Electrifying Experiments to Streamline Multifamily Retrofits: Five Years of Misadventures, Breakthroughs, and Lessons Learned with Low-GWP Mechanical Pods

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ABSTRACT

Multifamily decarbonization efforts face persistent barriers including: high costs, bespoke design constraints, intrusive construction, and complex multi-trade coordination, which are compounded by the practical limits of today's dominant heat pump and heat pump water heating technologies (e.g.: airflow needs; extensive refrigerant, electrical and controls infrastructure).

Between 2020 and 2025, with California Energy Commission funding (EPC 19-032), we conducted field and laboratory research to explore a variety of all-in-one, combi-, integrated-, modular-, and multi-function heat pump systems (MFHPs) that combine most or all of the heating, cooling, ventilation, and water heating functions into pods or packages intended to simplify design, streamline installation, and enhance performance and affordability.

In this paper, we present findings to evaluate three different MFHP system types across metrics including energy performance, affordability, installability, retrofit invasiveness, system interactions, robustness, and scalability. Through detailed monitoring, we report on real-world operation and efficiency, document costs, and explore emergent technical challenges such as: optimizing heat recovery from cooling, managing refrigerant charge and safety with low-GWP refrigerants, and addressing space and access limitations.

We share our experiences to highlight trade-offs encountered when clever design ideas collide with reality in the field. Then, we synthesize these lessons into practical guidance on what building typologies and retrofit conditions are most promising for various MFHP systems, what performance and cost advantages each strategy may offer, and what implementation pitfalls to anticipate. By illuminating practical successes and cautionary lessons, we offer a realistic assessment of where MFHPs could achieve their promise of accelerating affordable multifamily decarbonization at scale.

Introduction

Multifamily decarbonization efforts frequently collide with a multitude of tangible constraints: limited mechanical space, limited electrical capacity, and limited tolerance for disruptive retrofit construction. Although modern heat pumps can perform well and efficiently, retrofits can become a multi-trade "octopus" of equipment, controls, penetrations, refrigerant piping, and electrical infrastructure–each one individually reasonable, but collectively costly and difficult to schedule, permit, and finance.

Combined mechanical systems–herein referred to as multifunction heat pumps (MFHP)–aim to simplify this puzzle by consolidating major end uses–space heating, space cooling, domestic hot water (DHW), and sometimes ventilation–into fewer pieces of equipment with fewer interfaces. In theory, this consolidation could potentially reduce first cost, minimize electrical upgrades, improve efficiency (e.g. by enabling heat recovery), and streamline retrofit processes (Tomlinson et al. 2005; Modera et al. 2014). In practice, these innovative mechanical system architectures can also introduce new challenges and failure modes: a single device can become a single point of failure for multiple services, and tight packaging can create efficiency, serviceability, and code-compliance headaches. The balance of advantages and challenges depends significantly on the specific details of the retrofit project in question.

This paper synthesizes five years of EPIC-funded research on low-GWP MFHP systems for California's dominant multifamily archetype: low-rise buildings, which represent 82% of CA's multifamily building stock (Reyna 2022). We focus on lessons learned from three MFHP system archetypes and various installation, distribution, and controls strategies developed to support installation of these technologies. Rather than presenting an idealized success story, we share what worked, what didn't, and what would need to change–in products, practices, programs, and policy–for combined systems to scale in affordable multifamily retrofits.

Project Overview and Methods

Between 2020-2025, with funding from the California Energy Commission (EPC 19-032), the Association for Energy Affordability, Inc. (AEA) led a research team composed of Emanant Systems, Lawrence Berkeley National Laboratory (LBNL), RMI, and Smith Group.

We evaluated candidate MFHP products through a combination of market screening, laboratory testing at LBNL, and field demonstrations at two occupied affordable housing properties in the California San Joaquin Valley and Southern California. These evaluation efforts also uncovered a need to reduce challenges with mechanical distribution associated with MFHPs in retrofit applications, and so we pursued product development for such a retrofit solution in parallel. Evaluation metrics included installation labor and costs, retrofit invasiveness (e.g., need for new chases, ductwork, or penetrations), operational performance (including seasonal coefficient of performance where measurable), code and permitting complexity, and perceived tenant/operations impacts (Jiles 2024).

We evaluated three MFHP archetypes via laboratory testing and field demonstrations:

1. A fully packaged all-in-one unit that provides, heating, cooling, domestic hot water and ventilation (Systemair Genius), paired with a low-profile factory-constructed modular insulated multi-duct soffit air-distribution retrofit (Thermaduct SoffitDuct)
2. A partially packaged MFHP (Villara AquaThermAire) that combines a split unitary central ducted heat pump with a domestic water heating tank and can reuse existing ducts and some electrical infrastructure
3. A distributed room-by-room approach using compact packaged terminal heat pumps with energy recovery ventilation (Ephoca AIO WM + ERV), paired with a central heat-pump water-heating plant (SanCO_2)

Table 1: Demonstration sites and primary evaluations.

Location	Climate	System Archetype(s)	Primary Evaluation(s)
LBNL Lab	n/a	(1.) Systemair Genius	Lab performance testing (410a system and R32 system); capacity, airflow, efficiency, DHW; refrigerant transition lessons; design for field install

Corona Site	CA CZ10	Thermaduct SoffitDuct	Product development, prototyping+ field install; assess retrofit feasibility, layout and install constraints
Planada Site	CA CZ12	(2.) Villara AquaThermAire	Field install + monitoring; assess cost, labor time, seasonal COPs, reliability, controls, usability, tangible constraints
Corona Site	CA CZ10	(3.) Ephoca AIO WM + ERV + SanCO$_2$	Field install + monitoring; assess cost, labor time, seasonal COPs, reliability, controls, usability, ventilation performance, tangible constraints

Technologies Evaluated

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

System Archetype #1: Systemair Genius

The Systemair Genius is an MFHP system that provides space heating, space cooling, domestic hot water, and heat recovery ventilation. These subsystems are contained within one large refrigerator-sized box, composed of three core sections: the base section contains a 40-gallon hot water storage tank, water pump, refrigerant-to-water heat exchanger, and the electrical components and control board; the middle section contains the heat pump with the compressor, refrigerant circuit, and refrigerant-to-air heat exchangers (i.e.: condenser and evaporator) ; and the top section contains the heat recovery ventilator. This MFHP archetype is particularly unique because: the single unit provides all core mechanical services; refrigerant is factory charged and contained within the packaged unit; condenser airflow is ducted to the unit from outdoors; and ventilation, heating, and cooling are distributed to the space through the shared ductwork. We laboratory tested equipment using R410a (GWP$_{100}$=2088) and R32 (GWP$_{100}$=675) (IPCC 2021). Although we developed detailed plans to test the equipment in the field, and constructed supportive infrastructure (electrical, piping, ductwork, plumbing), we ultimately chose not to install the equipment because laboratory tests revealed critical reliability and safety concerns.

Figure 1: (Left) Diagram of the Systemair Genius product, (center) the system set up for testing in the Lab, and (right) the compact design of the heat pump module.

Thermaduct SoffitDuct – *developed to pair with System Archetype #1*

The Thermaduct SoffitDuct is an innovation that emerged from the research; the team designed and developed the technology in collaboration with Thermaduct. It was developed to pair with the all-in-one-box MFHP, but could be used with different types of air-based MFHP systems. The SoffitDuct is a lightweight, prefabricated, insulated, multi-channel, phenolic soffit duct solution composing multiple ducts (e.g. supply, return, and exhaust) as well as a chaseway for routing electrical and plumbing. It is constructed of rigid faced phenolic insulation board–the material that comprises Thermaduct's KoolDuct product for large commercial and industrial ductwork. The SoffitDuct has the potential to improve distribution system performance, speed of installation, and labor intensity, while minimizing the invasiveness of the retrofit compared to business-as-useful distribution routing and framed soffit construction. The SoffitDuct is particularly impactful in retrofit scenarios without an attic or crawlspace, and where ductwork did not previously exist.

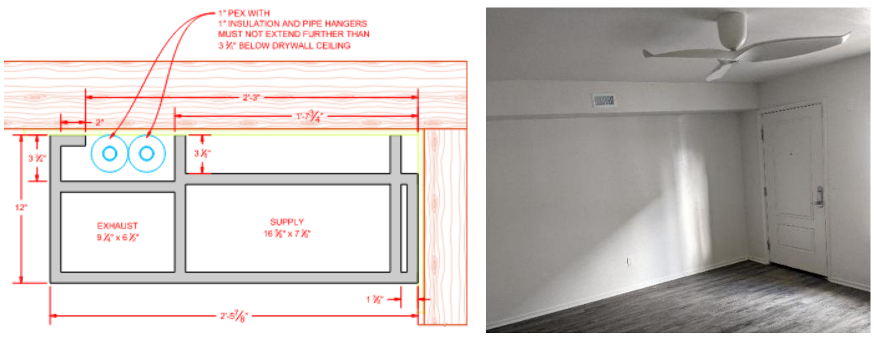

Figure 2: (Left) Schematic drawing of the Thermaduct SoffitDuct and (right) the product installed in the field.

System Archetype #2: Villara AquaThermAire

The Villara AquaThermAire (AQTA) is a 3-in-1 MFHP that provides space heating, space cooling, and domestic hot water with a semi-packaged form factor. The equipment tested uses R454b (GWP_{100}=466) (IPCC 2021). The system is comprised of an off-the-shelf air handler and standard-efficiency outdoor unit (a.k.a. "condenser"), with a refrigerant management system that enables the single compressor and outdoor coil to serve both the air handler and the domestic water heating tank. The unique hot water tank was designed and manufactured by Villara and integrates a refrigerant coil located inside the tank, which heats the water in the tank, and then transfers that heat to potable DHW coil also located inside 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.

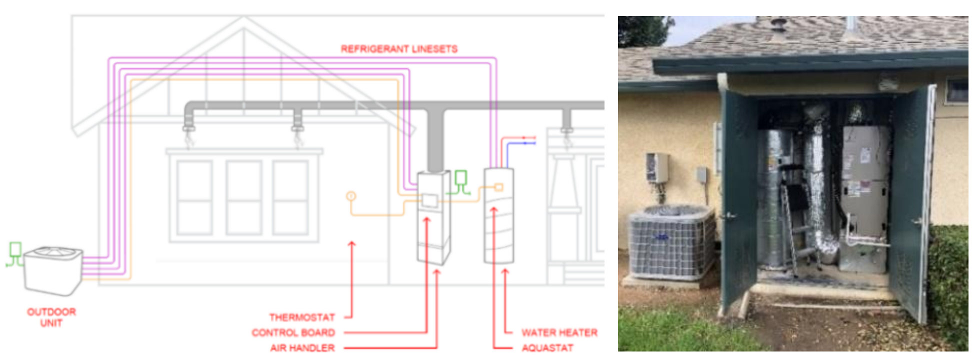

Figure 3: (Left) Schematic of the Villara AquaThermAir product and (right) photo of system installed.

The system can perform 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 water tank instead of extracting heat from the conditioned space. This facilitates much shorter defrost cycles (typically only two to three minutes) and offers thermal comfort advantages.

System Archetype #3: Ephoca All-In-One Wall Mount + ERV and SanCO_2 HPWH

The Ephoca All-In-One Wall Mount (AIO WM) + energy recovery ventilator (ERV) unit is a modular, zonal 3-in-1 multifunction packaged terminal heat pump that delivers space heating, space cooling, and energy recovery ventilation. The equipment can be hardwired or plug-in. The ERV is a modular component that can be added to the AIO WM module. The AIO WM module can function without the ERV module, but the ERV module cannot be installed independently. This product is available with various refrigerant options – we tested units using R32. The SanCO_2 HPWH 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. The SanCO_2 uses R744 refrigerant (GWP_{100}=1) (IPCC 2021). The field demonstration also incorporated enhanced controls to enable central coordination of the individual zonal AIO WM units, and automatic function of ceiling fans for improved thermal comfort in each room at an elevated cooling setpoint.

Figure 4: Diagram of the Ephoca All-In-One Wall Mount plus energy recovery ventilator unit

Demonstration Data Collection

We collected extensive data and lessons about each technology through the design, planning, and costing phases of each demonstration project. We collected performance data through laboratory testing. Then, we collected information and learnings through the course of installation and commissioning. Finally, for the systems installed in the field, we deployed a comprehensive array of instrumentation and data acquisition systems to monitor system behavior, performance, and efficiency during real world operations in multiple seasons, over the course of several months. Empirical data included costs, installation time, temperatures, pressures, humidity, electric power, airflow and water flow rates, and heat transfer rates.

The Villara AQTA was installed in two apartments at the Planada site, both of which were instrumented to measure air and water flow rates, air and water temperatures, air humidity, power draw, and refrigerant pressure and temperature. These measurements allowed us to perform timeseries assessment of heat transfer rates, and efficiency for the heating, cooling, and hot water systems.

The Ephoca AIO WM+ERV, integrated controls, and $SanCO_2$ HPWH package were installed in four apartments at the Corona site. Each apartment included four packaged terminal heat pumps, three of which included the ERV module. The four apartments share a central HPWH system with two $SanCO_2$ units and two 119-gallon hot water tanks. We instrumented the cHPWH serving the building to measure water flow rate, temperatures, and power draw. These measurements allowed us to perform timeseries assessment of heat transfer rates and efficiency for the domestic hot water system. One of the sixteen Ephoca AIO WM+ERV units at the Corona apartments was fully instrumented to measure supply, return, and ventilation air flow rates, air temperatures and humidities, as well as power draw. These measurements allowed us to perform timeseries assessment of heat transfer rates and efficiency for heating, cooling, and energy recovery ventilation.

We partnered with University of California, Davis's Western Cooling Efficiency Center (WCEC) on both demonstrations: at the Planada site where they led a separate study focused on load shifting with MFHPs, and at the Corona site specifically to perform detailed airflow and ventilation effectiveness testing on one of the Ephoca AIO WM+ERV units installed, the results of which informed significant system design revisions by the manufacturer. Additionally, despite abandoning installation of the R32 Genius unit at the Corona site, the research team continued to design and demonstrate the Thermaduct SoffitDuct that was intended to serve its distribution. Though not connected to anything, the SoffitDuct field installation demonstration allowed the research team to collect data on design challenges, pricing, and installation time that ultimately helped inform Thermaduct's product development.

Results

Through 4.5 years of research, development and demonstration, we identified what and where the studied MFHP systems archetypes are most applicable and in what ways they fall short, measured through real-world demonstrations in occupied multifamily apartments. The results shed light on the pain points and challenges for MFHP products as viable decarbonization retrofit solutions. We found that form factor and system component layout are two of the strongest determinants of whether a particular MFHP system is strategic for a multifamily retrofit, and MFHP systems come in a variety of form factors. MFHP products developed with specific retrofit applications in mind are most primed for market adoption and most likely to be successful retrofit solutions. The Villara AQTA is an example of a product designed for a specific common application. It slots in easily in the building typology for which it was designed, but would not be a good retrofit solution for an apartment with on-demand DHW and ductless HVAC, for example. In the following sections, we present data and findings to showcase the promise of and barriers for these MFHPs in multifamily retrofits.

Research Findings and Data

Through this research, we sought to evaluate the suitability of the three systems based on their installation cost, ease and speed of installation, and operational efficiency (seasonal COP). We compared these metrics across demonstration system type and with conventional systems, which consisted of a high-performance ducted HVAC heat pump, new ductwork, a unitary heat pump water heater (HPWH), and exhaust-only ventilation upgrades.[1] Assessment of these metrics help indicate the potential for these products as viable decarbonization retrofit solutions.

Installation time

We compared the installation time of the products demonstrated in the field to each other, and to a conventional retrofit, shown in Table 2. This comparison evaluates the speed of installation to understand whether these products could offer scalable retrofit solutions.

Table 2: Installation time per product demonstrated compared to conventional equipment.

Person-Hours per Install per Apartment	Apt 1 (hrs)	Apt 2 (hrs)
Conventional	**59**	
Split Direct Expansion (DX) Ducted HVAC Heat Pump	27	
HVAC Ductwork (attic)	8	
Unitary Tank-Type HPWH	8	
Exhaust-Only Ventilation	16	
Planada Site: Villara AquaThermAire	**44**	**86**
Villara AquaThermAire	44	66
AQTA Ventilation + Thermal Comfort	n/a	20
Corona Site: Ephoca AIO WM+ERV & SanCO_2	**65**	**61**
Ephoca AIO WM + ERV	23	21
Integrated Controls + Thermal Comfort	10	8
Exhaust Fans	8	8
SanCO_2 CHPWH	24[2]	
Corona Site: Thermaduct SoffitDuct	**40**	

A major caveat in quantifying installation time is the unknown amount of time associated with workforce learning for emerging technologies or a first-time install. For example, the contractor for the Planada site installed the two AQTA's with the same team a month apart. The first installation (Apt 2) took 86 hours, while the second installation (Apt 1) took nearly 50% less time. Despite the learning curve, the installation time of both MFHP retrofits took similar or less time than the conventional retrofit (Chakraborty et al. 2024). Similarly, the SoffitDuct was a first-of-its-kind installation, and displaced the need for extensive interior soffit construction – a common baseline approach that was not measured in our study.

Installation cost

We also compared the material and labor costs for the MFHP products demonstrated in the field, and to a conventional retrofit, shown in Table 3. This cost comparison provides an economic view to consider current market viability, though it is not exactly an apples-to-apples comparison because the different systems archetypes are at varying TRLs, and are each best suited to different applications; and because the tabulated costs are drawn from different sites, installed by different contractors, at different times.

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[1] This package of conventional mechanical retrofits was studied through one of EPC-17-040 REALIZE-CA's demonstration projects (Jiles 2024). Data is from a real retrofit project involving some of the same team members.

[2] SanCO_2 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.

Though we decided not to install the Systemair Genius, we 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 to install emerging technology. Considerable cost compression for the system and installation labor would be needed for it to be competitive. Even with such cost compression, the added infrastructure and space needed to incorporate this system type cannot be ignored. We did install the SoffitDuct, and confirmed it has considerable promise compared to conventional soffits to route ductwork, piping, and other services within conditioned space.

Table 3: Installed cost per demonstration product priced as compared to conventional equipment.

System Archetype System Subcomponent	**Material**	**Labor**	**Total**
Conventional - Measured[3]	**$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 Site: 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	$887
Corona Site: Ephoca AIO WM+ERV & SanCO$_2$ CHPWH	**$27,777**	**$23,836**	**$51,613**
Ephoca AIO WM + ERV	$17,575	$5,072	$22,647
Ephoca AIO WM Ancillaries[4] *(needed for install)*	$2,376	$7,756	$10,132
Integrated Controls + Thermal Comfort	$3,485	$8,870	$12,355
SanCO$_2$ CHPWH *(per apartment)*	$4,341	$2,138	$6,479
Planada Site: Villara AquaThermAire	**$19,868**	**$10,239**	**$30,107**
Villara AquaThermAire	$16,406	$4,735	$21,141

The room-by-room Ephoca AIO WM+ERVs and SanCO$_2$ CHPWH was also more expensive than the conventional approach, though they differ in: centralized versus room-by-room HVAC, ducted versus ductless HVAC, central versus unitary DHW, and balanced energy recovery ventilation versus exhaust-only ventilation. Energy recovery ventilation is a major feature provided by the Ephoca and Systemair solutions, but is missing from the AquaThermAire and conventional heat pump solutions. Additionally, post-retrofit surveys revealed that residents valued the room-by-room controls offered by the Ephoca systems. These and other benefits are not quantified in the accounting of costs in Table 3.

[3] The material and labor costs for the conventional installation are from an actual project whose retrofit was studied through another CEC EPIC project, CEC EPC 17-040 REALIZE-CA.
[4] Ephoca AIO WM ancillaries include existing equipment removal, running electrical and condensate, and waterproofing and other envelope integration measures.

Notably, the Villara AQTA and conventional heat pump retrofit strategy have very similar total installed costs. The AQTA equipment was $3,107 more expensive than the conventional approach; however, the AQTA labor was $1,656 cheaper. Villara priced the AQTA installation and was uniquely positioned as both the manufacturer and installation contractor, and so the pricing more likely represents "mature market" costs 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.

Overall, our observations indicate that there is likely opportunity for MFHPs like the AQTA to improve affordability for retrofit decarbonization in low-rise multifamily buildings with existing split-unitary ducted equipment, and unitary water heating. The other MFHP archetypes might also offer cost compression in certain scenarios, such as in certain new construction scenarios, or where existing conditions would prohibit the retrofit addition of unitary air handlers and unitary domestic hot water, where balanced energy recovery ventilation, or room-by-room zone control is desired. Regardless, such potential cost advantages will likely require reduced equipment and installation costs. This data indicates that cost compression for both material and labor is needed to achieve cost-parity or -reduction compared to conventional approaches, but this is possible for some products.

System performance

Next, we compared the performance of each system to understand system efficiency. We tested both R410A and R32 Systemair Genius systems in LBNL's testing chamber. Performance data comes solely from lab testing since we could not install the equipment in the field, and using the federal testing standards for individual systems since federal testing standards do not exist for MFHPs. Table 4 summarizes the performance metrics, showing that the Systemair Genius did not meet the stated efficiency goals or the federal minimum efficiency standards.

Table 4: 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[5]

EER = energy efficiency ratio; gpm = gallons per minute

Conversely, the equipment demonstrated in the field (Villara and Ephoca) did not undergo lab testing, and for this reason, we used seasonal COP per mode of operation as the

[5] 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.

efficiency metric for field testing. Table 5 summarizes the performance of the demonstration equipment when operating in occupied apartments.

Table 5: Seasonal coefficient of performance measured in the 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 + Water Heating	1.52[6]	1.22
Ephoca AIO WM + ERV		
Space Heating	None Measured[7]	
Space Cooling	2.30	
$SanCO_2$ CHPWH	3-4[8]	

Overall, the equipment COPs measured in the field were lower than we expected and lower than the equipment's respective ratings in a controlled laboratory environment (Chakraborty et al. 2026). Calculating COP per mode of operation in a MFHP was also challenging because timeseries measurements of various thermal energy flows, and electric energy uses, had to be carefully disaggregated. This was particularly challenging for the Villara AQTA's water heating functionality since water heating and hot water use are not coincident. It was also challenging for determining the COP of "simultaneous cooling + water heating" mode– this metric actually reports the efficiency of space cooling while using the water heating tank as a heat sink, and does not credit the value of thermal energy transferred to domestic hot water. However, since there is not a clear way to determine what portion of the thermal energy measured for DHW use arises from operation in one mode or another (because use and generation are non-coincident), all of the thermal energy transferred to water heating in the "simultaneous cooling + water heating" mode is counted in the COP for water heating.

Technical, Market and Policy Barriers

We identified several technical, market and policy challenges that present barriers to broader adoption of low-GWP MFHP systems. The following summarizes the barriers we encountered.

Technical and market barrier: space constraints in affordable multifamily housing

Space for mechanical equipment is often very limited in multifamily housing, which presents a major technical challenge and market barrier for System Archetype #1, which has a large contiguous footprint, especially when equipment clearances are considered. Although interior or exterior mechanical closets are common (present at both the Corona and Planada demonstration sites) they are usually sized for smaller conventional equipment, or are not located appropriately to accommodate this central mechanical pod. At the Corona site, we designed and

[6] The COP values in both apartments represent the COP for space cooling, while in Simultaneous mode, and do not account for the benefits provided to DHW.
[7] No space heating events were captured from the monitored Ephoca AIO WM-ERV unit during the monitoring period mid-April 2024 through early-January 2025.
[8] 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.

constructed a custom10’x7’ mechanical shed in the outdoor patio space to house two Genius units. This shed cost an additional $22,008 and deprived the households of a significant portion of their outdoor space. At the same time, the closet that housed the old furnace was sealed off and became an empty cavity in the wall. In rare cases, apartments are located over garage or storage space, which could facilitate the use of this system type. Although there may be some strategic opportunities, since the form factor differs significantly from any conventional mechanical equipment, there is almost no opportunity to reuse existing mechanical spaces, or mechanical distribution pathways, so incorporation of this system type must sacrifice other valuable space, and construct new distribution systems to reach the chosen equipment location. The lack of an outdoor rated enclosure significantly limits siting options for the product tested.

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 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 conducted at the Corona site 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 4.

Contrary to the space constraints and lost value at the Corona site, the Villara AQTA system was very easy to install at the Planada site. 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. Those challenges were minor and overall, the design and installation were easy, and space was 100% effectively reused without any forfeit from the resident. The flexible design of the AQTA can allow for locating components in places like a mechanical closet or an attic, and its form mimics conventional split unitary heat pumps or A/Cs, and unitary water heaters, so it can take advantage of spaces originally designed around that equipment type.

Technical design challenges for all-in-one-box MFHP systems

System Archetype #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 they do not fit in typical mechanical system locations in this residential market.

System Archetype #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 to terminate at a single location, which creates both space and routing challenges. Depending on the layout of the duct connections on the equipment itself, it can be very difficult to efficiently route ductwork. Additionally, re-routing MEP distribution to one single location that is different from where mechanical equipment existed before demands invasive rework to existing infrastructure to accommodate such connections. Complying with code that requires 10ft of clearance between fresh air inlet and exhaust outlet exacerbates these challenges (ASHRAE 2010).

At the Corona site, major design challenges arose in locating, housing, and orienting the equipment, then routing ductwork, electrical, and plumbing. The design exercise resulted in a “ductwork medusa” as shown in Figure 5. The system demanded more space to accommodate this web of ductwork and ensure it met the re-entrainment standards defined by code. The challenges associated with routing electrical, plumbing, and ductwork within the conditioned space led us to develop and demonstrate the Thermaduct SoffitDuct product, which provided a low-profile, and easy to install solution that satisfied all distribution needs. The installation contractor at the Corona site commented that the product was very easy to work with and install.

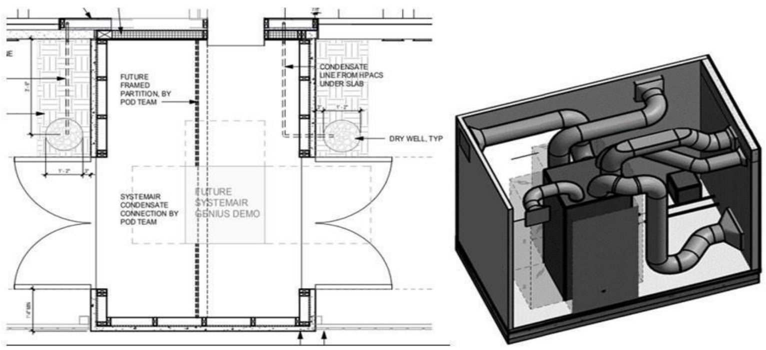

Figure 5: Mechanical pod shed design showing larger space needed for clearances and connections (left) and "ductwork medusa" created by all MEP connections being made at one piece of equipment (right). Credit: SmithGroup, Introba

Impact compact design has on efficiency

The design of compact heat pump systems can be at odds with goals to improve system efficiency. Higher efficiency heat pumps require larger heat exchangers, larger vapor compression system components, and larger lower pressure drop air pathways. Careful design of heat pump equipment in MFHPs is critical when combining multiple end uses into one system, particularly into one box. Figure 1 shows how tightly the heat pump componentry is packed into the Systemair Genius’s heat pump module, a contributing factor to its low efficiency.

Our performance monitoring at the Corona site suggests that design of the Ephoca AIO WM+ERV also compromises efficiency in exchange for a more compact footprint. 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. In the balance, we cannot help but observe that despite reaching for compact design, MFHP strategies still impose undesirable space constraints.

Low natural occurrence of coincident cooling and water heating demand

One of the key selling points for certain MFHP archetypes is the potential efficiency benefits associated with recovering waste heat from cooling to generate domestic hot water. In theory, the total thermal energy in waste heat from cooling for a residence exceeds the thermal energy needed for domestic hot water. However, there are many factors that make it difficult to recover this waste heat in practice. For one, the natural demand for space cooling and water heating are generally not simultaneous. For the AQTA, the “simultaneous space cooling + water heating” mode was initiated only when there was both a call for space cooling from the thermostat, and a call for water heating from the aquastat – and this occurred infrequently. As tabulated in **Error! Reference source not found.**, across the cooling season (April – October) the AQTA only operated for 18.4% of the hours; 52.2% of the operating hours were for space cooling, 13.1% of the hours were for water heating, but space cooling and water heating needs only intersected for 4.8% of the hours. Consequently, only a minor fraction of the domestic hot water was sourced from cooling waste heat, and an even smaller fraction of the cooling waste heat was captured.

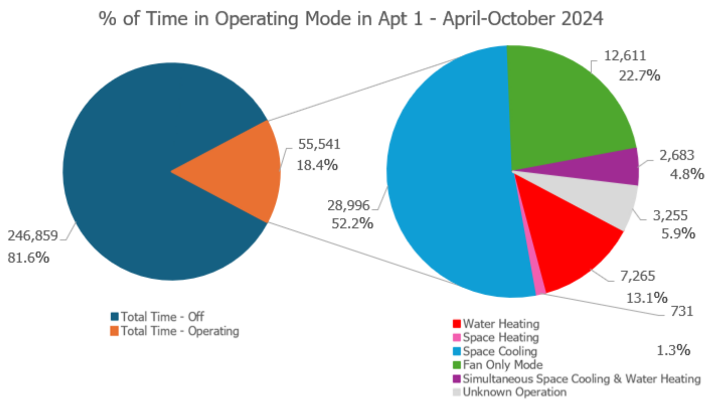

Figure 6: Minutes and percent of time per operating mode of Planada site's Apt 1 AQTA, April to October 2024.

It is likely that future MFHP could improve efficiency through waste heat recovery, but innovations with system architecture and control are critical to ensure that cooling waste heat can be captured effectively, and without compromising the efficiency of cooling.

Introduction of potential envelope inefficiencies with room-by-room solutions

Room-by-room combined HVAC solutions, such as the Ephoca AIO WM+ERV system, could potentially offer certain energy and cost savings opportunities.[9] However, there are some drawbacks to this HVAC configuration, the most prominent of which is the number of envelope penetrations required. The efficiency impact of these penetrations was quantified at the Corona site 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, we conducted both types of blower door tests again after taping all HVAC penetrations to mimic an uninterrupted envelope and eliminate the air leakage at that interface. The results of these comparative tests are shown in Table 6.

Table 6: Whole-building air leakage testing results with and without HVAC penetrations at Corona site.

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

Source information: UC Davis WCEC; ACH50 = air changes per hour at 50 pascals

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. We do not anticipate missing

9 Post-retrofit resident survey conducted at the Corona site on October 11, 2024, and November 6, 2024.

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 that does not compromise envelope air boundary integrity.

Refrigerant safety and leak potential

With the introduction of A2L refrigerants in split direct expansion systems, the prospect of a refrigerant leak is not only an issue of performance and climate pollution, but also one of safety. Partially-packaged MFHPs that have a split unitary system architecture with separate modules connected by refrigerant piping, like the Villara AQTA (System Archetype #2), have greater likelihood and consequences of an A2L refrigerant leak than do packaged, factory-charged systems, because all refrigerant charging and maintenance occur in the field. The inherent risk of refrigerant leakage from a MFHP like the AQTA is even greater than that of a typical split unitary heat pump because of the additional tank and complicated refrigerant circuit (several solenoid valves and other fittings for refrigerant path management in each mode), and the field installed portions require extensive network of refrigerant piping for the heat exchanger in the water heating tank, multiple refrigerant linesets, and multiple field installed joints.

One AQTA system installed at the Planada site experienced several refrigerant leaks during the field demonstration. Our monitoring data indicated poor performance, which empowered us to have the contractor investigate, identify and fix refrigerant leaks and also tune the expansion valve and charge volume to improve system performance. Refrigerant leaks at this system occurred multiple times. To address the first leak, the contractor added to the existing refrigerant charge. Monitoring data indicated refrigerant pressure and temperatures that did not make sense psychometrically for R454b. The contractor returned to vacuum out existing refrigerant and fully recharge the system anew, as R454b is an azeotropic refrigerant and partially recharging the refrigerant circuit likely led to a change in the refrigerant's composition. After the contractor fully removed and recharged the refrigerant circuit, we observed clear performance improvements. In general, in addition to the flammability risks associated with A2L refrigerants, the intersection between increased leak potential associated with multi-branch split unitary heat pumps and the use of azeotropic refrigerants demand consideration for associated risks of A2L refrigerants in these system configurations.

Complexity of system controls and operation

MFHP systems often have more complex controls and operating sequences than conventional 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 the Corona site, residents reported being confused about when to use the wall-mounted thermostats (used to facilitate central control of heat pumps and integration with ceiling fans) versus the Ephoca AIO's onboard controls. 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 in fear of utility bill increases. We provided tenant education materials, but follow-up was limited so it was difficult to determine what impact the educational materials may have had.

Lack of an MFHP product test standard

There is currently no testing standard, system performance standard, or dedicated compliance pathway for MFHP systems, and it could be challenging to create a singular test standard that is flexible enough to characterize and compare the many types of MFHP. This made lab testing challenging in this project. Lack of clear compliance pathways means that potential performance benefits for MFHPs are not measured or quantified adequately.

We tested the SystemAir Genius at LBNL using the 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 impacted the test results. A more relevant test procedure would account for the multi-function nature of the machine, and measure efficiency of providing the multiple services at once.

Reality Check on the Promise and Application of MFHPs

Our five years of laboratory and field research suggest that MFHPs are not a one-size-fits-all cost-saving alternative for conventional heat pumps, but rather a set of emerging strategies that may solve specific retrofit problems in specific buildings. Across the three archetypes we studied, the potential advantages were real: consolidating multiple end uses, reducing some coordination burdens, enabling balanced ventilation or room-by-room control, and providing a foundation for heat recovery and load shifting. At the same time, each archetype introduced its own drawbacks relative to conventional heat pump retrofits, including higher installed cost, siting constraints, controls complexity, envelope or refrigerant leak risk, and, at least for the products we studied: lower-than-expected measured performance. The balance of these tradeoffs depended strongly on building conditions and system architecture.

Our demonstrations showed that form factor and compatibility with existing conditions are decisive. The Villara AquaThermAire fit the Planada apartments well because it reused the existing mechanical location, ducts, and much of the electrical and plumbing infrastructure; its installed cost was close to the conventional retrofit benchmark. In contrast, the Systemair Genius illustrated the limits of the all-in-one pod approach for typical low-rise multifamily retrofits: its footprint, clearance requirements, and need to bring all ductwork, plumbing, and electrical to one location created major siting and routing challenges, and required costly added infrastructure. The Ephoca room-by-room strategy solved different problems by avoiding central duct distribution and offering zonal control with integrated ventilation, but it also consumed interior space, constrained furniture layout, required extensive electrical work, and required careful detailing of wall penetrations to avoid significant envelope leakage.

The measured performance results also caution against assuming integration automatically improves efficiency. In theory, MFHPs can capture waste heat, reduce redundant equipment, and coordinate end uses more effectively. In our study, however, none of the tested systems clearly delivered those expected gains. The Systemair Genius did not meet the stated efficiency goals or federal minimum efficiency standards in laboratory testing. The Villara AQTA and Ephoca systems operated in the field with seasonal COPs that were generally lower than expected. For the AQTA, simultaneous cooling and water-heating occurred infrequently, limiting the practical benefit of heat recovery. These findings suggest that the efficiency promise of MFHPs remains possible, but is not yet realized reliably in currently available products.

Taken together, our results indicate that the MFHP market is promising but still maturing. Some system types appear better suited to affordable multifamily retrofits than others, while some may be more appropriate in new construction or less space-constrained buildings than in.

Early adopters should therefore apply these technologies thoughtfully, where they solve real design or retrofit constraints that conventional systems do not address well. Continued progress will require better workforce training, installation best practices, commissioning procedures, tenant and operator education, more robust controls, and clearer test and compliance pathways. MFHPs merit continued attention and development, but our experience suggests that successful deployment will depend on careful matching of technology to building type, rather than assuming that packaging and integration alone produces better outcomes.

References

ASHRAE Standing Standard Project Committee 62.2. ASHRAE Standard 62.2-2010, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, Section 6.8. 2010. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Chakraborty, Subhrajit, Morgane Gaucher, Meghan Duff, Scott Adler, and Jonathan Woolley. 2024. "Can Multi-Function Heat Pumps with Low-Global Warming Potential Refrigerant Effectively Decarbonize Heating for Low-Income Homes?" In ACEEE 2024 Summer Study in Buildings. https://escholarship.org/uc/item/2fq1m263.

Chakraborty, Subhrajit, David Vernon, Matthew Ellis, and Vinod Narayanan. 2026. "Experimental Investigation of Air-to-Air Multi-Function Heat Pump across Operating Modes." Applied Thermal Engineering 298 (June): 130894. doi:10.1016/j.applthermaleng.2026.130894.

Intergovernmental Panel on Climate Change (IPCC) (2021) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by V. Masson-Delmotte et al. Cambridge: Cambridge University Press. https://doi.org/10.1017/9781009157896.

Jiles, Nick, Brett Webster, and Martha Campbell. 2024. Mass Deployment of Energy Efficiency Retrofits in Multifamily Homes in California. California Energy Commission. Publication Number: CEC-500-2025-028.

M. Modera, J. Woolley, B. Dakin, M. Koenig. (2014). One machine for heating, cooling, and domestic hot water: multi-function heat pumps to enable zero net energy homes. ACEEE 2014 Summer Study on Energy Efficiency in Buildings. American Council for an Energy-Efficient Economy.

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.

Tomlinson, J.J., C.K. Rice, and E. Baskin. 2005. "Integrated Heat Pumps for Combined Space Conditioning and Water Heating." 8th IEA Heat Pump Conference.