Bay Area Regional Energy Network (BayREN)

BayREN Existing Buildings Study

Energy Conservation Measure Analysis Methodology (Task 4)

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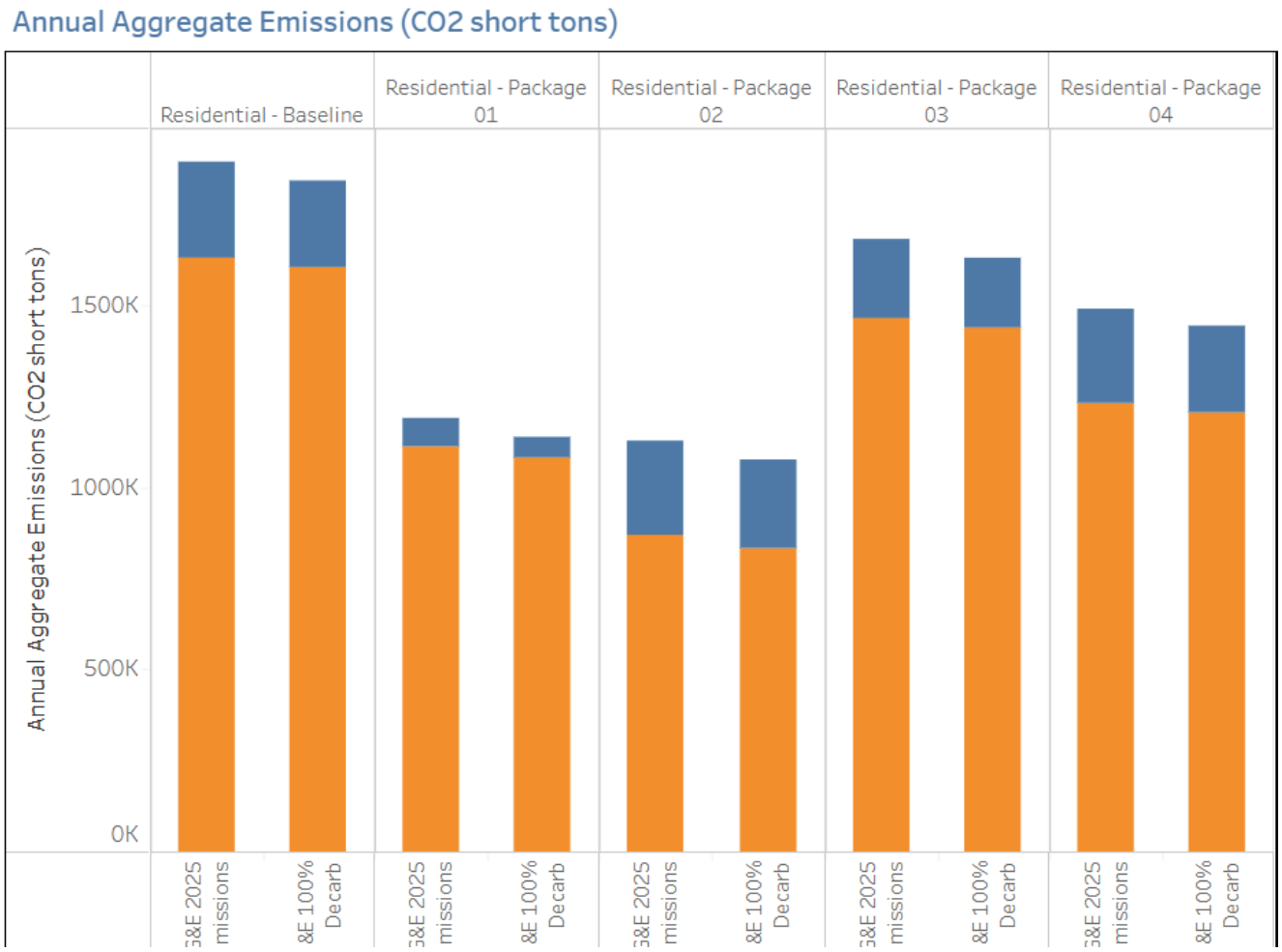

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1. Introduction

The BayREN Existing Buildings Dashboard provides a portal for understanding existing building quantity and characteristics across all Bay Area counties and cities. The dashboard is intended to enable local jurisdictions to understand their building stock and identify common challenges and opportunities for decarbonizing their buildings. The dashboard is the most comprehensive high-level representation of the Bay Area building stock to date, reporting estimates for building type, vintage, rent/own, and average building Energy Use Intensity (EUI) at the jurisdiction level.

The dashboard was originally built in mid-2024 to provide an overview of existing buildings and energy use by use type, age, ownership, and jurisdiction. In 2025, the dashboard was updated to include energy conservation strategies applicable to each building type and their impact on energy use and greenhouse gas (GHG) emissions. The goal of the decarbonization measures is to identify the highest impact strategies to achieve zero operational carbon buildings. The data is filterable by jurisdiction and category to support users in city and county agencies to develop programs and support strategies that move furthest toward this goal.

Data in the dashboard is compiled from various sources and uses energy modeling to provide estimated emissions impacts. It builds on the data sources and processes documented in the Existing Building Characterization Report and the Additional Building Characteristics Report. This document provides an overview of data presentation in the dashboard and summarizes the methodology and data sources used to build the decarbonization measure impacts into the Existing Building Dashboard.

2. Dashboard Overview

The Bay Area Existing Buildings Dashboard is built in Tableau and available in a web-based interface on the BayREN website. The dashboard function and suggested use cases are noted in the sections below.

2.1 Dashboard Function and Use

Carbon and energy impacts from efficiency and electrification measures are summarized in a new tab on the dashboard titled “Decarbonization Strategies.” Similar to prior tabs on the dashboard, the tab allows for the user to select a single or multiple counties or cities to view the resulting data. Selections are made via dropdown menus, and multiple sections can be used to view a selection of cities. Beyond jurisdiction selection, data is parsed to use category (Residential or Commercial) prior to making other selections. Once residential or commercial is selected, further refinement is available based on building use types or years built. In all cases other than residential and commercial, multiple or single selections are supported to allow customized viewing of the data.

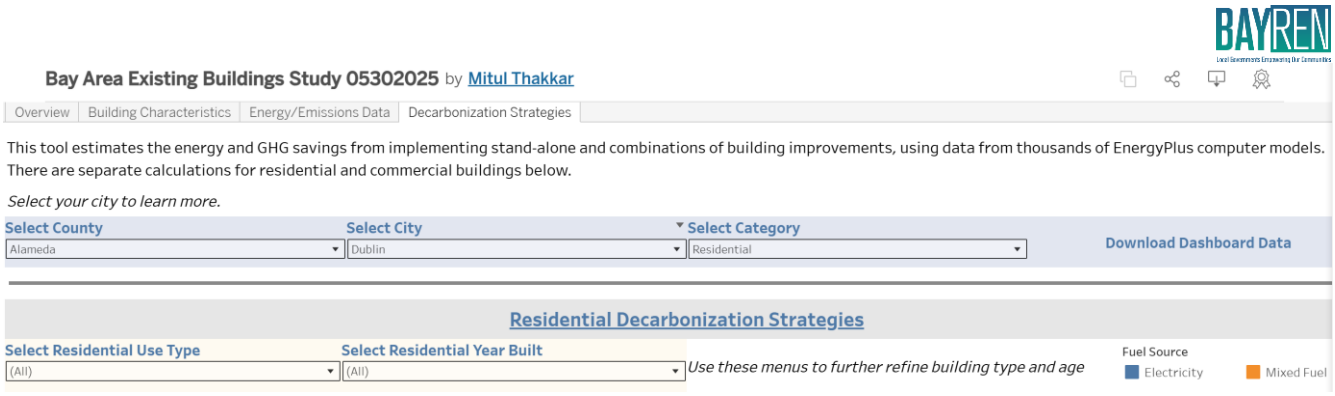

Figure 1: Dropdown menus on the Tableau interface for the Decarbonization Strategies tab. The Use Type is selected to show how sub-options can be selected. Selection is made by checking or unchecking the box next to the appropriate category.

Once jurisdiction(s), residential/commercial, building type(s), and year(s) are selected, two graphs populate with the combinations of decarbonization strategies that are most impactful for reducing emissions and energy. These are compared to a baseline scenario which represents building performance and emissions today. These are intended to provide an immediate summary of the greatest potential for energy and emissions reduction. In addition to the charts, a table above shows the water heating, heating/cooling, appliances, envelope, and lighting upgrades that contribute to the top combinations of measures.

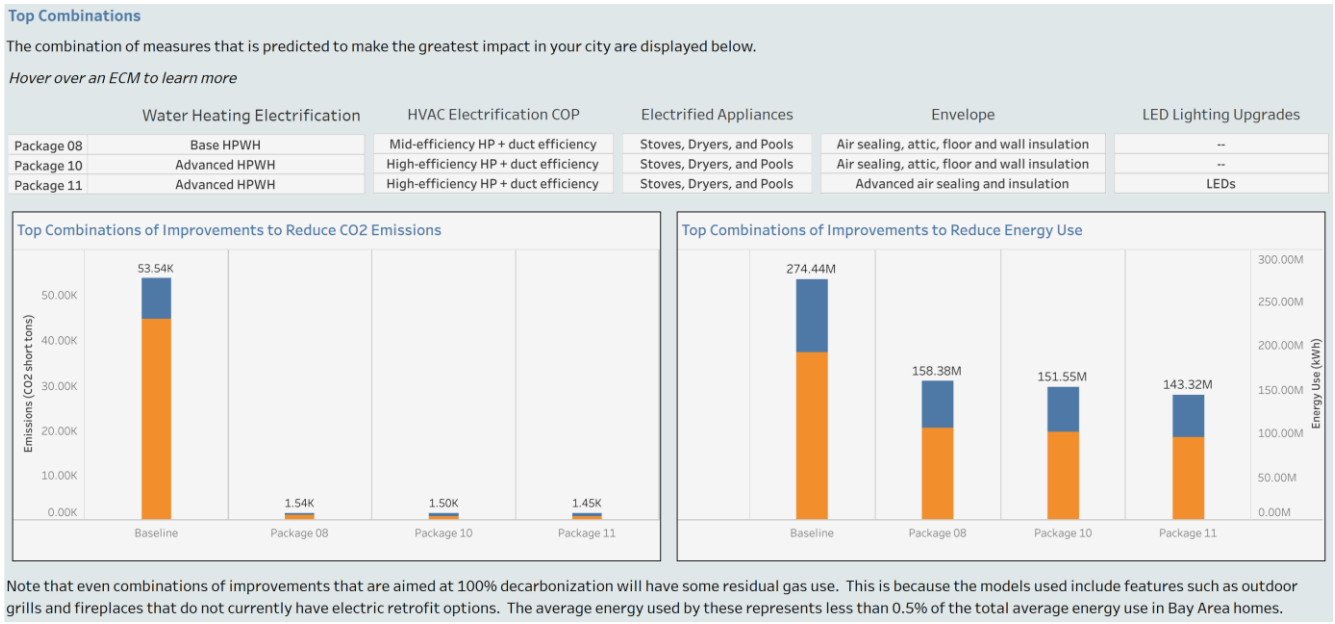

Figure 2: Top decarbonization strategy graphs on the dashboard.

Below these graphs are two filters, which allow for further selection of measure packages to investigate impact. Two drop down menus allow for selection of additional characteristics by which to review data. These are intended to be selected in order. The first slicer allows for review of data based on the package focus. These include maximizing emissions reduction, minimizing energy use, prioritizing light touch envelope improvements, or viewing equipment upgrades as stand-alone measures. The second drop down allows for selection of one or more of the resulting packages that meet the first objective. The intent of these selections and graphs is to facilitate comparison of the measure combinations and selection of specific packages for further comparison at user's discretion.

Below the graphs, a table provides the description of each package, with the relevant characteristics of the packages for water heating, appliances, heating and air conditioning (HVAC), envelope, and lighting in blue text. Gray text means the packages do not contain that selection.

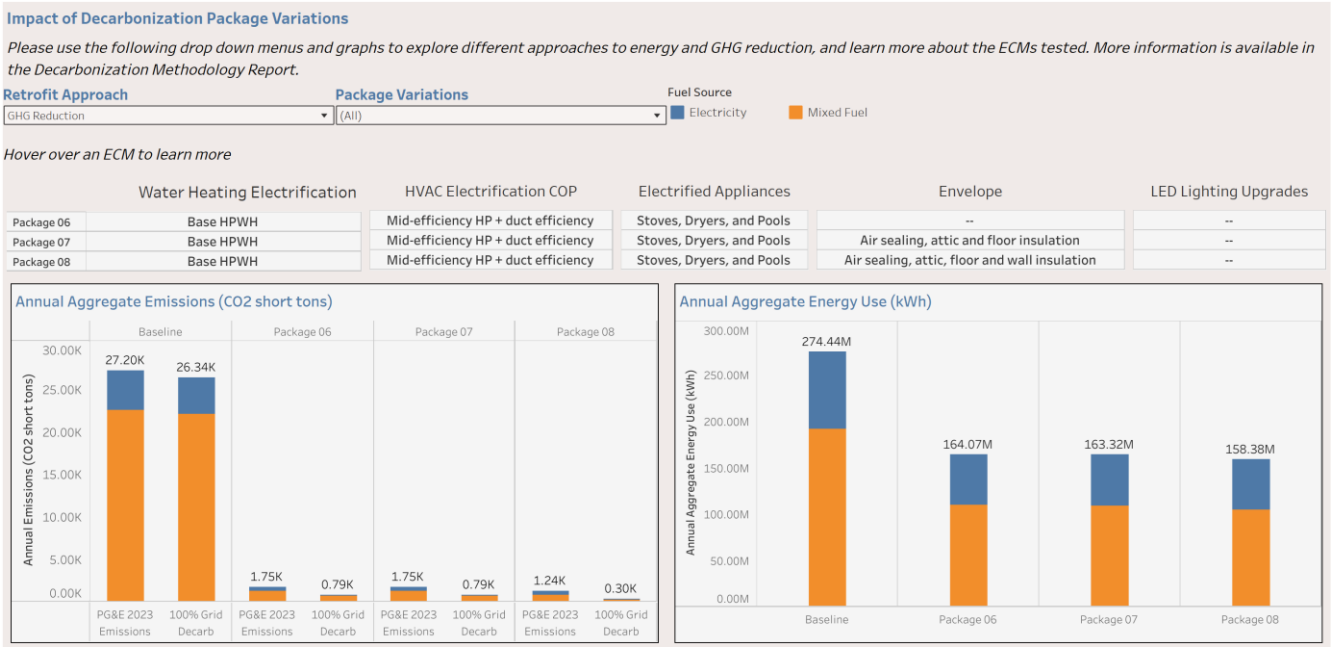

Figure 3: Comparison viewer of packages across multiple objectives with the first selection menu visible.

In all graphs, the column charts indicate the portion of energy and emissions that are attributable to electricity and mixed fossil fuels. Notably, in the Bay Area the mixed fossil fuels are over 97% natural gas with limited propane for remote and mobile buildings. Additionally, the columns show how the emissions differ with the 2023 Pacific Gas and Electric (PG&E) carbon content of 12 lbs CO2 per MWh[1] and a future where all electricity is decarbonized (equivalent to 0 lbs CO2 per MWh). This impacts emissions only; energy use is unimpacted by the source of energy.

In all packages, lingering natural gas consumption is present. This is explained in greater detail in the sections that follow but is due to hard to decarbonize end uses in residential buildings for which electrification measures were not evaluated, such as gas fireplaces and outdoor barbecues.

The final section of the dashboard is the numeric data. This provides a view of all data captured in the graphs based on the selections. Data can be copied from the web interface or downloaded to a Comma Separated Value (.csv) or Excel format using the download icon in the upper right of the page.

County	City	Building Us..	ECM Package	Emissions (CO2 short tons)	Residential Energy Use (kWh)	Avg. Total EUI (kBtu/sf)
Alameda	Unincorporated	Mobile homes	Baseline	1k	15M	48
			Package 01	1k	12M	40
			Package 02	1k	12M	40
			Package 03	1k	14M	47
			Package 04	1k	13M	44
			Package 05	1k	12M	40
			Package 06	0k	8M	29
			Package 07	0k	8M	29
			Package 08	0k	8M	28
			Package 09	1k	14M	45
			Package 10	0k	8M	27

Figure 4: Data table example for emissions and energy use.

[1] https://www.pge.com/assets/pge/docs/account/billing-and-assistance/bill-inserts/1224-power-content-label.pdf

3. GIS Data Integration

The dashboard summarizes data from all parcels in the nine counties of the San Francisco Bay Area. Data is compiled at a parcel level from a variety of sources and aggregated at the county and city level within the dashboard. This is described fully in the Existing Building Characterization Report dated October, 2024, and summarized briefly in this section for completeness.

3.1 Energy Model and GIS data integration

The following overarching workflow was applied to aggregate and derive relevant building characteristics and estimate baseline building energy use intensity and emissions. This approach is noted in the following sections, with additional process flow diagrams for key steps of the process.

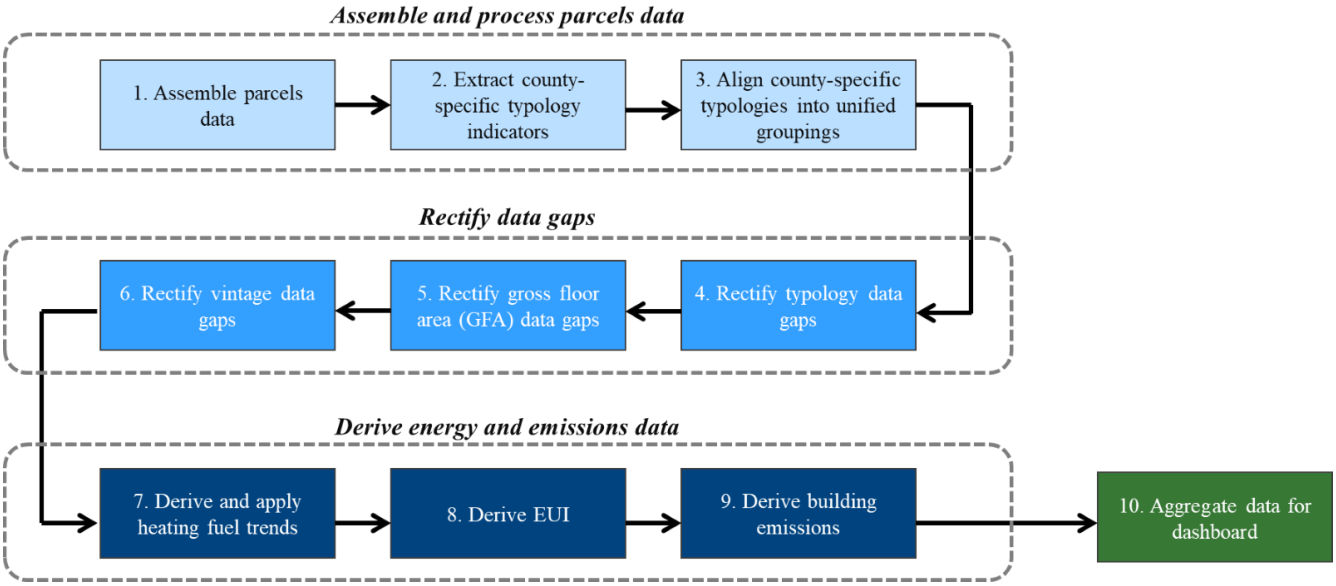

Figure 5: Overview for aggregating energy and emissions data for the dashboard from parcel data

To appropriately derive energy use intensity (EUI) and building emissions, parcel characteristics are matched to a prototype energy model that represents the particular use. Energy models follow those created by the National Renewable Energy Laboratory (NREL) for the ResStock2 and ComStock3 databases. These two databases are intended to represent a full range of representative building types in the national building stock.

ResStock and ComStock include estimates of energy conservation measure impacts including electrification. Measures are tailored to individual building types and construction typologies. This allows for a single measure to encompass a range of representative buildings. For instance, insulating residential home walls to an R-15 standard applies only to homes in the database with less than R-15 as the starting condition, and assumes different wall insulation construction for stud walls, brick walls, and other common constructions. This ultimately impacts the expected performance of each prototype.

In the Bay Area Existing Buildings dashboard, each use type is mapped to a distribution of construction types based on age, size, climate zone, and use. This distribution allows for statistically representative aggregation of the impact of an energy conservation measure on the population of buildings with the starting characteristics. More documentation on this process is further in this report, in the Existing Building Characterization Report dated October, 2024, and can be found at the NREL ResStock and ComStock websites.

4. Residential Energy Conservation Measure Methodology

The residential energy conservation measures (ECM) analyzed for the dashboard were based on consultation with BayREN staff and are intended to reflect common interventions to improve efficiency and electrification. Tailoring model findings from ResStock required additional processing of data to ensure accuracy for the Bay Area building types and climates. Details of the post-processing activities are covered in Appendix A.1 and Appendix A.2. This section presents the measures selected and the details of their implementation.

4.1 Residential Building ECMs Selected for BayREN Analysis

Selected residential ECMs were chosen from a list of available measures in ResStock. The intent of selected measures was to identify common electrification approaches and efficiency interventions, which support managing potential energy cost impacts of electrification. Appliance efficiencies were reviewed and compared against minimum requirements for California standards and program incentives. Only those that met or exceeded these requirements were included.

The measures selected are listed and described below. Each is applied to the building prototypes in ResStock based on the construction characteristics in the prototypes as noted in the last column of the table.

Table 1: Energy Conservation Measure Details and Applicability

Grouping	Measure	Details	Applicability
DHW	Standard HPWH	Replace all residential water heating with standard HPWHs (UEF 3.35)	Applies to any home that does not use a HPWH with UEF 3.35+ for water heating
	Advanced HPWH	Replace all residential water heating with heat pump water heaters (UEF 3.8)	Applies to any home that does not use a HPWH with UEF 3.8+ for water heating
HVAC	Mid-efficiency HP + duct efficiency	Replace all residential HVAC systems with a mid-efficiency heat pump (SEER 16, HSPF 9.5) with electric resistance back up heating.	Applies to any home that does not use a more efficient heat pump for heating.
		Seal all duct systems to 10% leakage and insulate ducts to R-8 in unconditioned space.	Applies to any home with leakier and/or less-insulated ducts in unconditioned spaces
	High-efficiency HP + duct efficiency	Replace all residential HVAC systems with a high efficiency heat pump (SEER 20, HSPF 11) with electric resistance back up heating.	Applies to any home that does not use a more efficient heat pump for heating
		Seal all duct systems to 10% leakage and insulate ducts to R-8 in unconditioned space.	Applies to any home with leakier and/or less-insulated ducts in unconditioned spaces
Appliances	Electrified	Replace all residential gas or propane clothes dryers with electric clothes dryers, CEF 3.93.	Applies to any home with gas or propane clothes dryers.
		Replace all indoor gas or propane ranges and ovens with electric resistance ranges and ovens.	Applies to any home with gas or propane ranges or ovens.
		Replace all gas pool and spa heaters with electric resistance pool and spa heaters.	Applies to any home with gas pool or spa heaters.
Envelope	Light upgrade	Insulate attic floor to R-49.	Applies to any home with a vented attic and less than R-49 attic floor insulation.
		Seal vented crawlspaces.	Applies to any home with a vented crawlspace.

		Insulate foundation wall to R-10 or floor cavities to R-19.	Applies to any home without foundation wall or floor insulation.
		Reduce air leakage by 30%.	Applies to any home with greater than 10 ACH50.
	Medium upgrade	All "light" upgrades	All "light" applicability
		Insulate wall cavities to R-13.	Applies to any home with uninsulated wood stud walls.
	Advanced upgrade	All "medium" upgrades	All "medium" applicability
		Insulate attic floor to R-49 or roof assembly to R-30	Applies to any home with a finished attic or cathedral ceiling and less than R-30 roof insulation.
		Replace windows with U-factor 0.28 windows	Applies to any home with less than R-19 wall insulation
		Add R-5 continuous exterior wall insulation	Applies to any home with window U-factors more than 0.28.
		Reduce air leakage to 3 ACH50	Applies to any home with greater than 3 ACH50.
		Install exhaust ventilation	Applies to any home that does not have mechanical ventilation.
Lighting	LEDs	Replace all non-LED lighting with LEDs	Applies to any home with less than 100% LED lighting.

To model the impact of these measures on the Bay Area building stock, the team used ResStock version 2024.1. ResStock 2024.1 includes 2.2 million building energy models. About 47,000 of these are relevant to representing the existing conditions of the 3 million homes in the Bay Area. ResStock 2024.1 also includes 55 distinct ECMs that provide electrification for heating, water heating, and appliances as well as envelope and lighting efficiency. Combinations of these measures result in 260 ECM packages for each baseline model.

The ResStock ECM packages and underlying equipment distribution did not perfectly align with the desired BayREN analysis packages, so the ResStock data was post-processed and combined to achieve the desired measure packages. Appendix A.1 Residential Package Post-Processing describes the post-processing methodology. The “BayREN Residential Packages” section in Appendix A.1 includes details about each BayREN package and the measures included in them. The following sections summarize the specific characteristics and measures that were used and modified.

4.1.1 HVAC Electrification

The data sources used by ResStock to determine which homes have air conditioning in the national building stock were deemed not granular enough to represent the geographic differences in air conditioning presence across the Bay Area, so the team used data from 2019 California Residential Appliance Saturation Study (RASS 2019) to determine air conditioning saturation. This is critical for understanding the impact of replacing existing HVAC systems with heat pumps.

4.1.1.1 Heat Pumps

Based on the team’s experience with heat pump retrofits in the Bay Area, the analysis uses the mid-efficiency heat pump retrofit for most packages and the high-efficiency heat pump retrofit for the advanced decarbonization packages.

There are two types of heat pumps used for the retrofits:

- Centrally ducted air-source heat pumps (“ASHP, Ducted”) – these systems replace existing HVAC systems that have ducts in ResStock

- Ductless mini-split heat pumps ("MSHP, Ductless") – these systems replace existing HVAC systems that do not have ducts in ResStock

Each ResStock heat pump can either use the existing baseline heating system for backup or use an electric resistance backup coil. Since the goal of this analysis is to show 100% electrification, BayREN requested the use of the second option for all heat pump retrofits, the electric resistance backup coil.

4.1.1.2 Shared HVAC

ResStock does not provide HVAC retrofit options for shared HVAC systems, such as central boiler heating in multifamily buildings. For ResStock homes with shared HVAC systems, the team used engineering calculations to model a ductless mini-split heat pump retrofit.

4.1.2 Water Heating Electrification

ResStock only offers one HPWH retrofit measure, a standard efficiency HPWH with a Uniform Energy Factor (UEF) of 3.35. To account for more advanced HPWHs with UEFs of 3.8, the team ran and compared EnergyPlus models with different HPWH efficiencies and used the results to adjust the ResStock water heating energy. The team found that the advanced HPWHs use about 12% less water heating energy than the standard efficiency HPWHs.

4.1.3 Electrified Cooking

This study assumes that gas stoves are replaced with conventional electric resistance stoves to be conservative. However, Although induction stoves are slightly more efficient than electric resistance stoves, the overall energy use of electrical cooking equipment only represents an average of less than three percent of total household energy in the Bay Area. So, the energy and GHG results would look very similar if the analysis used induction stove replacements instead.

4.1.4 Envelope Improvements

Duct Sealing and Insulation

ResStock upgrade packages include duct sealing and insulation measures, but they are paired with other envelope insulation measures. Since HVAC retrofits in California typically require homes to also make duct leakage and insulation improvements, the team decided that it would be more appropriate for the duct efficiency retrofits to be included with any heat pump retrofit packages instead of envelope improvement packages. The team used engineering calculations and assumptions to account for duct efficiency measures in the heat pump retrofit heating and cooling energy savings.

Foundation Insulation

The least invasive ResStock envelope improvement package, "Light Envelope Upgrade," only includes air leakage reduction, attic insulation, and duct efficiency measures, whereas the "Medium Envelope Upgrade" also includes foundation and cavity wall insulation. The team determined that adding cavity floor insulation is generally easier than cavity wall insulation. Floor and foundation insulation impacts are therefore included with the "Light Envelope Upgrade" used in the BayREN analysis.

4.2 Residential Building Packages

The residential analysis focuses on the impacts of eleven measure packages selected in consultation with BayREN staff. The goal of these packages is to understand the impact of individual system electrification or efficiency, such as standalone heat pump retrofits or envelope-only retrofits, as well as total electrification retrofits with different levels of mechanical and envelope efficiency improvements. The following table summarizes these packages. The "Applicability to Bay Area" column shows the percentage of Bay Area homes thatin the Bay Are would receive the retrofit package based on the building type and existing equipment in the home.

Table 2: Residential Packages Used in BayREN Analysis

Package Number	DHW	HVAC	Appliances	Envelope	Lighting	Applicability to Bay Area
1	Standard HPWH					99%
2		Mid-efficiency HP + duct efficiency				97%
3			Electrified			67%
4				Medium upgrade		88%
5		Mid-efficiency HP + duct efficiency		Light upgrade		97%
6	Standard HPWH	Mid-efficiency HP + duct efficiency	Electrified			99%
7	Standard HPWH	Mid-efficiency HP + duct efficiency	Electrified	Light upgrade		99%
8	Standard HPWH	Mid-efficiency HP + duct efficiency	Electrified	Medium upgrade		>99%
9				Light upgrade	LEDs	91%
10	Advanced HPWH	High-efficiency HP + duct efficiency	Electrified	Medium upgrade		>99%
11	Advanced HPWH	High-efficiency HP + duct efficiency	Electrified	Advanced upgrade	LEDs	>99%

5. Commercial Energy Conservation Measure Methodology

The commercial building energy conservation measures (ECM) analyzed for the Bay Area Existing Buildings dashboard were chosen with consultation from BayREN staff. They represent common categories of measures to improve the efficiency and electrification of buildings. This section details the selection of measures and key characteristics for modeling.

5.1 Commercial Building ECMs Available in ComStock

NREL's ComStock 2024.1 dataset includes 26 distinct energy conservation measures (ECMs) and 5 packages of said measures. Commercial ECMs can be broadly categorized as follows:

- Envelope: Measures focused on upgrades to exterior roofs, walls, and glazing
- Interior equipment & lighting: Measures related to kitchen equipment (where applicable) and lighting upgrades
- Enhanced HVAC components & controls: Measures related to demand control ventilation, occupancy controls, economizing controls, and thermostat controls for load shed/shift.
- Air-source heat pump / VRF: Substantial HVAC upgrades including air-source heat pump and air-source VRF systems
- Ground-source heat pump: Geothermal heat pumps of varying types

These measures are summarized in the following table.

Table 3: Complete ComStock 2024.1 Measures Summary

Grouping	Measure	Details
Envelope	Exterior Wall Insulation	Introduce additional wall insulation to achieve values recommended by ASHRAE *Advanced Energy Design Guide*.[2] Typically involves upgrade to total exterior wall assembly insulation value of R-15 to R-20 for Bay Area buildings, depending on typology and existing wall type.
	Roof Insulation	Introduce additional roof insulation to achieve values recommended by ASHRAE *Advanced Energy Design Guide*.[2] Typically involves upgrade to roof insulation value of R-27 for Bay Area buildings.
	Secondary Window System	Addition of a secondary window to the inside of existing windows to improve U-value, solar heat response, and light transmittance properties.
	Window Film	Window film retrofitted onto existing glazing per film specifications of products currently available on the market.
	Window Replacement	Replace windows to yield performance recommended by ASHRAE *Advanced Energy Design Guide*.[2] Typically involves upgrade to window U-value of 0.4 for Bay Area buildings.
Interior equipment & lighting	LED Lighting	Includes buildings where LED lights can be directly swapped into existing non-LED fixtures, and buildings where LEDs are retrofitted through full luminaire replacement.
	Electric Kitchen Equipment	Assumes electric appliance retrofits for ovens, ranges, steamers, fryers, etc.

[2] https://www.ashrae.org/technical-resources/aedgs/50-percent-aedg-free-download

Enhanced HVAC components & controls	Air Side Economizers for AHUs	Assumes HVAC controls that enable increasing the amount of cool and dry outdoor air into the air-conditioning system to reduce the mechanical cooling energy used for space conditioning.
	Demand Control Ventilation	Assumes CO2 sensors are used to enable reducing ventilation air when indoor CO2 levels fall below a set threshold.
	Exhaust Air Heat/Energy Recovery	Introduces plate heat exchangers to recover heat from exhaust air.
	Advanced Rooftop Unit Control	Replaces constant-speed rooftop unit fans with variable-speed fans and includes options for demand control ventilation and air-side economizing.
	Improved Fan/OA Controls	Assumes that fan operating schedules are aligned with occupancy schedules, including shutting off outdoor air supply in ventilation systems during periods when buildings are unoccupied for extended periods.
	Thermostat Control for Load Shedding	Applies heating and cooling temperature setpoint offsets (+/- 2°C or 3.5°F) for reducing the heating and cooling load during the peak consumption timeframes.
	Thermostat Control for Load Shifting	Applies heating and cooling temperature setpoint adjustment for pre-conditioning before peak consumption timeframes.
Air-Source Heat Pump / VRF	Variable Speed HP RTU, Electric Backup	Replaces gas furnace and electric resistance RTUs with high-efficiency variable-speed heat pump rooftop units (HP-RTUs) with electric resistance backup heating.
	Variable-Speed Heat Pump RTU with Original Fuel Backup	Replaces gas furnace and electric resistance rooftop units (RTUs) with high-efficiency variable-speed HP-RTUs with supplemental heat that matches the original fuel type of the replaced system.
	Heat Pump RTU with Exhaust Air Energy Recovery	Replaces gas furnace and electric resistance rooftop units with high-efficiency variable-speed HP-RTUs that include exhaust air heat or energy recovery via a plate heat exchanger.
	Standard Performance HP RTU, Electric Backup	Replaces gas furnace and electric resistance RTUs with standard-efficiency heat pump rooftop units (HP-RTUs) with electric resistance backup heating.
	Variable Refrigerant Flow (VRF) Heat Recovery with Dedicated Outside Air System (DOAS)	Replaces existing multizone variable air volume (VAV) systems or single-zone rooftop units (RTU) with a VRF with heat recovery system coupled with a DOAS that includes an energy/heat recovery ventilator (E/HRV).
	Variable Refrigerant Flow (VRF) with 25% Upsizing Allowance for Heating	A VRF (with heat recovery) heating and cooling system coupled with a dedicated outdoor air system (DOAS) for ventilation, where 25% upsizing (or 125% of the original size) is allowed for heating in colder climates (i.e., heating-dominant regions).
	Dedicated Outside Air System (DOAS) with Mini Split Heat Pumps (MSHPs)	Replaces gas-fired and electric resistance rooftop units (RTUs) with high-efficiency (~30 seasonal energy efficiency ratio; 14 heating seasonal performance factor), variable speed MSHPs and a DOAS system with an energy recovery ventilator (ERV) or heat recovery ventilator (HRV). The DOAS system uses the existing ductwork from the replaced RTU.
	Air-Source Heat Pump Boiler, Electric Backup	Replaces natural gas-fired boilers with an air-source heat pump boiler. When the outdoor air temperature is below the cutoff temperature of the heat pump boiler, an electric boiler is used as a backup.
	Air-Source Heat Pump Boiler and Natural Gas Boiler Backup	Replaces natural gas-fired boilers with an air-source heat pump boiler. When the outdoor air temperature is below the cutoff temperature of the heat pump boiler, a natural gas boiler is used as a backup.
Ground-source heat pump	Central Ground-Source Water-to-Water Heat Pump	Retrofit of hydronic HVAC systems to use ground-coupled, water-to-water heat pumps as primary equipment.
	Packaged Water-to-Air Geothermal Heat Pump	Retrofit of single-zone packaged rooftop units with packaged rooftop water-to-air geothermal heat pumps

		(GHP), tied to a common condenser loop coupled with a ground heat exchanger.
	Ground-Coupled Console Water-to-Air Heat Pump	Conversion of an existing heating, ventilating, and air-conditioning (HVAC) system to a series of "console" water-to-air heat pumps served by a ground heat exchanger. Console water-to-air geothermal heat pumps (GHP) are all-in-one packages that have no or minimal ductwork and serve individual spaces.

Commercial buildings have much more variation in use types, systems, and load patterns as compared with residential buildings; for this reason, the measures summarized above are not universally applicable to all commercial building types. The tables in subsequent pages summarize the applicability of each measure across the 14 commercial building types represented in the ComStock dataset (specifically for buildings in the 9 Bay Area counties). Applicability is determined by assessing the share of Bay Area buildings for which energy and emissions are impacted by upgrade measures relative to the baseline (business-as-usual) condition. Key takeaways from this assessment include:

Measures with high savings potential across a majority of typologies:

- Heat pump Rooftop Units (RTUs): This measure most commonly applies to schools, small and medium offices, outpatient, and retail buildings. For buildings in which it applies, this measure typically achieves 20-35% energy savings and significant emissions reductions across Bay Area buildings.
- Air-source heat pump boilers: This measure is applicable to buildings with large centralized heating systems such as medium and large offices, larger schools, and hospitals. Where applicable, the measure can achieve over 30% energy savings.
- Ventilation controls (RTU controls, demand control ventilation, improved fan controls): these measures is not applicable to all typologies (for example, they don't often apply to hotels or warehouses), they do frequently apply to office, hotel, food service, and medical buildings, yielding up over 20% energy savings for buildings in which they apply.
- Light Emitting Diode (LED) lighting: This measure has the potential to save energy across all ComStock commercial building typologies (unlike certain HVAC-related measures which are only applicable to select building types). In total, around 43% of Bay Area commercial floor area can achieve energy savings via LED retrofits, per ComStock trends. The remaining 57% of commercial floor area already contains energy efficient LED fixtures in the baseline scenario. For buildings that are retrofittable with LED lighting, this measure generally achieves between 2-6% energy savings (on a whole-building basis).
- Exterior wall and roof insulation: This measure applies to a majority of all commercial building types (generally 90% or more of Bay Area buildings). Exterior wall measure applies to buildings with mass, steel-framed and wood-framed walls. The roof measure applies to buildings with roof insulation R-values that are below those specified in the advanced energy design guide published by ASHRAE. These measures typically yield between 2-5% energy savings and appreciable emissions reductions.

Measures with high savings potential across a limited set of typologies:

- Electric kitchen equipment: This measure has limited applicability (only common in food service, schools, large hotel, and hospital buildings), though typically achieves 10-20% energy savings and high amounts of emissions savings when applied.
- Variable refrigerant flow (VRF) measures: These measures are generally most applicable to offices, schools, outpatient, and retail buildings. They generally achieve the highest energy and emissions reductions of any measures (over 50% savings for certain typologies).

- DOAS with mini-split heat pumps: This measure most typically applies to small office, food service, and retail stripmall buildings, achieving up to 40% energy savings and significant emissions reductions where applicable.

Measures with limited applicability for ComStock commercial buildings:

- Thermostat control for load shedding and load shifting: The ComStock dataset only applies this measure to large and medium office buildings, with NREL documentation noting that the measures will be applied to other commercial building types in subsequent release. The load shedding and load shifting measures are intended to provide demand flexibility by shaving load peaks on a daily basis, rather than targeting energy or emissions savings. Given the focus on emissions reduction potential for this study, these two measures are not considered in the ECM packages for this scope.

- Ground-source / geothermal heat pump measures: This measure frequently applies to schools, small and medium offices, food service and retail buildings, however it tends be more difficult to apply in practice due to higher capital expenditure costs, exterior space requirements, and more significant building disruptions.

Measures with frequent detrimental impacts on energy and emissions:

These measures are generally more suited toward climates with more extreme heating and cooling demands, and can often lead to energy penalties when applied in the moderate climate of the Bay Area, as described below:

- Window thermal performance and film application: The window replacement / secondary window system measures generally result in modest emissions reductions for hotels and restaurants, but lead to emissions penalties for medium and large offices, schools, hospitals, standalone retail buildings, and warehouses. The window film measure results in energy and emissions penalties in a high percentage of cases. The low savings potential, or in some cases penalties, associated with these measures are a result of the reduction in “free heating” from solar gains in buildings outweighing the benefit to cooling energy savings. This conclusion is specific to the Bay Area region where summer temperatures are relatively mild. In select cases, these measures may add value for buildings with concerns beyond just energy and emissions savings, including concerns related to visual comfort, privacy, aesthetics, and ultraviolet protection. Due to the frequent detrimental energy impacts, these measures are not included in the ECM packages for this study.

- Window replacement and secondary window system: Measures which involve improving the thermal performance of windows generally result in modest emissions reductions for hotels and restaurants, but lead to emissions penalties for medium and large offices, schools, hospitals, standalone retail buildings, and warehouses. The penalties are due to the same reason described above for window films.

- Exhaust air energy recovery: This measure is broadly applicable to offices, schools, medical, and retail buildings, however it often yields emissions penalties for larger buildings (large offices and hospitals). These energy penalties are generally attributed to the fact that in temperate climates like the Bay Area, outdoor air is often already at a comfortable temperature for use inside buildings, so capturing and adding extra heat through heat recovery systems can unintentionally make the air too warm—creating the need for additional cooling that cancels out the intended energy savings.

Table 4: ComStock measure applicability to each typology for Bay Area buildings. Percents and coloring indicate proportion of buildings of each typology for which a given upgrade is applicable.

		ComStock share of Bay Area buildings for which measure is applicable.													
Category	Upgrade	Large Office	Medium Office	Small Office	Secondary School	Primary School	Large Hotel	Small Hotel	Full Service Restaurant	Quick Service Restaurant	Retail Stripmall	Retail Standalone	Hospital	Outpatient	Warehouse
Envelope	Exterior Wall Insulation	93%	94%	98%	95%	87%	97%	92%	91%	95%	99%	86%	93%	99%	99%
	Roof Insulation	95%	94%	100%	93%	88%	100%	94%	98%	98%	100%	92%	87%	100%	100%
	Secondary Window System	68%	72%	90%	62%	75%	97%	98%	85%	95%	84%	44%	40%	76%	27%
	Window Film	15%	33%	34%	45%	53%	53%	69%	54%	43%	24%	21%	20%	20%	0%
	Window Replacement	39%	54%	78%	59%	69%	85%	94%	79%	82%	69%	44%	20%	59%	13%
Interior equipment & lighting	LED Lighting	44%	36%	44%	46%	36%	48%	42%	46%	35%	43%	34%	33%	39%	43%
	Elec. Kitchen Equipment	0%	0%	0%	53%	45%	100%	0%	99%	86%	69%	0%	100%	0%	0%
Enhanced HVAC components & controls	Air Side Economizers for AHUs	13%	71%	60%	37%	52%	0%	1%	75%	74%	72%	43%	13%	55%	0%
	Demand Control Ventilation	59%	52%	13%	43%	59%	0%	0%	0%	0%	5%	67%	93%	38%	0%
	Exhaust Air Heat/Energy Recovery	27%	37%	66%	43%	26%	32%	3%	0%	0%	89%	64%	27%	71%	0%
	Advanced Rooftop Unit Control	0%	33%	68%	38%	58%	0%	1%	90%	98%	91%	36%	20%	47%	0%
	Improved Fan/OA Controls	91%	96%	84%	38%	0%	0%	1%	91%	98%	97%	42%	47%	100%	0%
	Tstat Control for Load Shedding	72%	5%	0%	0%	0%	0%	0%	0%	**0%**	0%	0%	0%	0%	0%
	Tstat Control for Load Shifting	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Air-cource heat pump / VRF	VS HP RTU, Elec. Backup	0%	28%	61%	30%	57%	0%	0%	87%	87%	90%	35%	20%	43%	0%
	VS HP RTU w/ Orig. Fuel Backup	0%	28%	61%	30%	57%	0%	0%	87%	87%	90%	35%	20%	43%	0%
	HP RTU w/ EA Energy Recovery	0%	28%	61%	30%	57%	0%	0%	87%	87%	90%	35%	20%	43%	0%
	Std. Perf. HP RTU, Elec. Backup	0%	28%	61%	30%	57%	0%	0%	87%	87%	90%	35%	20%	43%	0%
	VRF Heat Recovery w/ DOAS	50%	90%	77%	61%	93%	0%	0%	0%	**0%**	99%	93%	0%	87%	0%
	VRF w/ 25% Htg. Upsizing	50%	90%	77%	61%	93%	0%	0%	0%	0%	99%	93%	0%	87%	0%
	DOAS w/ Mini Split HPs	0%	5%	61%	8%	1%	0%	0%	87%	87%	56%	17%	0%	30%	0%
	ASHP Boiler, Elec. Backup	63%	48%	5%	36%	26%	15%	14%	0%	3%	0%	46%	80%	30%	9%
	ASHP Boiler and Gas Backup	63%	48%	5%	36%	26%	15%	14%	0%	3%	0%	46%	80%	30%	9%
Ground-source heat pump	Central GS Water-to-Water HP	50%	5%	1%	25%	16%	12%	2%	1%	0%	1%	3%	80%	1%	0%
	Pkg Water-to-Air Geo. HP	17%	90%	70%	49%	75%	0%	1%	96%	93%	96%	91%	13%	79%	0%
	Console Water-to-Air GSHP	0%	0%	11%	1%	0%	68%	82%	0%	1%	0%	5%	0%	0%	0%

Table 5: ComStock measure average energy savings or penalty per typology for Bay Area buildings. Percents and coloring indicate energy impact; energy savings shown as positive values and green coloring, while energy penalties are shown as negative percentages and red coloring.

		ComStock average energy savings (positive %) or penalty (negative %) by typology and upgrade.													
Category	Upgrade	Large Office	Medium Office	Small Office	Secondary School	Primary School	Large Hotel	Small Hotel	Full Service Restaurant	Quick Service Restaurant	Retail Stripmall	Retail Standalone	Hospital	Outpatient	Warehouse
Envelope	Exterior Wall Insulation	2%	2%	5%	0%	0%	1%	4%	0%	1%	2%	2%	1%	4%	12%
	Roof Insulation	0%	1%	2%	1%	1%	0%	5%	0%	0%	1%	1%	0%	2%	4%
	Secondary Window System	1%	0%	1%	0%	0%	1%	3%	0%	0%	0%	0%	0%	1%	0%
	Window Film	-5%	-3%	-1%	0%	-1%	0%	2%	0%	0%	0%	-2%	-1%	-2%	-10%
	Window Replacement	-1%	-1%	2%	0%	0%	1%	5%	0%	0%	0%	-1%	0%	0%	-4%
Interior equipment & lighting	LED Lighting	3%	4%	2%	1%	2%	4%	8%	2%	2%	4%	3%	6%	3%	6%
	Elec. Kitchen Equipment	N/A	N/A	N/A	1%	2%	18%	N/A	23%	14%	9%	0%	4%	N/A	N/A
Enhanced HVAC components & controls	Air Side Economizers for AHUs	1%	2%	1%	2%	2%	N/A	1%	2%	1%	2%	1%	2%	1%	N/A
	Demand Control Ventilation	0%	0%	-1%	1%	2%	N/A	N/A	N/A	N/A	7%	3%	0%	0%	N/A
	Exhaust Air Heat/Energy Recovery	-1%	0%	6%	2%	0%	6%	18%	N/A	N/A	5%	4%	0%	3%	N/A
	Advanced Rooftop Unit Control	N/A	20%	15%	19%	24%	N/A	24%	9%	14%	13%	20%	10%	12%	N/A
	Improved Fan/OA Controls	14%	16%	22%	19%	N/A	N/A	6%	2%	1%	16%	26%	0%	17%	N/A
	Tstat Control for Load Shedding	1%	1%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0%	N/A
	Tstat Control for Load Shifting	0%	0%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0%	N/A
Air-cource heat pump / VRF	VS HP RTU, Elec. Backup	N/A	22%	33%	23%	26%	N/A	N/A	5%	4%	22%	37%	7%	25%	N/A
	VS HP RTU w/ Orig. Fuel Backup	N/A	22%	33%	23%	26%	N/A	N/A	5%	4%	22%	37%	7%	25%	N/A
	HP RTU w/ EA Energy Recovery	N/A	19%	31%	20%	22%	N/A	N/A	5%	4%	19%	33%	6%	22%	N/A
	Std. Perf. HP RTU, Elec. Backup	N/A	15%	24%	15%	17%	N/A	N/A	3%	3%	15%	25%	5%	18%	N/A
	VRF Heat Recovery w/ DOAS	39%	35%	40%	42%	38%	N/A	N/A	N/A	N/A	23%	57%	N/A	34%	N/A
	VRF w/ 25% Htg. Upsizing	39%	35%	40%	42%	38%	N/A	N/A	N/A	N/A	23%	57%	N/A	34%	N/A
	DOAS w/ Mini Split HPs	N/A	33%	42%	21%	6%	N/A	N/A	4%	4%	22%	42%	N/A	34%	N/A
	ASHP Boiler, Elec. Backup	18%	17%	8%	29%	32%	15%	10%	N/A	6%	N/A	32%	4%	17%	17%
	ASHP Boiler and Gas Backup	18%	17%	8%	29%	32%	15%	10%	N/A	6%	N/A	32%	4%	17%	17%
Ground-source heat pump	Central GS Water-to-Water HP	23%	21%	-14%	46%	47%	17%	17%	6%	N/A	1%	51%	7%	21%	N/A
	Pkg Water-to-Air Geo. HP	43%	30%	17%	25%	27%	N/A	5%	5%	11%	14%	50%	3%	25%	N/A
	Console Water-to-Air GSHP	N/A	N/A	9%	1%	N/A	8%	7%	N/A	2%	N/A	5%	N/A	N/A	N/A

Table 6: ComStock measure total emissions saved for each upgrade, by topology, for Bay Area buildings. Values and coloring indicate short tons of emissions avoided; emissions avoided are shown as positive values with green coloring, while emissions penalties are shown as negative values and red coloring.

		ComStock Bay Area buildings emissions savings by typology and upgrade; emissions avoided shown as positive, emissions penalty shown as negative.													
Category	**Upgrade**	**Large Office**	**Medium Office**	**Small Office**	**Secondary School**	**Primary School**	**Large Hotel**	**Small Hotel**	**Full Service Restaurant**	**Quick Service Restaurant**	**Retail Stripmall**	**Retail Standalone**	**Hospital**	**Outpatient**	**Warehouse**
Envelope	Exterior Wall Insulation	8,592	7,137	15,265	1,066	1,796	2,737	614	1,540	674	8,619	7,991	3,210	3,521	25,331
	Roof Insulation	1,623	3,602	7,168	2,954	4,862	1,566	1,500	1,248	342	8,228	5,830	1,070	2,357	10,638
	Secondary Window System	5,413	2,369	5,172	108	22	3,174	697	436	107	2,167	-1,077	78	727	-160
	Window Film	-34,186	-17,000	-1,038	-1,707	-4,435	1,771	633	310	-18	-2,060	-15,307	-4,472	-2,982	-22,641
	Window Replacement	-9,014	-4,622	7,023	-628	-2,020	6,446	1,243	725	147	2,385	-8,203	-1,831	-389	-8,209
Interior equipment & lighting	LED Lighting	9,645	9,890	3,226	4,749	5,253	9,402	1,227	4,995	754	15,046	7,891	10,238	2,015	7,813
	Elec. Kitchen Equipment	0	0	0	6,459	7,812	60,263	0	115,187	15,424	58,314	0	14,501	0	0
Enhanced HVAC components & controls	Air Side Economizers for AHUs	1,309	8,344	3,123	3,768	6,990	0	8	7,377	1,159	13,010	3,356	943	1,059	0
	Demand Control Ventilation	1,495	1,035	-2,829	2,032	7,769	0	0	0	0	1,691	14,713	1,366	352	0
	Exhaust Air Heat/Energy Recovery	-8,087	-2,863	18,187	4,040	1,617	1,849	354	0	0	29,695	18,836	-1,367	2,900	0
	Advanced Rooftop Unit Control	0	41,765	42,278	41,187	83,294	0	258	45,296	16,570	110,341	44,303	9,069	8,575	0
	Improved Fan/OA Controls	79,147	90,057	72,218	35,722	0	0	60	11,060	1,566	118,422	63,380	1,588	22,837	0
	Tstat Control for Load Shedding	3,766	698	0	0	0	0	0	0	0	0	0	0	4	0
	Tstat Control for Load Shifting	-925	-158	0	0	0	0	0	0	0	0	0	0	-2	0
Air-cource heat pump / VRF	VS HP RTU, Elec. Backup	0	37,213	79,146	36,585	88,688	0	0	22,187	3,913	140,901	67,177	7,090	13,036	0
	VS HP RTU w/ Orig. Fuel Backup	0	37,213	79,177	36,569	88,627	0	0	22,179	3,909	140,760	67,064	7,085	13,026	0
	HP RTU w/ EA Energy Recovery	0	31,799	73,118	32,873	76,923	0	0	22,187	3,913	122,077	58,524	6,311	11,380	0
	Std. Perf. HP RTU, Elec. Backup	0	23,775	54,888	23,355	59,542	0	0	15,274	2,625	93,576	45,093	4,116	8,838	0
	VRF Heat Recovery w/ DOAS	74,950	201,674	124,252	140,181	278,451	0	0	0	0	184,643	414,252	0	40,319	0
	VRF w/ 25% Htg. Upsizing	73,511	200,763	124,314	140,182	278,446	0	0	0	0	184,643	414,250	0	40,322	0
	DOAS w/ Mini Split HPs	0	1,978	99,464	901	56	0	0	19,334	3,692	41,511	15,760	0	6,943	1
	ASHP Boiler, Elec. Backup	87,460	54,293	2,009	60,688	80,006	6,639	534	0	354	0	127,409	15,310	9,666	3,267
	ASHP Boiler and Gas Backup	87,758	54,237	2,012	60,674	79,963	6,639	534	0	354	0	127,294	15,307	9,622	3,266
Ground-source heat pump	Central GS Water-to-Water HP	115,277	5,712	264	77,251	72,147	4,979	381	217	0	-21	9,270	27,987	148	0
	Pkg Water-to-Air Geo. HP	50,677	180,143	52,097	75,997	179,751	0	56	26,391	11,422	122,358	378,587	2,951	30,194	0
	Console Water-to-Air GSHP	0	0	4,168	-495	0	23,315	1,391	0	31	0	1,007	0	0	0

Note: Emissions savings displayed above are as directly reported by ComStock using static eGRID emissions factors, and are intended to show relative emissions impact between typologies and measures.

5.2 Commercial Building ECMs Selected for BayREN analysis

After assessing the applicability and impact of commercial building measures in the ComStock dataset, the measures with the highest potential to achieve electrification and emissions savings were selected and grouped into a variety of packages for BayREN buildings analysis. The selected measures are summarized below, including the methodology for calculating their impact on building energy and emissions.

5.2.1 HVAC Electrification – Base COP

This measure considers the electrification of heating systems in Bay Area commercial buildings, with different baseline heating systems being upgraded with corresponding all-electric alternatives as follows:

- Commercial buildings with existing gas furnace rooftop unit (RTU) heating systems are assumed to be upgraded to heat pump RTU heating systems. These heat pump retrofit systems are modeled with an assumed reference heating coefficient of performance (COP) ranging from 3.8 at a 47F outdoor temperature to 2.7 at a 17F reference outdoor temperature.
- Commercial buildings with existing gas boiler heating systems are assumed to be upgraded to air-source heat pump boiler systems. Heat pump performance varies with operating conditions; ComStock documentation reports an average heating COP of 2.65 for air-source heat pump boiler retrofits in the California climate (statewide average). Heating efficiency varies with outdoor temperature and thus accounts for the unique climate of Bay Area counties.
- Commercial buildings with existing electric resistance heating systems (either boiler or RTU systems) are upgraded to like-for-like corresponding heat pump systems with COPs aligned with the values described above. These buildings will continue to operate with all-electric heating systems but will see significantly improved heating efficiency, as electric resistance heating systems are generally capped at a maximum possible COP of 1.0.

When calculating energy savings potential from heat pump retrofits, only savings to heating energy is considered. This analysis assumes that cooling systems remain unchanged, or any changes to cooling systems that are administered in tandem with heating upgrades will not results in an appreciable change in cooling system energy efficiency. No new cooling systems are assumed to be introduced to commercial buildings which previously did not have cooling systems. This assumption is relatively inconsequential for commercial buildings, as over 99% of Bay Area commercial building floor area is served by existing cooling systems per ComStock trends.

In practice, heat pump systems contain backup heating components for extreme cold conditions when compressors and condensers cannot sufficiently meet heating demands; these backup systems are generally either electric resistance- or fossil fuel-based. Fossil fuel backup heating is more commonly found in climates that experience extreme cold temperatures for much of the year, such as the northern Midwest and the Northeast. Given the more temperate climates of Bay Area counties, the heat pump retrofits assumed in this analysis assume only electric resistance backup heating. Thus, the heat pump retrofits result in 100% elimination of all fossil fuel energy consumption for space heating.

5.2.2 HVAC Electrification – Advanced COP

This measure applies the same scheme for gas heating system retrofit described above, but with improvements to heat pump COP representing top-of-the-line heat pump systems on the market today. Such systems are expected to achieve additional savings to heating energy but are associated with higher costs.

In calculating energy savings for the advanced HVAC electrification measure, heating COP improvements range from 4% (under cold outdoor conditions) to 10% (under moderate outdoor conditions) in comparison to the standard performance heat pump COPs described above. These performance specifications are aligned with COPs for top performing commercial HVAC products as noted in ComStock documentation.

5.2.3 Water Heating Electrification

This ECM considers retrofitting commercial building water heaters with high-efficiency heat pump alternatives. Currently, uptake of heat pump water heaters for commercial buildings is low; precise statistics for commercial buildings are not readily available, however an inference can be made from studies on residential HPWHs, which estimate the total share of HPWHs to be only 4%. Furthermore, the ComStock dataset only includes fossil fuel-based or electric resistance-based water heaters for Bay Area commercial buildings in the baseline scenario, reinforcing the low prevalence of heat pump water heaters in commercial buildings across the region.

For this study, both electric resistance water heaters, and any baseline fossil fuel water heaters, are assumed to be eligible for the HPWH upgrade measure. Baseline water heating energy is assigned via ComStock EUI trends in the same manner as other energy end uses. Energy savings from heat pump water heaters are then estimated via post processing with the following scheme:

- Baseline fossil fuel water heaters are assumed to have a thermal efficiency of 80% and are replaced with HPWHs with a UEF of 3.45, aligned with the residential building HPWH methodology.[3]
- Baseline electric resistance water heaters are assumed to have a thermal efficiency of 98% (given that electric resistance heating systems have a theoretical efficiency of 100% plus a small amount of fouling of the heating components and other miscellaneous thermal losses) and are replaced with HPWHs with the same UEF of 3.45.

The water heater analysis assumes that both small-scale domestic water heaters (common in small commercial buildings) and large-scale central water heaters (common in larger commercial and industrial buildings) are eligible for this upgrade with the efficiencies outlined above.

5.2.4 Electrified Cooking and Process Equipment

This ECM involves the retrofitting of all natural gas-based interior equipment (including kitchen equipment and miscellaneous industrial process loads) with like-for-like alternative electric systems. The fuel switch from natural gas to electricity will lead to emissions savings as the electrical grid becomes increasingly decarbonized; however, given that ComSteock does not present a detailed breakdown of types of natural gas equipment in its dataset to enable an efficiency analysis, no changes to efficiency are assumed in the process of this fuel conversion.

This assumption of equal energy efficiency between electric and gas systems has relatively low bearing on overall results due to the low prevalence of these natural gas equipment loads; natural gas process loads comprise just 5% of all Bay Area natural gas energy calculated in this study, and only 2% of total energy.

5.2.5 Roof Insulation Upgrade

The roof insulation ECM assumes that a building's roof insulation is upgraded to R-26; this aligns with total roof assembly insulation specified in ASHRAE's Advanced Energy Design Guide (AEDG) for the ASHRAE Climate Zone 3C (the prevailing climate zone for Bay Area counties). Energy savings from roof insulation upgrades are achieved through reduced heating and cooling energy; the BayREN analysis incorporates the energy savings for these end uses as calculated in the ComStock dataset for Bay Area buildings, with calculations being dependent on building type. Energy savings calculations take into account the fact that some roofs already have insulation levels at or above the AEDG target; such roofs are considered to be left as-is, and no energy savings are considered for them.

This ECM is considered a "light touch" envelope upgrade given that roof insulation can generally be improved with minimally-invasive retrofit methods. This measure has the highest impact for low-rise commercial buildings for which the ratio of roof area to total envelope area is higher than for high-rise buildings. As

[3] The UEF metric is intended for residential water heaters, representing efficiency over the course of a seasonal test period rather than a point-in-time efficiency. For the purpose of this analysis, the metric is extrapolated to commercial water heaters as well, since the post processing involves manipulation of full-year data rather than point-in-time efficiency calculations.

summarized in the preceding tables, the roof insulation measure is highly applicable to Bay Area commercial buildings (with between 85-100% of buildings being eligible for this upgrade depending on building type), however the savings potential is relatively small (0-4% energy savings achievable depending on building type).

5.2.6 Exterior Wall Insulation Upgrade

The exterior wall insulation ECM assumes that a building's exterior wall insulation is upgraded to R-16; this aligns with total exterior wall assembly insulation specified in ASHRAE's Advanced Energy Design Guide (AEDG)7 for the ASHRAE Climate Zone 3C (the prevailing climate zone for Bay Area counties). Energy savings from exterior wall insulation upgrades are achieved through reduced heating and cooling energy; the BayREN analysis incorporates the energy savings for these end uses as calculated in the ComStock dataset for Bay Area buildings, with calculations being dependent on building type. Energy savings calculations take into account the fact that some exterior walls already have insulation levels at or above the AEDG target; such buildings are considered to be left as-is, and no energy savings are considered for them.

This ECM is considered an "advanced" envelope upgrade given that upgrading wall insulation generally requires higher cost, more invasive techniques when compared to weatherization measures or roof insulation upgrades. As summarized in the preceding tables, the exterior wall insulation measure is highly applicable to Bay Area commercial buildings (with between 85-100% of buildings being eligible for this upgrade depending on building type), while the savings potential is higher than for roof upgrades (0-12% energy savings achievable depending on building type).

5.2.7 Improved Weatherization

This relatively non-intrusive measure involves improving the airtightness of the building to reduce HVAC heating and cooling energy consumption. ComStock does not include a standalone ECM related to airtightness improvements. To derive heating and cooling energy impact, Arup carried out bespoke energy modeling of 6 commercial building types using DOE Commercial Prototype Building Models in the ASHRAE climate zone corresponding to Bay Area counties. Models were run under business-as-usual airtightness conditions (aligned with ASHRAE 90.1-2016) vs. a 30% improvement (inputted as a 30% reduction in infiltration rates of outdoor air.

The energy model results demonstrate that heating energy can be reduced by between 0-9% and cooling energy by 0-2%, depending on typology. Savings potential is lower for typologies with high outdoor air demands (such as hospitals) where heating and cooling energy is more dominated by high outdoor ventilation rates rather than unintentional infiltration of outdoor air.

These values for infiltration savings potential were applied to BayREN typologies according to the same typology mapping scheme described in the Dashboard Methodology Report, pages 9-10.[4]

5.2.8 LED Lighting Upgrades

This measure assumes all non-LED lighting fixtures are retrofitted with LED fixtures in commercial building stock. Per ComStock methodology, the measure only applies to interior lighting; exterior lighting is left unchanged. Interior lighting is assumed to represent the majority of lighting-based energy for Bay Area commercial buildings (73% of all lighting energy per ComStock baseline data).

The following tables summarize the different commercial building lighting classifications in ComStock, broken down by lighting "generations". Buildings with lighting falling under Generations 1 through 3 are assumed to be generally energy inefficient and will be upgraded. Generations 4 through 8 represent LED fixtures available in today's market or in the near future; Generation 4 represents early LED technology (the first LEDs available on the market) while Generation 8 represents LED fixtures assumed to be widely available in 2035.

[4] https://www.bayren.org/sites/default/files/documents/2025/BayREN%20Existing%20Buildings%20Dashboard%20Report%20103124.pdf

For the purpose of BayREN ECM analysis, commercial buildings with Generation 1-3 lighting are assumed to be upgraded to Generation 5 lighting. Generation 4 lighting is left as is (given that this represents LED lighting with remaining useful life), while Generation 5-8 lighting is considered to be highly energy efficient and is also left as-is.

Table 7: Commercial building LED lighting classifications a consdiered in LED lighting ECM

Generation	General Lighting Technology	General Lighting (High Bay) Technology	Task Lighting Technology	Supplemental Lighting Technology	Wall Wash Lighting Technology	Upgrade
Generation 1	T12 Linear Fluorescent	High Intensity Discharge (HID) Mercury Vapor	Incandescent A-Shape	Incandescent Decorative	Incandescent Decorative	Upgrade to Generation 5
Generation 2	T8 Linear Fluorescent	HID Metal Halide	Halogen A-Shape	Halogen Decorative	Halogen Decorative	
Generation 3	T5 Linear Fluorescent	HID Metal Halide	Compact Fluorescent Screw	Compact Fluorescent Pin	Compact Fluorescent Pin	
Generation 4-8	LED Linear	LED High Bay Luminaire	LED General Purpose	LED Decorative	LED Directional	Assume no retrofit

The following table summarizes lighting power densities, in units of W/ft2, for the different commercial building lighting classes, broken down by ComStock building type. The assumed correlations between ComStock typologies and the typologies assumed in BayREN buildings analysis are summarized in the Dashboard Methodology Report, page 30.[5]

Table 8: Lighting power densities (in W/ft2) of lighting technologies for different building types. ComStock only provides lighting power densities for Generations 1 through 5; Generations 6-8 are assumed to be incrementally improved from Generation 5.

ComStock Building Type	Non-LED Technologies		LED Technologies		
	Generation 1	Generation 2	Generation 3	Generation 4	Generation 5
Full Service Restaurant	1.51	0.96	0.45	0.43	0.39
Hospital	1 .59	1 .07	0.63	0.58	0.52
Large Hotel	1.31	0.8	0.29	0.23	0.21
Large Office	1 .18	0.8	0.5	0.53	0.47
Medium Office	1 .18	0.8	0.5	0.53	0.47
Outpatient	1 .27	0.85	0.53	0.52	0.47
Primary School	0.73	0.56	0.48	0.47	0.42
Quick Service Restaurant	1 .73	1.11	0.56	0.52	0.47
Retail - Standalone	1 .17	0.75	0.54	0.47	0.42
Secondary School	0.88	0.58	0.48	0.45	0.4
Small Hotel	1 .08	0.63	0.28	0.25	0.22
Small Office	1 .18	0.79	0.5	0.52	0.47
Retail - Strip Mall	1 .59	1 .07	0.65	0.64	0.59
Warehouse	0.83	0.4	0.39	0.3	0.27

5.2.9 Optimized Plug Load Controls

This measure considers plug load control strategies such as scheduled downtime, automatic sleep mode for select appliances after a period of non-use, and deactivation of unused appliances such as small refrigerators in office spaces. This ECM is not included in ComStock; energy savings potential is thus applied through post-processing via trends from NREL studies and the U.S. General Services Administration Sustainable Facilities Tool. This measure applies to buildings with predictable daily occupancy schedules and equipment which is not considered to be mission-critical. For example, the measure is applied to offices of all sizes (with estimated 43%

[5] https://www.bayren.org/sites/default/files/documents/2025/BayREN%20Existing%20Buildings%20Dashboard%20Report%20103124.pdf

savings potential for interior equipment energy as informed by the GSA Sustainable Facilities Tool) but not applied to hospitals and warehouses where deactivating plug loads might risk interruptions to logistics processes or life safety equipment.

5.3 Commercial Building Packages

The commercial building ECMs described above are grouped into 16 packages of measures, including several "standalone" packages where individual ECMs are studied in isolation, along with measures intended to optimize for GHG reduction, energy reduction, and cost effectiveness.

Table 9: Commercial Building ECM Packages

Package Type	Package Number	HVAC Elec. Base COP[6]	HVAC Elec. Advanced COP[7]	Water Heating Elec.[8]	Elec. Cooking & Process Equip.[9]	Light Touch Envelope[10]	Advanced Envelope[11]	Plug Load Controls[12]	LED Lighting[13]
Standalone ECMs	1			x					
	2	x							
	3		x						
	4				x				
	5						x		
	6							x	x
GHG Reduction	7	x		x	x	x		x	x
	8		x	x	x	x		x	x
	9	x		x	x				
	10		x	x	x				
Energy Reduction	11		x	x	x	x			
	12		x	x	x		x		
	13		x	x	x		x	x	x
	14						x	x	x
Budget	15			x		x		x	
	16	x		x		x		x	

[6] Applicable HVAC equipment per building type with code minimum COPs

[7] Applicable HVAC equipment per building type with best-in-market COPs

[8] Industry average efficiency, UEF 3.45

[9] Electrification of cooking equipment (broilers, fryers, griddles, ovens, ranges, and steamers) and all other miscellaneous gas equipment (industrial process loads, process steam).

[10] Roof/Attic insulation improvements (R-26) and weatherization around doors, windows, and other infiltration points.

[11] Light touch + Window (U-0.40) and wall (R-16) improvements

[12] Reduce plug load energy consumption via smart scheduling devices

[13] Includes buildings where LEDs can be swapped into existing fixtures, and buildings where the full fixture can be retrofitted.

6. Potential Future Improvements

The Bay Area Existing Buildings Dashboard relies on a wealth of data that is likely to be continually improved in the future. In compiling the data for the dashboard and underlying analysis, we noted the following areas for future improvement:

- Parcel use types are based on data from the ReGrid 2024 dataset and County Assessor data as of 2024. Use characterization, particularly for outlying buildings that are likely to have little or no energy use, is expected to improve as the combination of scanning, machine learning, and computer vision underpinning datasets such as ReGrid are improved.

- Similarly, the datasets used for energy and emissions in the dashboard are primarily based on ResStock and ComStock models with adjustments to validated actual data where available based on California and Bay Area specific surveys of building energy performance. Further development of NREL's models underpinning ResStock and ComStock are expected to improve the accuracy of energy and emissions data and energy conservation measures impacts. This is particularly true for ComStock, where approximately 33% of building uses are not covered and adjustments have been made by the Existing Buildings Study team to adjust modeled outputs based on benchmark data for these building types.

- Electricity emissions factors were limited in the study to PG&E despite the multitude of Community Choice Energy (CCE) providers in the Bay Area. Currently, CCEs do not have transparent reporting of base emissions values in their Power Content Labels due to reporting requirements from the California Public Utilities Commission. However many offer lower carbon products to customers, and this can be a straightforward and cost-effective means of reducing emissions. As improved reporting of accurate emission labeling for CCEs is available, this could be integrated to the dashboard in addition to PG&E and decarbonized electricity options.

A.1 Residential Data Post-Processing

Residential Package Post-Processing

This appendix provides additional details on how data is organized in ResStock, the gaps in ResStock measure data and data needed for this analysis, and how the ResStock data was post-processed to bridge those gaps. This appendix also provides additional details on the measures used in each BayREN package and how each package applies to the Bay Area building stock.

ResStock Data Description and Limitations

Distribution of Homes with Air Conditioning:

The increased load from adding cooling in the form of heat pumps to homes that did not previously have a cooling system is critical for any decarbonization study of the Bay Area, where many homes do not currently have cooling. Because of this, it is very important to use the most geographically granular representation of the distribution of homes with cooling systems when modeling heat pump impacts. ResStock's cooling type data source is the U.S. EIA 2020 RECS microdata. However, other sources suggest that the ResStock values may overestimate cooling prevalence in some counties. The 2019 California Residential Appliance Saturation Study (RASS 2019) used surveys and energy data from approximately 40,000 California homes to determine population-level estimates for cooling saturation by California forecasting climate zones. For California, RASS 2019 contains about 35 times more home observations than ResStock. ResStock shows more homes with cooling of any kind than RASS in all Bay Area counties besides Solano. Also, ResStock specifically shows more room-level ACs for multifamily cooling than RASS.

To incorporate the RASS data into this study, the team adjusted the ResStock baseline energy use data to match the cooling saturations present in RASS for each county. The team removed cooling energy use from a selection of models in each county, except for Solano County, to represent a more accurate baseline of homes with cooing. In Solano County, the team added cooling energy use to a selection of models using the following logic:

$$energy_{cool} = \overline{t}_{cool} \times \overline{cap\ per\ s.f.}_{cool} \times CFA$$

Where:

- $\overline{t}_{cool}$ is the average runtime of a cooling system in Solano County
- $\overline{cap\ per\ s.f.}_{cool}$ is the average cooling capacity per conditioned square foot in Solano County
- CFA is the model's conditioned floor area

The average runtimes and capacities were determined by building type (single-family or multifamily).

Systems using Fossil Fuels:

ResStock models include fossil fuel use for the following end uses:

- Space heating
- Water heating
- Indoor cooking
- Outdoor grills
- Clothes drying
- Pool heating
- Spa/hot tub heating
- Lighting

- Fireplaces

All other end uses are powered by electricity in ResStock models, including clothes washers and other appliances. ResStock does not include electrification retrofit options for three of these measures:

- Outdoor grills
- Lighting
- Fireplaces

These end uses are less common and do not represent a significant source of fossil fuel use. Less than 3% of homes have these end uses and the average energy used by all three end uses combined represents less than 0.5% of total average energy use in Bay Area homes.

Heat Pump Replacements

There are three efficiency levels for ResStock heat pump retrofits:

- Standard efficiency ("ENERGY STAR") – SEER 16, 9.2 HSPF, capacity retention of 50% @ 5°F, single-stage
- Mid-efficiency ("ENERGY STAR Cold Climate") – SEER 16, 9.5 HSPF, capacity retention of 70% @ 5°F, variable speed
- High-efficiency ("Higher Efficiency Cold Climate") – SEER 20, 11 HSPF, capacity retention of 90% @ 5°F, variable speed

Based on the team's experience with heat pump retrofits in the Bay Area, the analysis uses the mid-efficiency heat pump retrofit for most packages and the high-efficiency heat pump retrofit for the advanced decarbonization packages. There are two types of heat pumps used for the retrofits:

- Centrally ducted air-source heat pumps ("ASHP, Ducted") – these systems replace existing HVAC systems that have ducts in ResStock
- Ductless mini-split heat pumps ("MSHP, Ductless") – these systems replace existing HVAC systems that do not have ducts in ResStock

Each ResStock heat pump can either use the existing baseline heating system for backup or use an electric resistance backup coil. Because the goal of this analysis is to show 100% electrification, BayREN requested the use of the second option for all heat pump retrofits, the electric resistance backup coil. Appendix A.2 Residential Backup Heating shows the impact of this heating coil for different heat pump efficiencies in the Bay Area.

Shared HVAC Systems

ResStock does not provide HVAC retrofit options for shared HVAC systems, such as central boiler heating in multifamily buildings. Where a home has a shared HVAC system in ResStock, the team used engineering calculations to model a ductless mini-split heat pump retrofit. The following general formula determined the new heating and cooling energy for each unit:

$$energy_{heat\ pump} = energy_{baseline} \times \frac{COP_{baseline}}{COP_{heat\ pump}}$$

Where:

- $COP_{baseline}$ is the coefficient of performance of the baseline heating or cooling system. This is assumed to be 0.78 for shared fossil fuel heating, 0.98 for shared electric heating, and calculated based on a SEER 15 shared cooling system.

- $COP_{heat\ pump}$ is calculated based on the SEER and HSPF of the heat pump retrofit (either mid-efficiency or high efficiency).

In cases where buildings did not have cooling in the baseline, the cooling energy was estimated with the following equation using data from baseline homes with cooling:

$$energy_{cool_{heat\ pump}} = \overline{t_{cool}} \times \overline{cap.\ per\ s.f._{cool}} \times CFA \times \frac{\overline{COP_{cool_{baseline}}}}{COP_{cool_{heat\ pump}}}$$

Where:

- $\overline{t_{cool}}$ is the average runtime of a cooling system for a given building type across all models
- $\overline{cap.\ per\ s.f._{cool}}$ is the average cooling capacity per conditioned square foot for a given building type across all models
- CFA is the model's conditioned floor area
- $\overline{COP_{cool_{baseline}}}$ is the average cooling coefficient of performance for a given baseline building type across all models
- $COP_{cool_{heat\ pump}}$ is calculated based on the SEER and HSPF of the heat pump retrofit (either mid- or high-efficiency)

Duct Sealing and Insulation Savings

In ResStock, duct efficiency retrofits are only included in Package 2.04 "Envelope, Intermediate." This package reduces duct leakage to 10% and insulates ducts to R-8 if the ducts are in unconditioned spaces, but it is paired with other envelope insulation and sealing measures. BayREN provided feedback that HVAC retrofits typically require homes to also make duct leakage and insulation improvements and that it would be more appropriate for the duct efficiency retrofits to be included with any heat pump retrofit packages instead of the medium envelope retrofit package.

ResStock models are run in EnergyPlus, which handles ducts differently depending on location. If the location of ductwork is in a conditioned space (e.g., living space, heated basement, buried in sufficient attic insulation), duct leakage and duct insulation do not have any impact on energy use because the heating and cooling impacts are contained within the conditioned area. If ductwork is in an unconditioned space (e.g., vented crawlspace, uninsulated in attics), then energy is lost to the exterior environment if there is duct leakage and a lack of insulation. The ResStock Package 2.04 will not show heating and cooling savings from duct sealing and insulation measures unless a model has ducts in an unconditioned space. So, by grouping models receiving the 2.04 upgrade by either ducts in unconditioned space or ducts not in unconditioned space, the team was able to determine the energy impact of the 2.04 duct measures.

The team used the following equations to isolate the impacts of duct sealing and insulation in the ResStock Package 2.04 (each building type had this equation applied for both heating and cooling energy):

$$\overline{\%\ energy\ savings_{duct\ measures}} = \overline{\%\ energy\ savings_{2.04_{ducts\ unconditioned}}} - \overline{\%\ energy\ savings_{2.04_{ducts\ conditioned}}}$$

Where:

- $\overline{\%\ energy\ savings_{2.04_{ducts\ unconditioned}}}$ is the average percent energy savings for either heating or cooling for ResStock package 2.04 for models with ducts in unconditioned spaces, applied for each building type

- $\overline{\%\ energy\ savings_{2.04_{ducts\ conditioned}}}$ is the average percent energy savings for either heating or cooling for ResStock package 2.04 for models without ducts in unconditioned spaces, applied for each building type.

This represents the percentage of heating and cooling savings by building type attributable to duct efficiency measures.

Foundation Insulation Savings

BayREN noted concerns that there was a large step in installation intensity between the ResStock Package 2.03 "Envelope, Light Touch" and the ResStock Package 2.04 "Envelope, Intermediate." To lessen this gap, BayREN suggested that a relatively low-effort retrofit in the Bay Area is adding R-19 floor insulation to homes with vented crawlspaces or unconditioned basements. ResStock Package 2.04 "Envelope, Intermediate" opts to handle vented crawlspaces by first sealing them and then insulating the rim joist and foundation wall to R-10. To show that R-19 floor insulation and R-10 foundation wall insulation have similar energy impacts, the team referenced the residential 2024 International Energy Conservation Code (IECC) Table R402.1.3, Insulation Minimum R-Values and Fenestration Requirements by Component. This indicates that R-19 floor cavity insulation and R-10 continuous insulation in unvented crawlspace walls are equivalent options for compliance. So, the team used this foundation insulation measure as a proxy for cavity floor insulation.

Adding cavity floor insulation is generally easier to install than cavity wall insulation. So, the team included floor/foundation insulation impacts with the "Light Envelope Upgrade" used in the BayREN analysis, which also includes air leakage and attic insulation measures.

To isolate the foundation insulation measure from ResStock 2.04, the team removed the impacts of the duct efficiency measures as described in the section above and then used the following equations to separate wall insulation impacts from foundation insulation impacts:

$$\Delta UA_{foundation} = \Delta U_{foundation_{retrofit}} \times area_{foundation}$$

$$\Delta UA_{wall} = \Delta U_{wall_{retrofit}} \times area_{wall}$$

Where:

- $\Delta U_{retrofit}$ is the change in U-factor for the foundation and above-ground walls from the baseline to the retrofit.

These changes in component UAs are then used to determine energy savings from foundation insulation changes (this equation was applied to each building type for both heating and cooling energy):

$$\%\ energy\ savings_{foundation} = \%\ energy\ savings_{med-light} \times \frac{\Delta UA_{foundation}}{\Delta UA_{foundation} + \Delta UA_{wall}}$$

Where:

- $\%\ energy\ savings_{med-light}$ is the total percentage of energy savings for heating and cooling associated with the medium envelope package (with duct measures removed as described in the previous section) and the light envelope package.

The total percentage of energy savings for heating and cooling associated with medium envelope foundation measures is calculated using the ratio of change in foundation UA vs. the change in foundation plus wall UA. This assumes that average annual ground temperatures in the Bay Area are the same as average annual air temperatures.

Advanced HPWH Savings

ResStock only includes one HPWH measure, ResStock Package 4.04 “Water Heating, HPWH for All”, which uses a HPWH UEF of 3.35-3.45. BayREN requested that an advanced HPWH option be included in the analysis to show the impact of more efficient split HPWH models (often with UEF 3.8) being installed through various Bay Area programs.

The team modeled both a single-family and multifamily prototype in EnergyPlus with two different HPWH efficiencies: 3.35 and 3.8. Consistently, the hot water energy savings from the 3.8 UEF HPWH were around 12.0%. There can be interactive effects to heating and cooling if the HPWH is located in or adjacent to conditioned spaces, as the HPWH uses air from the surrounding area to pull heat. However, the team found these impacts to be, on average, less than a 1% change to overall heating and cooling energy. In packages using the advanced HPWH option, the ResStock 4.04 results for electric water heating energy were reduced by 12.0% to reflect these savings.

Electric Cooking

ResStock offers two electric cooking ECMs:

- Measure package 3.03 “Cooking, Electric, Induction, Replaces Non-Electric"
- Measure package 3.04 “Cooking, Electric, Conventional, Replaces Non-Electric"

From a cooking performance perspective, induction can provide quicker cooking times than conventional electric stoves, but induction stoves can be more expensive and also require tenants to purchase different cooking equipment with ferrous metal bottoms. From an energy perspective, there is very little difference between conduction and induction electric cooking. ResStock results show that natural gas cooking in the baseline models makes up an average of 5.1% of total energy, whereas electric cooking with the conventional stove makes up an average of 2.8% of total energy and electric cooking with the induction stove makes up an average of 2.6% of total energy. This analysis used 3.04, the conventional electric cooking replacement, but the energy and GHG results would look very similar if the analysis used induction stove replacements instead.

Interactive Effects

Where possible, the team used ResStock packages directly. But in most cases, multiple ResStock packages needed to be combined and post-processed to reflect the desired BayREN measure packages included in this analysis. For example, BayREN Package 8 uses different ResStock packages for heating and cooling energy, water heating energy, dryer energy, cooking energy, and pool and spa heating energy. This analysis does not include any potential interactive effects between different ResStock packages, but the overall effects are expected to be minimal across different end uses. To account for them in every package in the BayREN analysis that combines multiple ResStock packages, extensive bespoke modeling would be required. However, as described in the “Advanced HPWH Savings” section above, the team did create bespoke EnergyPlus models for one measure, the 3.8 UEF advanced HPWH, and found that there was less than a 1% impact to overall heating and cooling energy compared to the 3.35 UEF HPWH.

BayREN Residential Packages

The following section details the ResStock data that was used in each BayREN retrofit package, how measures apply to the Bay Area residential building stock, and how the modifications described above were implemented for each package element. The table below summarizes the packages included in this analysis.

Package Number	DHW	HVAC	Appliances	Envelope[a]	Lighting
1	Standard HPWH				
2		Mid-efficiency HP + duct efficiency			
3			Electrified		

4				Medium upgrade	
5		Mid-efficiency HP + duct efficiency		Light upgrade	
6	Standard HPWH	Mid-efficiency HP + duct efficiency	Electrified		
7	Standard HPWH	Mid-efficiency HP + duct efficiency	Electrified	Light upgrade	
8	Standard HPWH	Mid-efficiency HP + duct efficiency	Electrified	Medium upgrade	
9				Light upgrade	LEDs
10	Advanced HPWH	High-efficiency HP + duct efficiency	Electrified	Medium upgrade	
11	Advanced HPWH	High-efficiency HP + duct efficiency	Electrified	Advanced upgrade	LEDs

[a] These are the post-processed BayREN envelope packages detailed in the above section, not ResStock envelope packages.

Package 1: Stand-alone Standard HPWH

DHW	HVAC	Ducts	Appliances	Attic/ Roof	Wall	Foundation	Windows	Air Leakage	Lighting
HPWH, 3.35 UEF									

Description:

Replace all residential water heating with standard HPWHs (UEF 3.35).

Application:

Applies to any home that does not use a HPWH with UEF 3.35+ for water heating.

ResStock Data Used:

Package 4.04 “Water Heating, HPWH for All”

Post-Processing:

None

Package 2: Stand-alone mid-efficiency heat pump

DHW	**HVAC**	**Ducts**	Appliances	Attic/ Roof	Wall	Foundation	Windows	Air Leakage	Lighting
	ASHP, SEER 16 HSPF 9.5	Ducts sealed, insulated							

Description:

Replace all residential HVAC systems with a mid-efficiency heat pump (SEER 16, HSPF 9.5) with electric resistance back up heating.

Seal all duct systems to 10% leakage and insulate ducts to R-8 in unconditioned space.

Application:

HP: applies to any home that does not use a more efficient heat pump for heating.

Ducts: applies to any home with leakier and/or less-insulated ducts in unconditioned spaces.

ResStock Data Used:

Package 5.05 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Electric Heating”

Package 5.06 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing NG Heating”

Package 5.07 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Propane Heating”

Package 5.08 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Fuel Oil Heating”
Package 5.17 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Electric Heating”
Package 5.18 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing NG Heating”
Package 5.19 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Propane Heating”
Package 5.20 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Fuel Oil Heating”

Post-Processing:

Shared HVAC systems were replaced with ductless minisplits of SEER 16, HSPF 9.5 using engineering calculations to update heating and cooling energy.

Duct sealing and insulation impacts were added by isolating the duct sealing and insulation measure from the ResStock 2.04 package “Envelope, Intermediate.”

Package 3: Electrified appliances

DHW	HVAC	Ducts	**Appliances**	Attic/ Roof	Wall	Foundation	Windows	Air Leakage	Lighting
			Electric dryers, cooking, pool & spa heaters						

Description:

Replace all residential gas or propane clothes dryers with electric clothes dryers, CEF 3.93.
Replace all indoor gas or propane ranges and ovens with electric resistance ranges and ovens.
Replace all gas pool and spa heaters with electric resistance pool and spa heaters.

Application:

Clothes drying: applies to any home with gas or propane clothes dryers.
Cooking: applies to any home with gas or propane ranges or ovens.
Pool and spa: applies to any home with gas pool or spa heaters.

ResStock Data Used:

Package 3.02: “Dryer, Electric, Replaces Non-Electric"
Package 3.04: “Cooking, Electric, Conventional, Replaces Non-Electric "
Package 3.05: “Pool Heaters, Electric, Replaces Natural Gas"
Package 3.06: “Spa Heaters, Electric, Replaces Natural Gas”

Post-Processing:

None

Package 4: Medium envelope upgrades

DHW	HVAC	Ducts	Appliances	**Attic/ Roof**	**Wall**	**Foundation**	Windows	**Air Leakage**	Lighting
				R-49 attic floor	R-13 wall cavities	R-10, seal crawlspace or R-19 floor cavities		Reduce 30%	

Description:

Insulate attic floor to R-49.

Insulate wall cavities to R-13.
Seal vented crawlspaces.
Insulate foundation wall to R-10 or floor cavities to R-19.
Reduce air leakage by 30%.

Application:
Attic floor insulation: applies to any home with a vented attic and less than R-49 attic floor insulation.
Wall insulation: applies to any home with uninsulated wood stud walls.
Crawlspace sealing: applies to any home with a vented crawlspace.
Foundation/floor insulation: applies to any home without foundation wall or floor insulation.
Air leakage reduction: applies to any home with greater than 10 ACH50.

ResStock Data Used:
Package 2.04 "Envelope, Intermediate"

Post-Processing:
Duct sealing and insulation measures were originally included in the ResStock package for "Envelope, Intermediate," but the impacts were removed from BayREN envelope upgrades and instead included with HVAC upgrades.

Package 5: Mid-efficiency HP + light envelope upgrades

DHW	**HVAC**	**Ducts**	Appliances	**Attic/ Roof**	Wall	**Foundation**	Windows	**Air Leakage**	Lighting
	ASHP, SEER 16 HSPF 9.5	Ducts sealed, insulated		R-49 attic floor		R-10, seal crawlspace or R-19 floor cavities		Reduce 30%	

Description:
Replace all residential HVAC systems with a mid-efficiency heat pump (SEER 16, HSPF 9.5) with electric resistance back up heating.
Seal all duct systems to 10% leakage and insulate ducts to R-8 in unconditioned space.
Insulate attic floor to R-49.
Insulate foundation wall to R-10 or floor cavities to R-19.
Seal vented crawlspaces.
Reduce air leakage by 30%.

Application:
HP: applies to any home that does not use a more efficient heat pump for heating.
Ducts: applies to any home with leakier and/or less-insulated ducts in unconditioned spaces.
Attic floor insulation: applies to any home with a vented attic and less than R-49 attic floor insulation.
Foundation/floor insulation: applies to any home without foundation wall or floor insulation.
Crawlspace sealing: applies to any home with a vented crawlspace.
Air leakage reduction: applies to any home with greater than 10 ACH50.

ResStock Data Used:
Package 7.05 "ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Electric Heating + Envelope, Light Touch"

Package 7.06 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing NG Heating + Envelope, Light Touch”
Package 7.07 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Propane Heating + Envelope, Light Touch”
Package 7.08 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Fuel Oil Heating + Envelope, Light Touch”
Package 7.17 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Electric Heating + Envelope, Light Touch”
Package 7.18 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing NG Heating + Envelope, Light Touch”
Package 7.19 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Propane Heating + Envelope, Light Touch”
Package 7.20 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Fuel Oil Heating + Envelope, Light Touch”

Post-Processing:

Shared HVAC systems were replaced with ductless minisplits of SEER 16, HSPF 9.5 using engineering calculations to update heating and cooling energy.
Duct sealing and insulation impacts were added by isolating the duct sealing and insulation measure from the ResStock 2.04 package “Envelope, Intermediate”
Foundation insulation impacts were added by isolating the foundation insulation and sealing measures from the ResStock 2.04 package “Envelope, Intermediate.”

Package 6: Standard HPWH + mid-efficiency HP + electrified appliances

DHW	**HVAC**	**Ducts**	**Appliances**	Attic/ Roof	Wall	Foundation	Windows	Air Leakage	Lighting
HPWH, 3.35 UEF	ASHP, SEER 16 HSPF 9.5	Ducts sealed, insulated	Electric dryers, cooking, pool & spa heaters						

Description:

Replace all residential water heating with HPWHs (UEF 3.35).
Replace all residential HVAC systems with a mid-efficiency heat pump (SEER 16, HSPF 9.5) with electric resistance back up heating.
Seal all duct systems to 10% leakage and insulate ducts to R-8 in unconditioned space.
Replace all residential gas or propane clothes dryers with electric clothes dryers, CEF 3.93.
Replace all indoor gas or propane ranges and ovens with electric resistance ranges and ovens.
Replace all gas pool and spa heaters with electric resistance pool and spa heaters.

Application:

Water heating: applies to any home that does not use a HPWH with UEF 3.35+ for water heating.
HVAC: applies to any home that does not use a more efficient heat pump for heating.
Ducts: applies to any home with leakier and/or less-insulated ducts in unconditioned spaces.
Clothes drying: applies to any home with gas or propane clothes dryers.
Cooking: applies to any home with gas or propane ranges or ovens.
Pool & spa: applies to any home with gas pool or spa heaters.

ResStock Data Used:

Package 3.02: “Dryer, Electric, Replaces Non-Electric"
Package 3.04: “Cooking, Electric, Conventional, Replaces Non-Electric "
Package 3.05: “Pool Heaters, Electric, Replaces Natural Gas"
Package 3.06: “Spa Heaters, Electric, Replaces Natural Gas”
Package 13.01 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Electric Heating + HPWH”
Package 13.02 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing NG Heating + HPWH”
Package 13.03 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Propane Heating + HPWH”
Package 13.04 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Fuel Oil Heating + HPWH”
Package 13.05 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Electric Heating + HPWH”
Package 13.06 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing NG Heating + HPWH”
Package 13.07 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Propane Heating + HPWH”
Package 13.08 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Fuel Oil Heating + HPWH”

Post-Processing:

Shared HVAC systems were replaced with ductless minisplits of SEER 16, HSPF 9.5 using engineering calculations to update heating and cooling energy.
Duct sealing and insulation impacts were added by isolating the impact of the duct sealing and insulation measure from the ResStock 2.04 package “Envelope, Intermediate.”

Package 7: Standard HPWH + mid-efficiency HP + electrified appliances + light envelope upgrades

DHW	**HVAC**	**Ducts**	**Appliances**	**Attic/ Roof**	Wall	**Foundation**	Windows	**Air Leakage**	Lighting
HPWH, 3.35 UEF	ASHP, SEER 16 HSPF 9.5	Ducts sealed, insulated	Electric dryers, cooking, pool & spa heaters	R-49 attic floor		R-10, seal crawlspace or R-19 floor cavities		Reduce 30%	

Description:

Replace all residential water heating with HPWHs (UEF 3.35).
Replace all residential HVAC systems with a mid-efficiency heat pump (SEER 16, HSPF 9.5) with electric resistance back up heating.
Seal all duct systems to 10% leakage and insulate ducts to R-8 in unconditioned space.
Replace all residential gas or propane clothes dryers with electric clothes dryers, CEF 3.93.
Replace all indoor gas or propane ranges and ovens with electric resistance ranges & ovens.
Replace all gas pool and spa heaters with electric resistance pool and spa heaters.
Insulate attic floor to R-49.
Insulate foundation wall to R-10 or floor cavities to R-19.
Seal vented crawlspaces.
Reduce air leakage by 30%.

Application:

Water heating: applies to any home that does not use a HPWH with UEF 3.35+ for water heating.

HVAC: applies to any home that does not use a more efficient heat pump for heating.
Ducts: applies to any home with leakier and/or less-insulated ducts in unconditioned spaces.
Clothes drying: applies to any home with gas or propane clothes dryers.
Cooking: applies to any home with gas or propane ranges or ovens.
Pool & spa: applies to any home with gas pool or spa heaters.
Attic floor insulation: applies to any home with a vented attic and less than R-49 attic floor insulation.
Foundation/floor insulation: applies to any home without foundation wall or floor insulation.
Crawlspace sealing: applies to any home with a vented crawlspace.
Air leakage reduction: applies to any home with greater than 10 ACH50.

ResStock Data Used:

Package 3.02: “Dryer, Electric, Replaces Non-Electric"
Package 3.04: “Cooking, Electric, Conventional, Replaces Non-Electric "
Package 3.05: “Pool Heaters, Electric, Replaces Natural Gas"
Package 3.06: “Spa Heaters, Electric, Replaces Natural Gas”
Package 15.09 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Electric Heating + HPWH + Envelope, Light Touch”
Package 15.10 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing NG Heating + HPWH + Envelope, Light Touch”
Package 15.11 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Propane Heating + HPWH + Envelope, Light Touch”
Package 15.12 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Fuel Oil Heating + HPWH + Envelope, Light Touch”
Package 15.13 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Electric Heating + HPWH + Envelope, Light Touch”
Package 15.14 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing NG Heating + HPWH + Envelope, Light Touch”
Package 15.15 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Propane Heating + HPWH + Envelope, Light Touch”
Package 15.16 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Fuel Oil Heating + HPWH + Envelope, Light Touch”

Post-Processing:

Shared HVAC systems were replaced with ductless minisplits of SEER 16, HSPF 9.5 using engineering calculations to update heating and cooling energy.
Duct sealing and insulation impacts were added by isolating the impact of the duct sealing and insulation measure from the ResStock 2.04 package “Envelope, Intermediate.”
Foundation insulation impacts were added by isolating the foundation insulation and sealing measures from the ResStock 2.04 package “Envelope, Intermediate.”

Package 8: Standard HPWH + mid-efficiency HP + electrified appliances + medium envelope upgrades

DHW	**HVAC**	**Ducts**	**Appliances**	**Attic/ Roof**	**Wall**	**Foundation**	Windows	**Air Leakage**	Lighting
HPWH, 3.35 UEF	ASHP, SEER 16 HSPF 9.5	Ducts sealed, insulated	Electric dryers, cooking, pool & spa heaters	R-49 attic floor	R-13 wall cavities	R-10, seal crawlspace or R-19 floor cavities		Reduce 30%	

Description:

Replace all residential water heating with HPWHs (UEF 3.35).

Replace all residential HVAC systems with a mid-efficiency heat pump (SEER 16, HSPF 9.5) with electric resistance back up heating.
Seal all duct systems to 10% leakage and insulate ducts to R-8 in unconditioned space.
Replace all residential gas or propane clothes dryers with electric clothes dryers, CEF 3.93.
Replace all indoor gas or propane ranges and ovens with electric resistance ranges & ovens.
Replace all gas pool and spa heaters with electric resistance pool and spa heaters.
Insulate attic floor to R-49.
Insulate wall cavities to R-13.
Insulate foundation wall to R-10 or floor cavities to R-19.
Seal vented crawlspaces.
Reduce air leakage by 30%.

Application:

Water heating: applies to any home that does not use a HPWH with UEF 3.35+ for water heating.
HVAC: applies to any home that does not use a more efficient heat pump for heating.
Ducts: applies to any home with leakier and/or less-insulated ducts in unconditioned spaces.
Clothes drying: applies to any home with gas or propane clothes dryers.
Cooking: applies to any home with gas or propane ranges or ovens.
Pool & spa: applies to any home with gas pool or spa heaters.
Attic floor insulation: applies to any home with a vented attic and less than R-49 attic floor insulation.
Wall insulation: applies to any home with uninsulated wood stud walls.
Foundation/floor insulation: applies to any home without foundation wall or floor insulation.
Crawlspace sealing: applies to any home with a vented crawlspace.
Air leakage reduction: applies to any home with greater than 10 ACH50.

ResStock Data Used:

Package 3.02: “Dryer, Electric, Replaces Non-Electric"
Package 3.04: “Cooking, Electric, Conventional, Replaces Non-Electric "
Package 3.05: “Pool Heaters, Electric, Replaces Natural Gas"
Package 3.06: “Spa Heaters, Electric, Replaces Natural Gas”
Package 4.04 “Water Heating, HPWH for All”
Package 8.05 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Electric Heating + Envelope, Intermediate”
Package 8.06 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing NG Heating + Envelope, Intermediate”
Package 8.07 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Propane Heating + Envelope, Intermediate”
Package 8.08 “ASHP, ENERGY STAR Cold Climate Ducted, Elec Backup, if Existing Fuel Oil Heating + Envelope, Intermediate”
Package 8.17 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Electric Heating + Envelope, Intermediate”
Package 8.18 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing NG Heating + Envelope, Intermediate”
Package 8.19 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Propane Heating + Envelope, Intermediate”
Package 8.20 “MSHP, ENERGY STAR Cold Climate Ductless, Elec Backup, if Existing Fuel Oil Heating + Envelope, Intermediate”

Post-Processing:

Shared HVAC systems were replaced with ductless minisplits of SEER 16, HSPF 9.5 using engineering calculations to update heating and cooling energy.

Package 9: Light envelope upgrades + LEDs

DHW	HVAC	Ducts	Appliances	**Attic/ Roof**	Wall	**Foundation**	Windows	**Air Leakage**	**Lighting**
				R-49 attic floor		R-10, seal crawlspace or R-19 floor cavities		Reduce 30%	100% LED

Description:

Insulate attic floor to R-49.
Insulate foundation wall to R-10 or floor cavities to R-19.
Seal vented crawlspaces.
Reduce air leakage by 30%.
Replace all non-LED lighting with LEDs.

Application:

Attic floor insulation: applies to any home with a vented attic and less than R-49 attic floor insulation.
Foundation/floor insulation: applies to any home without foundation wall or floor insulation.
Crawlspace sealing: applies to any home with a vented crawlspace.
Air leakage reduction: applies to any home with greater than 10 ACH50.
LEDs: applies to any home with less than 100% LED lighting.

ResStock Data Used:

Package 2.03 “Envelope, Light Touch”
Package 3.07 “Lighting, Universal LEDs”

Post-Processing:

Foundation insulation impacts were added by isolating the foundation insulation and sealing measures from the ResStock 2.04 package “Envelope, Intermediate.”

Package 10: Advanced HPWH + high-efficiency HP + electrified appliances + medium envelope upgrades

DHW	**HVAC**	**Ducts**	**Appliances**	**Attic/ Roof**	**Wall**	**Foundation**	Windows	**Air Leakage**	Lighting
HPWH, 3.8 UEF	ASHP, SEER 20 HSPF 11	Ducts sealed, insulated	Electric dryers, cooking, pool & spa heaters	R-49 attic floor	R-13 wall cavities	R-10, seal crawlspace or R-19 floor cavities		Reduce 30%	

Description:

Replace all residential water heating with heat pump water heaters (UEF 3.8).
Replace all residential HVAC systems with a high efficiency heat pump (SEER 20, HSPF 11) with electric resistance back up heating.
Seal all duct systems to 10% leakage and insulate ducts to R-8 in unconditioned space.
Replace all residential gas or propane clothes dryers with electric clothes dryers, CEF 3.93.

Replace all indoor gas or propane ranges and ovens with electric resistance ranges & ovens.
Replace all gas pool and spa heaters with electric resistance pool and spa heaters.
Insulate attic floor to R-49.
Insulate wall cavities to R-13.
Insulate foundation wall to R-10 or floor cavities to R-19.
Seal vented crawlspaces.
Reduce air leakage by 30%.

Application:

Water heating: applies to any home that does not use a HPWH with UEF 3.8+ for water heating.
HVAC: applies to any home that does not use a more efficient heat pump for heating.
Ducts: applies to any home with leakier and/or less-insulated ducts in unconditioned spaces.
Clothes drying: applies to any home with gas or propane clothes dryers.
Cooking: applies to any home with gas or propane ranges or ovens.
Pool & spa: applies to any home with gas pool or spa heaters.
Attic floor insulation: applies to any home with a vented attic and less than R-49 attic floor insulation.
Wall insulation: applies to any home with uninsulated wood stud walls.
Foundation/floor insulation: applies to any home without foundation wall or floor insulation.
Crawlspace sealing: applies to any home with a vented crawlspace.
Air leakage reduction: applies to any home with greater than 10 ACH50.

ResStock Data Used:

Package 3.02: “Dryer, Electric, Replaces Non-Electric"
Package 3.04: “Cooking, Electric, Conventional, Replaces Non-Electric "
Package 3.05: “Pool Heaters, Electric, Replaces Natural Gas"
Package 3.06: “Spa Heaters, Electric, Replaces Natural Gas”
Package 4.04 “Water Heating, HPWH for All”
Package 8.09 “ASHP, Higher Efficiency Cold Climate Ducted, Elec Backup, if Existing Electric Heating + Envelope, Intermediate”
Package 8.10 “ASHP, Higher Efficiency Cold Climate Ducted, Elec Backup, if Existing NG Heating + Envelope, Intermediate”
Package 8.11 “ASHP, Higher Efficiency Cold Climate Ducted, Elec Backup, if Existing Propane Heating + Envelope, Intermediate”
Package 8.12 “ASHP, Higher Efficiency Cold Climate Ducted, Elec Backup, if Existing Fuel Oil Heating + Envelope, Intermediate”
Package 8.21 “MSHP, Higher Efficiency Cold Climate Ductless, Elec Backup, if Existing Electric Heating + Envelope, Intermediate”
Package 8.22 “MSHP, Higher Efficiency Cold Climate Ductless, Elec Backup, if Existing NG Heating + Envelope, Intermediate”
Package 8.23 “MSHP, Higher Efficiency Cold Climate Ductless, Elec Backup, if Existing Propane Heating + Envelope, Intermediate”
Package 8.24 “MSHP, Higher Efficiency Cold Climate Ductless, Elec Backup, if Existing Fuel Oil Heating + Envelope, Intermediate”

Post-Processing:

Shared HVAC systems were replaced with ductless minisplits of SEER 20, HSPF 11 using engineering calculations to update heating and cooling energy.
Advanced HPWH impacts incorporate the ResStock Package 4.04 “Water Heating, HPWH for All” savings and adjust for the higher UEF of the advanced HPWH.

Package 11: Advanced HPWH + high-efficiency HP + electrified appliances + advanced envelope upgrades + LEDs

DHW	HVAC	Ducts	Appliances	Attic/ Roof	Wall	Foundation	Windows	Air Leakage	Lighting
HPWH, 3.8 UEF	ASHP, SEER 20 HSPF 11, exhaust ventilation	Ducts sealed, insulated	Electric dryers, cooking, pool & spa heaters	R-49 attic floor or R-30 roof	R-13 wall cavities, R-5 exterior	R-10, seal crawlspace or R-19 floor cavities	0.28 U-factor	3.0 ACH50	100% LED

Description:

Replace all residential water heating with HPWHs (UEF 3.8).
Replace all residential HVAC systems with a high efficiency heat pump (SEER 20, HSPF 11) with electric resistance back up heating.
Install exhaust ventilation.
Seal all duct systems to 10% leakage and insulate ducts to R-8 in unconditioned space.
Replace all residential gas or propane clothes dryers with electric clothes dryers, CEF 3.93.
Replace all indoor gas or propane ranges and ovens with electric resistance ranges & ovens.
Replace all gas pool and spa heaters with electric resistance pool and spa heaters.
Insulate attic floor to R-49 or roof assembly to R-30.
Insulate wall cavities to R-13 and add R-5 continuous exterior wall insulation.
Insulate foundation wall to R-10 or floor cavities to R-19.
Seal vented crawlspaces.
Replace windows with U-factor 0.28 windows.
Reduce air leakage to 3 ACH50.
Replace all non-LED lighting with LEDs.

Application:

Water heating: applies to any home that does not use a HPWH with UEF 3.8+ for water heating.
HVAC: applies to any home that does not use a more efficient heat pump for heating.
Ventilation: applies to any home that does not have mechanical ventilation.
Ducts: applies to any home with leakier and/or less-insulated ducts in unconditioned spaces.
Clothes drying: applies to any home with gas or propane clothes dryers.
Cooking: applies to any home with gas or propane ranges or ovens.
Pool & spa: applies to any home with gas pool or spa heaters.
Attic floor insulation: applies to any home with a vented attic and less than R-49 attic floor insulation.
Roof assembly insulation: applies to any home with with a finished attic or cathedral ceiling and less than R-30 roof insulation.
Cavity wall insulation: applies to any home with uninsulated wood stud walls.
Continuous exterior wall insulation: applies to any home with less than R-19 wall insulation.
Foundation/floor insulation: applies to any home without foundation wall or floor insulation.
Crawlspace sealing: applies to any home with a vented crawlspace.
Windows: applies to any home with window U-factors more than 0.28.
Air leakage reduction: applies to any home with greater than 3 ACH50.
LEDs: applies to any home with less than 100% LED lighting.

ResStock Data Used:

Package 3.02: “Dryer, Electric, Replaces Non-Electric"
Package 3.04: “Cooking, Electric, Conventional, Replaces Non-Electric "
Package 3.05: “Pool Heaters, Electric, Replaces Natural Gas"

Package 3.06: “Spa Heaters, Electric, Replaces Natural Gas”
Package 3.07 “Lighting, Universal LEDs”
Package 4.04 “Water Heating, HPWH for All”
Package 9.09 “ASHP, Higher Efficiency Cold Climate Ducted, Elec Backup, if Existing Electric Heating + Envelope, Advanced”
Package 9.10 “ASHP, Higher Efficiency Cold Climate Ducted, Elec Backup, if Existing NG Heating + Envelope, Advanced”
Package 9.11 “ASHP, Higher Efficiency Cold Climate Ducted, Elec Backup, if Existing Propane Heating + Envelope, Advanced”
Package 9.12 “ASHP, Higher Efficiency Cold Climate Ducted, Elec Backup, if Existing Fuel Oil Heating + Envelope, Advanced”
Package 9.21 “MSHP, Higher Efficiency Cold Climate Ductless, Elec Backup, if Existing Electric Heating + Envelope, Advanced”
Package 9.22 “MSHP, Higher Efficiency Cold Climate Ductless, Elec Backup, if Existing NG Heating + Envelope, Advanced”
Package 9.23 “MSHP, Higher Efficiency Cold Climate Ductless, Elec Backup, if Existing Propane Heating + Envelope, Advanced”
Package 9.24 “MSHP, Higher Efficiency Cold Climate Ductless, Elec Backup, if Existing Fuel Oil Heating + Envelope, Advanced”

Post-Processing:

Shared HVAC systems were replaced with ductless minisplits of SEER 20, HSPF 11 using engineering calculations to update heating and cooling energy.

Advanced HPWH impacts incorporate the ResStock Package 4.04 “Water Heating, HPWH for All” savings and adjust for the higher UEF of the advanced HPWH.

A.2 Residential Backup Heating

All ResStock heat pump retrofit measures include backup heating functionality, either through adding electric resistance strip heating (commonly included with heat pump installations) or leaving in existing heating equipment as backup for the heat pump. Since this study is looking at total decarbonization, the team will focus on all-electric options only. Electric resistance backup heating can substantially add to winter peaks, since it is used during the coldest hours of the year. This can create spikes on the electric grid much higher than would be caused by heat pumps alone or fossil fuel heating. Electric resistance backup heating hours can also cause a disproportionate increase in energy use due to the discrepancy between heat pump efficiency and electric resistance heating.

Given the relatively mild climate for most parts of the Bay Area, the team hypothesized that homes installing heat pumps in the Bay Area may not need electric resistance backup heating to meet the heating load. The team investigated the ResStock modeling results to understand how often backup electric resistance heating is used in the current models, looking at two ResStock air source heat pump (ASHP) retrofit measures applied to a portion of the Bay Area building stock models:

- Measure 5.02: ASHP replacing natural gas heating systems, ENERGY STAR ducted with electric backup.
  - This will be referred to as the "standard ASHP" case.
- Measure 5.10: ASHP replacing natural gas heating systems, higher efficiency cold climate (ccASHP) ducted with electric backup.
  - This will be referred to as the "ccASHP" case.

Both of these heat pump retrofits were applied to homes that currently have natural gas heating in the Bay Area. These specific measures do not include any other building upgrades, however other packages are available with additional measures included, such as envelope upgrades. ResStock reports the energy used annually for heating by both the main heat pump system and the backup electric resistance heating. It also reports the size of the backup electric resistance heating system, which is autosized in the modeling process. From this, the team estimated the hours per year that the backup heating was used by dividing backup heating energy use (kWh) by backup heating size (kW).

Table 1 shows the grouping of Bay Area ResStock models retrofitted with standard ASHPs by building type and whether backup heating was used. To be clear, all of these models included backup resistance heating, but only a portion of them used the backup system. Figure 1 shows the percentage of models using backup heating with the standard ASHP retrofit by building type. Most single-family (SF) home and mobile home models use backup heating to meet their heating loads under the current modeling conditions, while most multifamily (MF) home models do not. On average, for models that do use backup heating, it is used for less than 22 hours a year (0.25% of the annual hours). However, this represents 5-10% of total heating energy. This suggests that backup heating is only necessary for a small number of hours for the models that use backup heating; the team will further explore if certain model settings such as thermostat setpoints and setbacks contributed to the backup heating use. This also shows that backup electric resistance heating can account for a disproportionate amount of heating energy compared to the runtime, highlighting the importance of minimizing electric resistance heating use.

Table 1. Backup Heating Energy for Standard ASHP Retrofits of NG Furnaces - ResStock Retrofit Measure 5.02

Backup Heating Energy for Standard ASHP Retrofits of NG Furnaces							
Building Type	**Backup Used?**	**Percent of Building Type**	**Avg HP Heating**	**Avg Backup**	**Backup as Total**	**Avg Backup**	**Estimated Avg.**

			Elec (kWh)	Heating Elec (kWh)	Pct of Heating	Size (kBtu/hr)	Hours of Backup
Mobile Home	No	21%	329.3	0.0	0.0%	12.0	0.0
Mobile Home	Yes	79%	1,471.1	137.0	8.5%	22.2	21.0
MF with 2 - 4 Units	No	77%	29.9	0.0	0.0%	1.4	0.0
MF with 2 - 4 Units	Yes	23%	1,075.1	92.6	7.9%	19.6	16.1
MF with 5+ Units	No	86%	35.3	0.0	0.0%	1.5	0.0
MF with 5+ Units	Yes	14%	655.3	34.5	5.0%	12.0	9.8
SF Attached	No	29%	220.1	0.0	0.0%	10.3	0.0
SF Attached	Yes	71%	1,150.2	118.5	9.3%	23.9	16.9
SF Detached	No	19%	839.7	0.0	0.0%	26.5	0.0
SF Detached	Yes	81%	2,695.4	285.9	9.6%	45.2	21.6

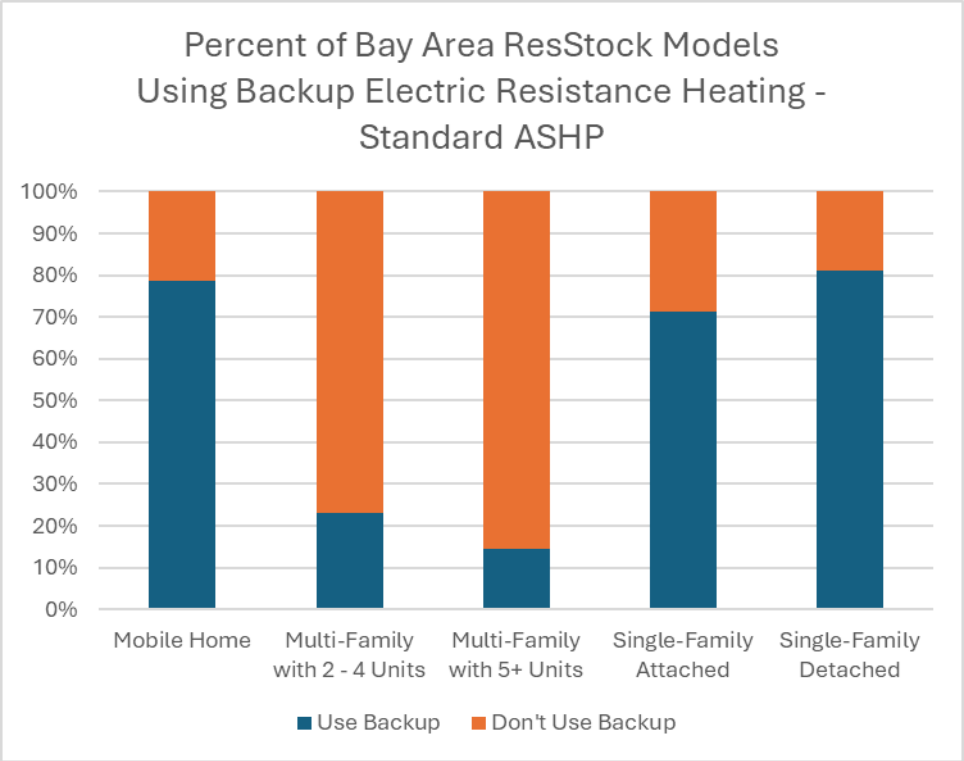

Figure 1. Percent of Bay ResStock Models Using Backup Electric Resistance Heating for Standard ASHP Retrofits of Natural Gas Furnaces (ResStock Retrofit Measure 5.02)

Table 2 shows the grouping of Bay Area ResStock models retrofitted with ccASHPs by building type and whether backup heating was used. Figure 2 shows the percent of homes using backup heating with the ccASHP retrofit by building type. Very few single-family or multi-family homes use backup electric resistance heating in these models. Those that do use the backup heating for less than 0.5% of total heating energy and for less than an hour of annual runtime on average. This suggests that models using ccASHPs do not need backup heating in the Bay Area except in rare instances.

Table 2. Backup Heating Energy for Cold Climate ASHP Retrofits of NG Furnaces - ResStock Retrofit Measure 5.10

Backup Heating Energy for ccASHP Retrofits of NG Furnaces

Building Type	Backup Used?	Percent of Building Type	Avg HP Heating Elec (kWh)	Avg Backup Heating Elec (kWh)	Backup as Total Pct of Heating	Avg Backup Size (kBtu/hr)	Estimated Avg. Hours of Backup
Mobile Home	No	75%	841.4	0.0	0.0%	20.7	0.0
Mobile Home	Yes	25%	1,181.1	3.7	0.3%	18.1	0.7
MF with 2 - 4 Units	No	96%	148.6	0.0	0.0%	5.1	0.0
MF with 2 - 4 Units	Yes	4%	1,171.2	5.0	0.4%	17.2	1.0
MF with 5+ Units	No	96%	72.9	0.0	0.0%	2.8	0.0
MF with 5+ Units	Yes	4%	469.1	2.0	0.4%	8.3	0.8
SF Attached	No	88%	627.6	0.0	0.0%	20.2	0.0
SF Attached	Yes	12%	879.1	3.2	0.4%	18.1	0.6
SF Detached	No	92%	1,693.1	0.0	0.0%	41.9	0.0
SF Detached	Yes	8%	3,283.5	7.8	0.2%	39.2	0.7

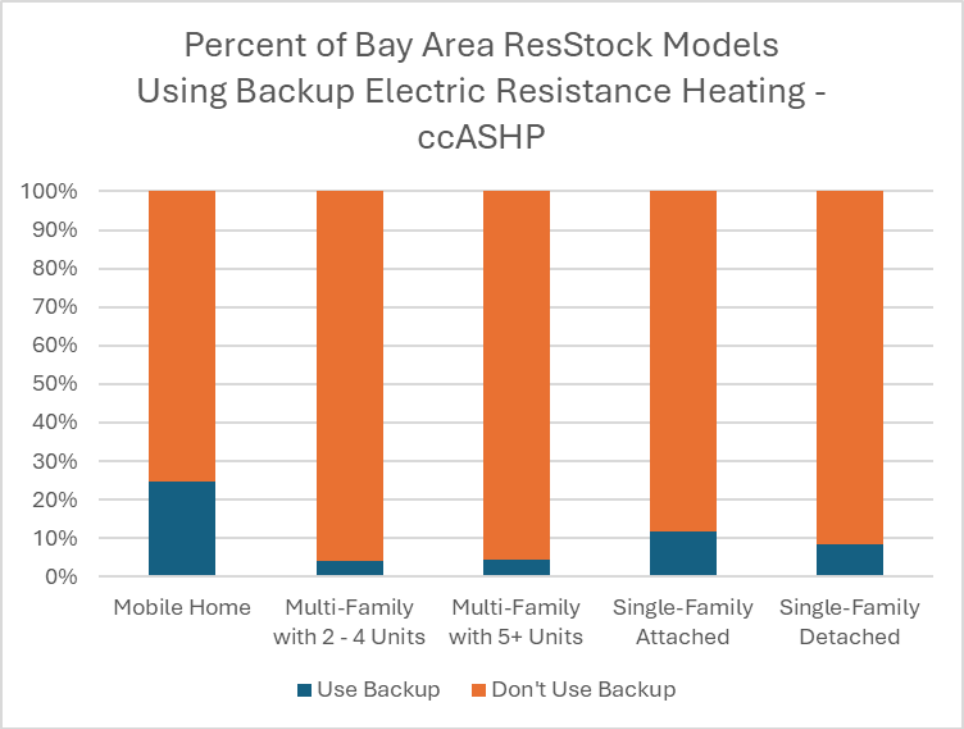

Figure 2. Percent of Bay Area ResStock Models Using Backup Electric Resistance Heating for Cold Climate ASHP Retrofits of NG Furnaces (ResStock Retrofit Measure 5.10)

Single-family detached homes make up the majority of homes in the Bay Area, so the team analyzed the single-family detached models further. This analysis assumed that the most common heat pump retrofit would be a standard ASHP (5.02 ResStock retrofit measure). Table 3 shows the breakdown of whether backup heating was used by climate zone, as designated by the California Energy Commission. Backup heating is less common in Climate Zone 4, which is exclusively Santa Clara County in the Bay Area, while it is more common and a higher percent of total heating energy in Climate Zones 1 and 2, which are Marin, Sonoma, and Napa Counties in the Bay Area. The table below also reports the average conditioned floor area by grouping. This shows that the average home using backup heating is larger than the average home that is not.

Table 3. Backup Heating by Climate Zone for Standard ASHP Retrofits of NG Furnaces in Single-Family Homes - ResStock Retrofit Measure 5.02

Backup Heating Energy for Standard ASHP Retrofits of NG Furnaces, Single-Family Homes					
CEC Climate Zone	Backup Used?	Percent of Climate Zone	Backup as Total Pct of Heating	Est. Hours of Backup	Avg Floor Area (s.f.)
1	No	13%	0.0%	0.0	1,244
1	Yes	87%	12.0%	29.1	2,170
2	No	14%	0.0%	0.0	1,661
2	Yes	86%	13.6%	30.7	1,984
3	No	18%	0.0%	0.0	1,694
3	Yes	82%	8.9%	19.4	1,901
4	No	24%	0.0%	0.0	1,870
4	Yes	76%	9.9%	19.7	2,023
12	No	18%	0.0%	0.0	1,829
12	Yes	82%	8.0%	21.0	2,088

Table 4 shows the breakdown of whether backup heating was used by vintage. The decade with the lowest percent of homes using backup heating is the 1950s and in general homes built before 1970 have a lower percentage of homes using backup heating. However, the differences are slight between decades, so vintage may not be the best indicator of backup heating usage. Pre-1970s homes are smaller on average compared to newer homes, which may contribute to the differences. However, when backup heating is used in pre-1970s homes, it results in a higher percentage of heating energy and runtime compared to newer homes. This may be because they are less insulated than newer homes.

Table 4. Backup Heating by Vintage for Standard ASHP Retrofits of NG Furnaces in Single-Family Homes - ResStock Retrofit Measure 5.02

Backup Heating Energy for Standard ASHP Retrofits of NG Furnaces, Single-Family Homes					
Vintage	Backup Used?	Percent of Vintage	Backup as Total Pct of Heating	Est. Hours of Backup	Avg Floor Area (s.f.)
<1940	No	19%	0.0%	0.0	1,598
<1940	Yes	81%	10.3%	23.4	1,902
1940s	No	19%	0.0%	0.0	1,502
1940s	Yes	81%	9.2%	21.9	1,687
1950s	No	23%	0.0%	0.0	1,557
1950s	Yes	77%	10.0%	23.4	1,692
1960s	No	19%	0.0%	0.0	1,842
1960s	Yes	81%	10.0%	23.7	2,002
1970s	No	16%	0.0%	0.0	1,770
1970s	Yes	84%	10.0%	22.8	1,988
1980s	No	18%	0.0%	0.0	2,079
1980s	Yes	82%	8.8%	18.4	2,186
1990s	No	16%	0.0%	0.0	1,977
1990s	Yes	84%	8.4%	16.0	2,154

2000s	No	16%	0.0%	0.0	2,300
2000s	Yes	84%	7.4%	14.9	2,540
2010s	No	18%	0.0%	0.0	2,367
2010s	Yes	82%	6.2%	12.0	2,509

The team found that some ResStock models in the Bay Area used backup electric resistance heating to meet heating loads with standard ASHPs; a much smaller proportion of models used backup heating when ccASHPs were used. Contractors may install backup electric resistance heating even in milder climates or smaller homes where backup heating may not be necessary, so the team wanted to present the potential impacts of backup resistance heating. Future work on this dataset could include analyzing the impact of removing the backup heating in terms of indoor air temperature and unmet heating hours, or the impact of running the ASHP at a lower performance level to replace periods where the electric resistance backup is used.