States Department of Energy
WCEC	Western Cooling Efficiency Center

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Project Deliverables

This list showcases all of the project deliverables produced for Agreement EPC-19-032. Other work products produced through this project are also included. Project deliverables, including interim project reports and other work products, are available upon request by submitting an email to pubs@energy.gov. The Final Report and all technology transfer work products (two technology briefs, case study, and webinar) can also be found on Association for Energy Affordability's website at https://aea.us.org/publications-resources/, Emanant System's website at https://www.emanant.systems/publications, and RMI's REALIZE-CA website at https://rmi.org/our-work/buildings/realize/realize-ca.

- Summary of Available Technologies
- Component & Controls Specification Plan
- Design Schematics Plan
- Design Drawings
- CPR Report #1
- Functional Testing Reports Phase I
- Functional Testing Reports - Phase II
- Design Documentation and Assessment Manual
- Emergency CPR
- CPR Report #2
- Demonstration Site List
- Draft Monitoring Plans
- Final Monitoring Plans
- Site Commitment Letters
- Field Demonstration Execution and Preliminary Monitoring Report
- CPR Report #3
- Evaluation, Measurement, and Verification Report - Part I
- Evaluation, Measurement, and Verification Report - Part II
- Kick-off Meeting Benefits Questionnaire
- Mid-term Benefits Questionnaire
- Final Meeting Benefits Questionnaire
- Draft Initial Fact Sheet

- Final Initial Fact Sheet
- Draft Final Project Fact Sheet
- Final Project Fact Sheet
- Draft Presentation Materials
- Final Presentation Materials
- High Quality Digital Photographs
- Draft Technology/Knowledge Transfer Plan
- Final Technology/Knowledge Transfer Plan
- Draft Technology/Knowledge Transfer Report
- Final Technology/Knowledge Transfer Report
- Draft Production Readiness Plan
- Final Production Readiness Plan

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A: Summary of Performance Outcomes in LG-MM Demonstrations

June 2025 | CEC-500-2025-029

APPENDIX A:
Summary of Performance Outcomes in LG-MM Demonstrations

Table A-1: Performance Outcomes

Demonstration Equipment Type	Demonstration Site	Installa-tion Cost ($)	Installa-tion Time (hours)	Seasonal COP - Heating / Cooling	COP-Water Heating	COP – Simultan-eous	Type of Refrigerant	Refrigerant GWP	TRL (at end)
Goal	n/a	40% Reduction	n/a	n/a	n/a	n/a	low-GWP	<750	Move from 4 to 7
Conventional	REALIZE-CADem	$37,000[38]	59	n/a	n/a	n/a	R410A/R134A	2,088/1,430	9
SystemType#1: SystemairGenius	LBNL/Corona Del Rey	$56,614	unknown	n/a	n/a	n/a	R32	675	5
ThermaductSoffi Duct	Corona Del Rey	$9,728	40	n/a	n/a	n/a	n/a	n/a	6
SystemType#2: VillaraAqthaTherm Aire	Bear Creek	$21,141	44	2.68/2.63	2.11	1.52	R454b	466	8
AQTAVentilation	Bear Creek	$8,966	20	n/a	n/a	n/a	n/a	n/a	5-9
SystemType#3: EphocaAIOWM+ERV	Corona Del Rey	$32,779	21	None measured[39]/ 2.30	n/a	n/a	R32	675	8
Integrated Controls + Thermal Comfort	Corona Del Rey	$12,355	8	n/a	n/a	n/a	n/a	n/a	6
SanCO2C HPWH	Corona Del Rey	$6,479	24[40]	n/a	3-4[41]	n/a	R744	1	9

Source Information: AEA

[38] $37,000 was the estimated cost of a full mechanical electrification retrofit using conventional equipment at the time of the proposal in 2019. This estimate included an HVAC heat pump, ductwork, heat pump water heater, heat recovery ventilation and necessary infrastructure, and electrical upgrades. The cost of these types of retrofits has since come down as electrification has become more popular; however, this value remains the stated goal as that is what is included in the Agreement's Scope of Work.

[39]No space heating events were captured from the monitored Ephoca AIO WM-ERV unit during the monitoring period mid-April through early-January. The resident did not use this particular room's equipment in space heating during the monitoring period, which is out of the research team's control.

[40] Total number of person-hours for a small SanCO2 CHPWH plant serving four units is estimated based on the project team's experience with this retrofit installation.

[41] Data quality from this demonstration was not good enough to solve for system COP. COP of 3-4 is what the research team has seen on other SanCO2 CHPWH monitoring projects.

CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX B: Assumptions for Investor-Owned Utility Ratepayer Benefits

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APPENDIX B: Assumptions for Investor-Owned Utility Ratepayer Benefits

Part of the results of this research showcase how the low-GWP combined mechanical systems could impact and deliver benefits to California investor-owned utility ratepayers. In the proposal that was awarded funding for this Agreement, the research team identified potential ratepayer benefits and quantified those benefits based on a set of assumptions. The team revisited these benefits at the end of the study to measure the impact of said benefits in the applied RD&D demonstration projects. The results of that quantification are listed in Table 2, Summary of Measured Ratepayer Benefits and in the supportive narrative in Chapter 1. This Appendix further expands on that table to explain the methodologies used and assumptions made to arrive at the reported values.

Below are the seven components that make up Table 2 in Chapter 1, and their reliant methodology and assumptions.

- Measurement Sector
  - The measurement sector defines the locale and portion of the market where impacts are being measured. Each of the four demonstration apartments report measured impacts and the sum-total of the four demonstration apartments' impacts are reported. Lastly, the measured impacts across the total market are reported, which are based on the average single demonstration apartment scaled up to the potentially addressable market. Based on the 2009 California Residential Appliance Saturation Study data, there are more than 1.6 million apartments with natural gas space and water heating.[42] The 1.6 million residential units was used to scale the average savings from a single demonstration apartment. Based on the assumptions listed above, if all of these households installed a low-GWP combined mechanical system, it could result in the stated statewide ratepayer benefits. The total market assumes participation from 100 percent of apartments because this research evaluated different combined mechanical systems of various form factors, which is necessary to address the multitude of building typologies and mechanical system install locations that make up the addressable market.
- Timeframe
  - The timeframe specifies over what period of time the savings are measured. Timeframe was added in place of annualizing each savings metric because one of the two demonstration sites (2 of 4 demonstration apartments)—Corona Del

[42] California Energy Commission. 2009. *2009 and 2003 Residential Appliance Saturation Study (RASS)*. Available at https://www.energy.ca.gov/data-reports/surveys/2019-residential-appliance-saturation-study/2009-and-2003-residential.

Rey—only had 8 full months of utility bills to use for the analysis. Instead of reporting annual savings and padding the measured savings with a 4-month estimate, the team decided to report actual measured savings over the time period available. The total market savings were reported in annual savings, which was achieved by some estimation. As noted in the Measurement Sector methodology and assumptions above, the total market savings were derived from the average savings for a single unit across the four individual demonstration apartments and scaled up to the full addressable market. Because two out of four demonstration apartments only had 8 months-worth of data measured, estimation was used to fill in the 4-month gap. The savings in each category were increased by 25 percent to estimate the missing four months only as part of the savings average to support reporting total market savings. This is not a perfect methodology to accurately depict energy, cost, and GHG emissions from combustion savings because seasonality implicates those savings; however, it was justifiable to arrive at a ballpark value.

- Energy Savings (kBtu)
    - Energy savings per demonstration apartment were measured by comparing utility bill-reported energy usage for the stated timeframe before the low-GWP combined mechanical system retrofit and for the same timeframe after the retrofit. The difference in electricity kWh and gas therm usage respectively pre- versus post-retrofit were converted to kBtu and added together for total kBtu savings. For the Bear Creek demonstration, the pre-electrification utility bill energy data was used to measure the energy savings from an electrification retrofit. In reality, this property's HVAC and DHW systems were electrified in a retrofit in 2019. The demonstration low-GWP combined mechanical system (the Villara AQTA) replaced electric heat pump HVAC and DHW systems, which does not represent the fuel-switching retrofit scenario that is the focus of the addressable market. Utility bill information was available through historic usage and because part of the research team worked on the property's original electrification retrofit in 2019. Scaling and estimation was needed for one of the demonstration apartments (Bear Creek Apt 1) because the utility could not share data from more than three years back. See the section in the Evaluation, Measurement & Verification Report that describes the methodology for estimating this apartment's 2018 to 2019 energy usage based on aggregated electricity and gas utility data from 28 units at the property. See Measurement Sector above to understand the methodology for estimating savings for the total market, which was applied to energy savings.
- Greenhouse Gas Emission Reductions (Combustion) ($MTCO_2e$)
    - GHG emission reductions from combustion were measured based on gas therm consumption reduction. For each demonstration apartment, utility bill data was used to measure the pre-retrofit gas therm consumption and post-retrofit gas therm consumption. Given that these demonstrations fuel-switched the

mechanical systems, post-retrofit gas therm consumption was zero. Electricity replacement is also considered in this methodology, and as such, relied on pre-versus post-retrofit electricity usage from utility bills. See description in Energy Savings section above for estimation information for one of the demonstration apartments at Bear Creek. The average natural gas and replacement electricity values from utility data were multiplied with the average annualized emissions factor of 0.000237 $MTCO_2e$ per kWh and 0.00531 $MTCO_2e$ per therm, which are the default emissions factors used by the California Air Resource Board for their California Climate Investments at the onset of this Agreement.[43] See Measurement Sector above to understand the methodology for estimating savings for the total market, which was applied to GHG emission reductions from combustion.

- Greenhouse Gas Emission Reductions (Refrigerant) ($MTCO_2e$)
  - GHG emission reductions from refrigerants were measured based on the GWP of the specific type of refrigerant and the volume of refrigerant used in each demonstration system. The volume of refrigerant in the system was divided by the product of the GWP for that refrigerant and 1,000. This calculation is completed assuming R410a and the low-GWP refrigerant used in the demonstration. The difference between the quotient from R410a and that from the low-GWP refrigerant is the reported GHG emissions reduction. This methodology assumes that the refrigerant is not appropriately captured and remediated. See section in the *Evaluation, Measurement & Verification Report* that uses the Refrigerant Impact Calculator from MEP 2040 for another type of impact evaluation regarding the refrigerants used in the demonstrations. See Measurement Sector above to understand the methodology for estimating savings for the total market, which was applied to GHG emission reductions from refrigerants.
- Air Emission Nitrous Oxides (NO_x) Reductions (lb/year)
  - Air emission NO_x reductions were measured based on gas therms consumption reduction. For each demonstration apartment, utility bill data was used to measure the pre-retrofit gas consumption and post-retrofit gas consumption. Given that these demonstrations fuel-switched the mechanical systems, post-retrofit gas consumption was zero. See description in Energy Savings section above for estimation information for one of the demonstration apartments at Bear Creek. The natural gas NO_x emissions factor of 0.0049 lb per therm for NO_x controlled gas water heating equipment, from United States Environmental Protection Agency, was applied to the pre- versus post-retrofit gas therms savings to arrive at pounds per year of NO_x.[44] See Measurement Sector above to

[43] California Air Resources Board. 2025b. *California Climate Investments Quantification, Benefits, and Reporting*. Available at: https://ww2.arb.ca.gov/resources/documents/california-climate-investments-quantification-benefits-and-reporting-materials.

[44] United States Environmental Protection Agency. 1998. "Natural Gas Combustion" in *Compilation of Air Emissions Factors from Stationary Sources (AP-42)*, Fifth Edition, Volume I, Chapter 1: External Combustion Sources. Available at https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf.

understand the methodology for estimating savings for the total market, which was applied to air emission NO_x reductions.

- Adjusted Utility Bill Impact – Savings ($)
  - Adjusted utility bill impact savings is a utility cost savings metric that references the same effective utility rate ($/energy unit) to properly quantify the impact of a retrofit on utility bills. Instead of comparing the actual utility bills paid pre-retrofit to post-retrofit, this methodology does so while also adjusting the pre-retrofit costs to the post-retrofit rates. This adjustment is important to allow for reasonable comparison because electricity and natural gas utility rates are increasing over time. For context and scale, the average residential rate in PG&E territory as increased around 49 percent since 2020.[45] This analysis took the pre-retrofit utility costs and divided total costs by total energy usage for that period to get the effective rate in $/kWh for electricity, and $/therm for gas. The same was done for the mirroring post-retrofit time period. Then, the pre-retrofit kWh electricity and therm gas usages were multiplied post-retrofit effective $/kWh and $/therm rates. This resulted in new electricity and gas utility cost values adjusted to the post-retrofit rates. The measured post-retrofit utility costs were subtracted by the adjusted pre-retrofit utility costs to result in adjusted utility bill impacts for each demonstration site. See description in Energy Savings section above for estimation information for one of the demonstration apartments at Bear Creek. See Measurement Sector above to understand the methodology for estimating savings for the total market, which was applied to adjusted utility bill impacts.

The team highlighted other non-quantified ratepayer benefits like improved health, safety, and resiliency. A low-GWP combined mechanical system will provide space cooling, which is not historically always present in apartments in California's relatively mild climates. As extreme heat events become more prevalent, access to cooling is a benefit—and can also be a necessity for health and safety. Additionally, improved safety also comes from converting from natural gas to electric modules, there will be reduced gas piping and infrastructure that could result in leaks or explosions, as well as reduced risk of localized carbon monoxide indoor air quality hazards. Additionally, new construction properties will not need to include costs for gas pipeline connections or gas piping within the building. Infrastructure resiliency and reliability are also benefits from electrification. Modern gas water heaters and nearly all furnaces require electricity to operate, and during an electricity outage, hot water availability for both gas and heat pump water heating systems would be limited to the amount of existing storage. Studies have also shown that during a natural disaster, such as an earthquake, the time for natural gas to become available will be longer than electricity. As such, a 100 percent electric module system can return to operation much sooner than a natural gas furnace and water heater, and can also be operated by an islanded PV+battery system when installed.[46] Lastly, low-GWP

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[45] Citadel Roofing & Solar. 2025. *A Timeline of PG&E's Rate Increases*. Available at https://blog.citadelrs.com/timeline-of-rate-increases-and-how-to-reduce-your-bill.

[46] After the Loma Prieta and Northridge earthquakes, it took 10 to 14 days (respectively) to restore 80 percent of natural gas accounts, while 70 percent to 99 percent (respectively) of electricity accounts were restored the same day and in no cases did it take longer than 5 days.

combined mechanical systems can provide grid reliability in the form of demand response and load shifting. With the potential for just one grid connection point, a utility that uses demand response and peak load shifting can rely upon one combined system to address multiple mechanical end uses. Interactivity between the end uses may also provide additional peak power savings. This has the potential to result in improved grid reliability and also ratepayer utility bill savings.

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APPENDIX C: Summary of Project Impact on Product Development

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APPENDIX C: Summary of Project Impact on Product Development

The project outcomes were a result of the LG-MM project team's close collaboration with the manufacturers of each product demonstrated during this research project. The team found that further development, which is summarized below, is needed for each product to reach a commercial-ready and scalable solution, but that each of the products demonstrated potential as a scalable decarbonization solution, whether for a multifamily retrofit or a single family new-build.

The team's first product impact ensued when proposing that product manufacturer, Systemair, redesign their Genius system to use R32 refrigerant. The Systemair Genius product manager and technical lead led the procurement of an R32 heat pump for the Genius system, electrical system re-build to be UL-ready for United States compliance, and facilitated discussions with the product's controls supplier to uptake the team's extensive controls recommendations, all in response to the project team's direction and request. The project team provided detailed recommendations to Systemair for how to adapt the unit to be more suitable for retrofit and the broader United States market, informed by the design process and lab testing. They also provided general market guidance for this type of product to assist with production planning. Collaboration over three years led Systemair to initiate redeveloping the next generation of the product, Systemair Genius 2.0, in 2024, which is still underway. It is the team's understanding that many of their suggestions, including the use of low-GWP refrigerant, will be incorporated into the Genius 2.0 system. Though the product is not suitable as a common retrofit solution in California's existing affordable multifamily market, it would be viable in other markets such as multifamily new construction or single-family homes. The product will need to meet the federal minimum efficiency standards, become UL-compliant and -listed, solve for the challenges around distribution connections, consider addressing the ability for the product to be located outdoors, and complete the heat pump redesign to use low-GWP refrigerant to achieve market viability in California.

Another product impact success lies with the team's collaboration with Kingspan's Thermaduct and the tri-duct SoffitDuct created and demonstrated in this project. The team pitched the idea of the tri-duct soffit as an adaptation of Thermaduct's existing KoolDuct product widely used in commercial duct systems. The team worked with Thermaduct's R&D lead for about two years from the conceptual schematic design phase, through many design iterations based on project needs and demonstration site existing conditions. Fabrication proved difficult and Thermaduct did not have additional resources to spend on the project to initiate next steps; however, the SoffitDuct product development and demonstration is one of the successes of this project. Team members continue to engage with Thermaduct to adapt and build upon the SoffitDuct product to arrive at a solution for the broader HVAC and DHW distribution retrofit markets. Further design and fabrication development, and manufacturing efficiency would be necessary to result in a commercial-ready product.

The team's next product impact was with Villara on their AQTA system, which previously underwent lab testing at UC Davis WCEC, was installed in several test sites, and was slated for production home sales. The team requested a low-GWP heat pump for use in its AQTA product demonstration, signaling demand for low-GWP refrigerant systems and providing an opportunity to test the AQTA system with a R454b heat pump, instead of the typical R410a used in other test systems. The team also presented to, and brainstormed with, Villara around ideas for integrating ventilation into the existing AQTA system. Integrated ventilation could not be incorporated into this demonstration, but design of coordinated ventilation controls presented potential for proof of concept. Through field demonstration troubleshooting, the team (including demonstration project partner, UC Davis WCEC) collaborated with Villara, and provided insight into and feedback on controls development needs. Further development and refinement of AQTA controls for a reliable and high-performing low-GWP system is necessary, and consideration of integrating ventilation with the product would further increase product value, both resulting in a commercial-ready product.

The final manufacturer with whom the team collaborated was Ephoca on their new ERV module product, which was developed during the term of this project and intended to be paired with the existing Ephoca AIO WM packaged terminal heat pump product. The team installed the first batch of the ERV modules in California and conducted airflow and ventilation effectiveness testing on the equipment. This testing revealed significant functionality issues. In response, the team provided their testing results to Ephoca and worked closely with the ERV module product design team. Ephoca's design team supported a second round of field testing, conducted in-house testing in their test chamber, and collaborated with the team to learn about product functionality in the field. This collaboration led to and resulted in the redesign and release of ERV module 2.0. Ephoca provided the team with an ERV 2.0 unit for a third round of field testing; however, due to unforeseen hurdles and delays, the team ran out of time to test the unit at the Corona Del Rey demonstration site. The Ephoca ERV 2.0 and an updated version of the Ephoca AIO WM unit designed to be compatible with the new ERV 2.0 were both shipped to UC Davis WCEC for airflow testing in their lab. This testing will reveal whether the redesign resulted in a viable system, or if further design changes are needed, which will be unveiled in future equipment version releases.