Comment Received From: NRDC
Submitted On: 4/5/2023
Docket Number: 22-BSTD-01

Earth Justice, NRDC, RMI, and Sierra Club Joint Comments on AC to HP Replacement Opportunity

Additional submitted attachment is included below.

April 5, 2023

Dear Commissioner McAllister,

We are writing to request that the California Energy Commission evaluate provisions for the 2025 Title 24 code cycle that would require or strongly encourage the replacement of residential air-conditioners (ACs) and commercial rooftop units (RTUs) with heat pump versions of this equipment at the time of equipment changeout. Our organizations represent hundreds of thousands of concerned Californians who are advocating for affordable and equitable building decarbonization and clean air policies to help mitigate the climate crisis. The attached memo documents a preliminary assessment of the feasibility, benefits, and costs of these recommended provisions.

We estimate that 1.9 million residential central ACs in California are currently due for replacement and that in California's commercial buildings, over a quarter of all heating and cooling units are gas RTUs, a substantial portion of which are also due for replacement. Heat pumps are essentially drop-in replacements for both ACs and RTUs, making these upcoming equipment changeouts a ripe opportunity to install heat pumps at a low cost. Requiring a heat pump in these changeout scenarios will not only reduce emissions, but also help safeguard against future gas price volatility and local requirements that may require heat pumps more broadly or disallow natural gas equipment.

For example, the recent Bay Area Air Quality Management District (BAAQMD) decision requires zero-emissions space heating equipment starting in 2029. The recommended code provision would ensure that anyone installing an AC in the Bay Area starting in 2026 would install a heat pump. This would protect Bay Area residents against the potentially costly scenario, when their furnace dies in the future, of having a newly installed AC that they must replace with a heat pump due to the BAAQMD policy, when they could have made this change for minimal incremental cost at the time of their AC installation. Since similar policies are likely to be passed throughout the state in the coming years, adding this provision to Title 24 will ensure that these replacements happen when they are most cost-effective, saving Californians money while reducing emissions.

As shown in the attached preliminary analysis, replacing air conditioners and gas RTUs with heat pumps is generally feasible and cost-effective in most climate zones. We request that the CEC further investigate potential requirements for the 2025 Title 24 Standards that would require or strongly encourage the installation of heat pumps upon replacement of commercial RTUs and residential ACs.

We appreciate the CEC's work to date on accelerating decarbonization through Title 24 and attention to this important issue. We would welcome any questions or further discussion.

Sincerely,

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MEMO

TO: Merrian Borgeson, NRDC

FROM: Meg Waltner and Sean Wynne, Energy 350

SUBJECT: Feasibility Assessment for Heat Pumps at Equipment Replacement

DATE: March 26, 2023

1. Executive Summary

Decarbonization of existing buildings is critical to achieving California's requirement to reduce greenhouse gas emissions 40 percent below 1990 levels by 2030 as well as its objective to achieve carbon neutrality by 2045. California's building code, Title 24, is a key tool to helping achieve these emissions reductions, including ensuring that decarbonization opportunities are realized in existing buildings at the time of renovation or equipment replacement.

This report analyzes the potential opportunity to require existing gas rooftop units (RTUs) to be replaced with heat pump RTUs in commercial buildings, and for air conditioners to be replaced with heat pumps in residential buildings at the time of equipment changeout or retrofit.[1] We focused on these equipment types because heat pumps can be essentially drop-in replacements for gas RTUs and residential ACs, reducing the cost and burden of decarbonization for building owners while delivering significant benefits, both in terms of life cycle cost savings for owners and societal benefits.

This study presents a high-level assessment of the feasibility of this potential measure, specifically looking at:

- Feasibility of replacement
- Identifying market segments where this will be more or less challenging
- Potential market and statewide impact
- Initial evaluation of cost-effectiveness

We found that for both residential and commercial buildings, replacing air conditioners and gas RTUs with heat pumps is generally feasible and cost-effective in most climate zones using the 2025 time dependent valuation (TDV) values.[2] We recommend that the

[1] For residential retrofits, the furnace could be left in place for backup/supplementary heat. We analyzed the impacts both with and without the furnace remaining in place, as presumably some consumers will choose to remove the furnace even if it is allowed to remain in place.

[2] Note that in this analysis the 2023 kBtu TDV to $ TDV adjustment factor was used, as the 2025 adjustment factor was not available.

CEC further investigate potential requirements for the 2025 Title 24 Standards that would require or strongly encourage[3] the installation of heat pumps upon replacement of commercial RTUs and residential air conditioners. Such requirements could help make significant progress towards the statewide goal of 6 million heat pumps deployed by 2030.

Commercial Buildings

In the commercial building sector, the feasibility study results for retrofit of gas RTUs with heat pump RTUs are promising. A review of market literature and product specifications found the following key considerations:

- **Market Potential:** We estimate that gas-fired single zone packaged RTUs account for approximately one-quarter of all commercial HVAC units in California. Within this, we found that the primary market segments for packaged RTUs in California are retail and office buildings (small and large). This indicates that a measure requiring the replacement of these RTUs with heat pump RTUs at the time of equipment changeout has the potential to have substantial impact on emissions reductions in California.
- **Product Line Availability:** We found that unit capacity is a limiting factor, particularly in large facilities. Conventional gas-fired RTUs are available in capacities from 2-150 tons of cooling capacity, whereas heat pump RTUs are only available from 2-28 tons. Any requirement should therefore be limited to units smaller than or equal to 28 tons until higher capacity heat pump RTUs are available. Notably, the cost analysis presented here only considers products up to 5 tons.
- **Heat Performance and Climate:** Heat pump heating capacity and operating efficiency declines at lower outdoor air temperatures when reliance on back up resistance heat increases. Additionally, compressor heating and cooling capacity are linked in a heat pump, giving less flexibility on sizing to meet the heating load or leading to oversizing on the cooling side. Because of these factors impacting some climate zones, a heat pump RTU requirement should be limited to those climate zones where it is cost-effective.
- **Installation Requirements:** Publicly available specifications showed that heat pump RTUs do not typically have unique installation challenges compared to conventional RTUs when retrofitting an existing unit. When compared to conventional units of the same capacity, heat pump RTUs typically have similar physical specifications (dimensions and weight), building connections (ductwork, electrical, etc.), and electrical requirements.
- **Product Costs:** Heat pump RTUs were found to cost 5 percent less on average than gas-fired RTUs of the same cooling capacity according to price data collected from online wholesalers for units of two to five tons.
- **Cost-effectiveness:** CBECC models were created to examine the cost effectiveness of a commercial heat pump RTU retrofit, using the small office building prototypes across five California climate zones – CZ03, CZ07, CZ09, CZ12, and CZ16. The results demonstrate that heat pump RTUs are likely to produce energy and cost

[3] E.g. through a set of prescriptive options with equivalent energy use.

savings in most climate zones compared to a code-minimum gas-fired RTU, with all but CZ16 showing TDV savings using the 2022 TDV.[4] Additionally, as unit costs for heat pumps were found to be less than gas-fired units, heat pump RTUs have the potential to result in both first year and life cycle cost savings compared to gas-fired units.

Residential Buildings

Replacing existing split system air conditioners with heat pumps at the time of equipment change out also appears to be promising. A review of market literature and product specifications found the following key considerations:

- **Market Potential:** We estimate that there are approximately 5.5 million residential central air conditioning units in California, 35 percent of which are greater than 14 years of age and thus due for replacement, indicating high market potential for heat pump retrofits.[5] If all 1.9 million central air conditioners due for replacement were replaced with heat pumps, this would represent substantial progress towards the state's 6 million heat pump goal.
- **Heat Performance and Climate:** As with commercial units, residential heat pump heating capacity and operating efficiency declines at lower outdoor air temperatures. We analyzed two scenarios: one where we kept the existing furnace in place as backup heat and one where we removed the furnace and relied solely on the heat pump. The first iteration was feasible and resulted in cost savings in all climate zones analyzed, while the second resulted in increased costs in climate zones with high heating loads. Our current recommendation would allow the gas furnace to remain in place if desired by the homeowner.
- **Product Line Availability:** Residential heat pumps are available in the same cooling and heating capacities as conventional split systems.
- **Installation Requirements:** Publicly available specifications showed that heat pumps do not typically present unique installation challenges compared to conventional DX air conditioners when retrofitting an existing unit. When compared to conventional units of the same capacity, heat pumps typically have similar physical specifications (dimensions and weight), building connections (ductwork, electrical, etc.), and electrical requirements.
- **Controls Requirements:** Retrofits in which the existing natural gas furnace is used for supplementary heating (i.e. dual fuel) require additional controls compared to a conventional split system. Retrofit may require the additional cost to install a capable thermostat and programming of appropriate heating lockout temperatures. Typical thermostats cost in the range of $100-$250 with an estimated additional $100-$200 for labor.
- **Product Costs:** Residential heat pumps have a cost premium compared to cooling-only direct expansion (DX) split system units. Heat pumps were found to cost 29

[4] We expect these savings to improve using the 2025 energy cost metric values.
[5] Based on data in the *2019 California Residential Appliance Saturation Survey* and U.S. Census housing data for the state of California

percent more on average, representing an incremental cost of $706, according to price data collected from online wholesalers for units of one to five tons.
- **Cost-effectiveness:** CBECC-res models were created to examine the cost effectiveness of replacing a residential air conditioner with a heat pump. We analyzed two scenarios: one where the furnace remained in place as supplemental heat and one where it was removed. The analysis looked at the two-story residential prototype across five California climate zones – CZ03, CZ07, CZ09, CZ12, and CZ16. When the furnace was allowed to remain in place as supplementary heat, the installation of a heat pump in place of an air conditioner resulted in TDV and TDS savings in every climate zone analyzed. The heat pump only model did not result in TDV savings in climate zone 16. The results demonstrate that heat pumps are likely to produce energy and cost savings in most climate zones compared to a code-minimum DX split system. Additionally, heat pumps with gas back up were found to have a benefit to cost ratio greater than one in all but Climate Zones 7 and 9, showing they are anticipated to be a cost-effective solution in most zones.

Recommendations

Based on these results we recommend that the CEC consider and further analyze the following measures for the 2025 code cycle: [6]

- **Commercial**: At time of equipment changeout, gas RTUs up to 5 tons of cooling capacity should be replaced with a heat pump RTU for all climate zones where this is found to be cost-effective using the 2025 energy cost metric values.
- **Residential:** At time of equipment change out, residential split ACs should be replaced with a split heat pump for all climate zones where this is found to be cost-effective using the 2025 energy cost metric values. This requirement would allow an existing gas furnace to remain as backup heat, if desired. We recommend that the CEC consider how such a requirement might pair with complementary state policies providing incentive funding for heat pumps that could help defray the incremental first cost of a heat pump compared to an air conditioner, particularly for low-income consumers.

There are multiple ways that these requirements could be structured. There could be a direct prescriptive requirement that simply prohibited the installation of a gas RTU or non-heat pump split system AC in an existing building unless certain exceptions were met. There are several precedents for this sort of requirement. For example, Title 24 2016 prohibited the installation of an electric water heater in an existing building unless no natural gas was connected to the building (2016 Title 24 Section 150.2(b)Gii). Similarly, the 2022 code prohibits the installation of resistance heating in an existing building unless certain exceptions are met (Title 24 2022 Section 150.2(b)G). Alternatively, the requirements could be structured as one of multiple prescriptive options with equivalent TDV energy use. This

[6] Note that our analysis did not consider all climate zones.

would be similar to the prescriptive options for residential water heating in new construction in the 2022 code (Title 24 2022 Section 150.1(c)8). Under both of these options, gas could still be allowed under the performance path.

2. Feasibility Study

2.1 Commercial Buildings –Packaged Heat Pump Rooftop Units

For commercial buildings, this study provides a high-level feasibility assessment of requiring existing gas rooftop units (RTUs) to be replaced with heat pump RTUs at the time of changeout or retrofit.

2.1.1 Market Potential

To assess the current market share of packaged rooftop units with natural gas heat we looked to the 2014 California Commercial Saturation Survey (CSS). The CSS found that packaged single zone systems, most commonly consisting of rooftop units, account for 59 percent of the commercial HVAC units in California, as shown in Figure 1.[7] Packaged single zone units can be direct expansion cooling with gas-fired heating, heat pump systems, or, less commonly, DX cooling with electric resistance heat. Though not delineated by system type, the survey showed that natural gas furnaces are used for heat in 44 percent of all HVAC units, while heat pumps only account for 31 percent of all units. By applying this distribution to the share of packaged single zone systems, **we estimate that natural gas-fired packaged single zone rooftop units account for approximately 26 percent of all commercial HVAC systems in California.**

[7] https://www.calmac.org/publications/California_Commercial_Saturation_Study_Report_Finalv2.pdf

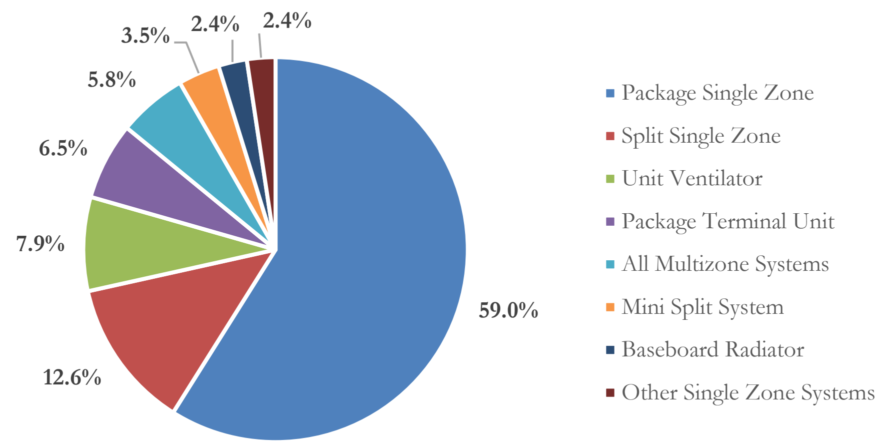

Figure 1 –Distribution of HVAC Units by System Type
Source: 2014 California Commercial Saturation Survey

Further, the CSS demonstrated that of the survey respondents 22 percent were older than the 15-year effective useful life (EUL) of a rooftop unit and 45 percent of units were missing age information. Assuming that the 2014 CSS results are representative, and no significant changes in equipment turnover rates have occurred in the years since, the survey demonstrates that **a substantial portion of HVAC units throughout the state of California are due for replacement at any given time.**

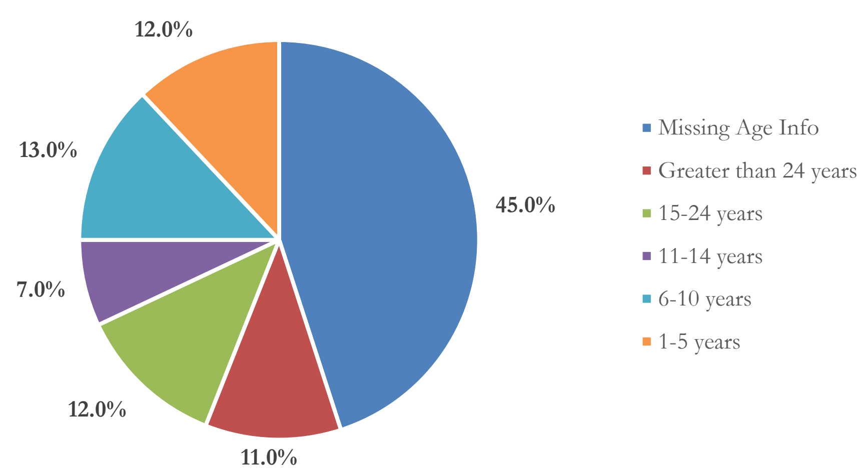

Figure 2 –Distribution of Commercial HVAC Units by Age
Source: 2014 California Commercial Saturation Survey

Regarding market sector, data collected by the Energy Information Administration's 2018 Commercial Building Energy Consumption Survey (CBECS) demonstrates that packaged heating and air conditioning units are most prevalent in mercantile (retail) and office buildings.[8] These building types also represent the most prevalent market for heat pump heating and cooling, followed by religious worship, education, and public assembly. Note that the CBECS definitions do not clearly distinguish between packaged heating units and heat pumps. It is thus possible that a fraction of the packaged heating units may in fact be heat pumps, and vis versa. However, as a source for identifying which sector each of these systems is most prevalent, the data is still valuable.

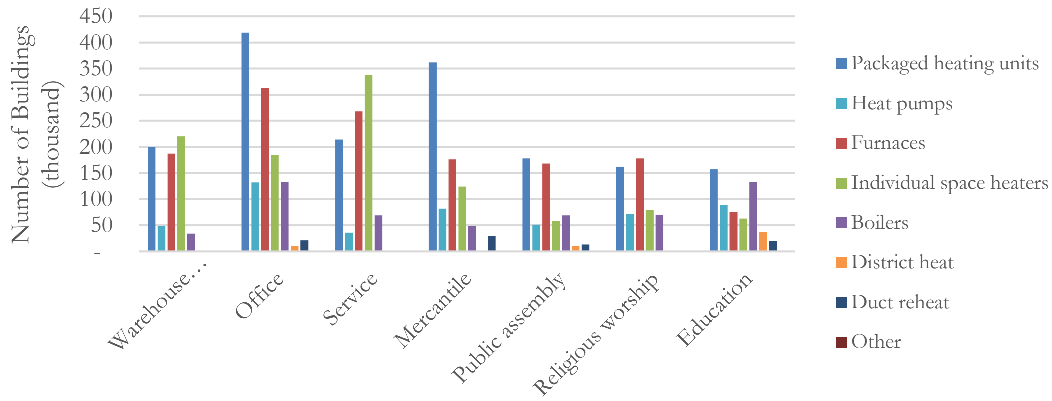

Figure 3 - U.S. Heating Equipment by Market Sector
Source: 2018 Commercial Building Energy Consumption Survey

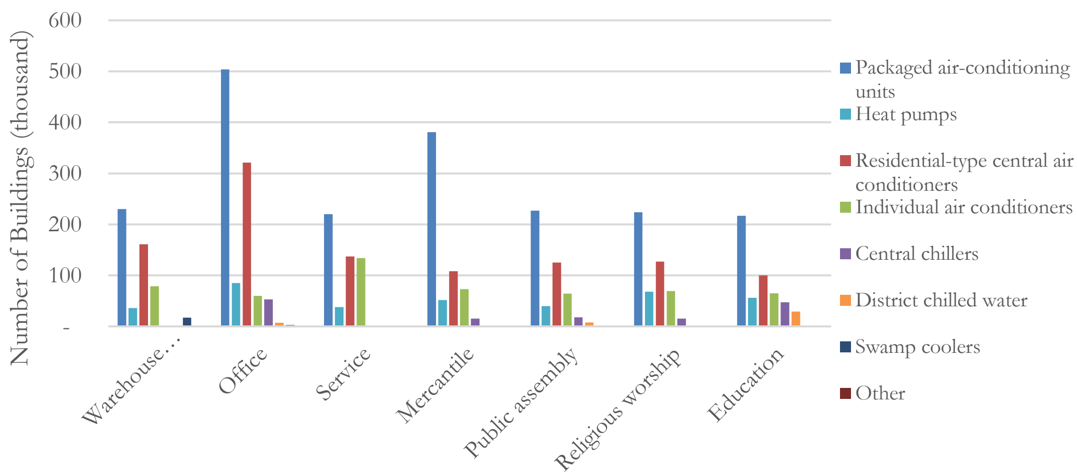

Figure 4 – U.S. Cooling Equipment by Market Sector
Source: 2018 Commercial Building Energy Consumption Survey

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[8] https://www.eia.gov/consumption/commercial/data/2018/index.php?view=characteristics (See Table B11)

2.1.2 Product Details

2.1.2.1 Cost

One of the primary factors in considering requiring heat pump RTUs would be the impact on installation costs incurred by the building owner. To represent this impact, we examined the incremental equipment cost between a code-minimum heat pump RTU and a code-minimum gas-fired RTU. Equipment costs were obtained from wholesale websites (one of the few sources of publicly available cost data for HVAC equipment), with cost obtained for two manufacturers, Daikin and Goodman.[9,10] Available cost information from these websites is generally limited to small capacity units (2-5 tons of cooling) with basic features. However, since the CSS found that small units of an average 3.6 tons in capacity account for 83 percent of HVAC units with DX cooling surveyed,[11] the cost data collected is assumed to represent a significant share of the RTU market. For the purposes of this feasibility study, it has been assumed that for a typical installation, labor, taxes and fees, and additional mark-ups will be similar between the heat pump and gas-fired units. Barriers specific to heat pump units may have adverse impacts on heat pump installation costs and are discussed in the following section. Figure 5 shows a summary of the average costs for forty-eight code-minimum gas-fired units and twenty-four code-minimum heat pump units. Unexpectedly, heat pump equipment costs were observed to be lower on average than those of gas-fired RTUs. For a unit between two and five tons, the equipment cost of a code-minimum heat pump RTU was found to be an average of 5 percent lower than the costs for a gas-fired unit.

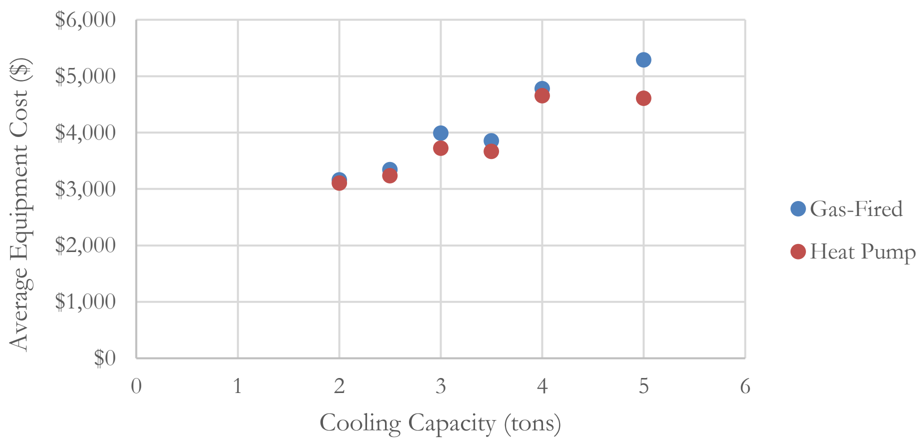

Figure 5 – Comparison of Equipment Costs for Code-minimum heat pump and gas-fired RTUs

2.1.2.2 Product Range

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9 https://www.theacoutlet.com/complete-ac-systems/packaged-systems.html
10 https://hvacdirect.com/packaged-rooftop-units/
11 https://www.calmac.org/publications/California_Commercial_Saturation_Study_Report_Finalv2.pdf

Commercial heat pump rooftop units have a narrower range of products than gas-fired rooftop units. This is likely a combination of technological limitations and market drivers. To assess the range of products available between the two cases, a survey of the available product line of three major RTU manufacturers was performed (Daikin, Trane, and Lennox). Currently, gas-fired RTUs are available from 2-150 tons of cooling capacity, while heat pump RTUs are only available in capacities of 2-28 tons. Cooling efficiencies are similar between the two product types, ranging from 14-17 SEER and 10.8-13 EER for gas-fired units, and 14-17 SEER and 11.2-12.6 EER for heat pump units.

2.1.2.3 Barriers

Installation Requirements

General installation requirements between heat pump and gas-fired RTUs are similar without specific heat pump barriers. Due to typical installation on rooftops, installation for each type will require a lift or crane for placement. Specifications for the 2-5 ton units examined showed that heat pump units weigh less on average than gas-fired units, likely due to the elimination of the gas-fired furnace, and thus would have no additional requirements for lift capacity. As the heat pump units are electricity only, no additional gas-piping work would be required beyond disconnecting the original unit and decommissioning the gas line as required by building code.

Electrical Requirements

Since upgrading from gas-fired to heat pump rooftop units converts the facility heating from natural gas to electricity, the heat pump will have a larger electric draw than the gas-fired system. Examination of specifications on units from the online HVAC wholesalers showed that most heat pumps RTUs had similar amperage requirements to gas-fired RTUs, with little variations in amps required between gas-fired and heat pump units of the same cooling capacity. Heat pumps are available as single phase and three phase across several voltage options, and thus an appropriate heat pump should be available for most circumstances. A comparison of sample gas-fired and heat pump RTU specifications is shown in

Table 1.

Table 1 – Comparison of Sample Commercial Packaged RTU Specifications

	Gas-Fired RTU	Heat Pump RTU
GroupKit	Multi-Position Package Unit Kit	Horizontal Package Unit Kit
Type	Gas Heat	Heat Pump
Brand	Goodman	
Ton	3.0 Ton	3.0 Ton
Seer	14 Seer	14 Seer
AFUE	81% Afue	
Category	Packaged Systems	Packaged Systems
Model Number(s)	GPG1436040M41	GPH1436H41
SEER	14	14
HSPF		8
Cooling Btu	34,200	34,400
Heating Btu	40,000	33,200
Cooling Stage(s)	1	1
Compressor Stage	Single	Single
Voltage	208/230V	208/230V
Electrical Phase(s)	1	1
Hertz (Hz)	60	60
Decibel Level (dB)	78	
Maximum CFM	1,200	1,200
Refrigerant Type	R-410A	R-410A
Height (Inches)	34.75	35
Length (Inches)	51	66.25
Width (Inches)	47	34
Total Shipping Weight (lbs.)	470	385
Parts Warranty (Years)	10	10
Compressor Warranty (Years)	10	10
Heat Exchanger Warranty (Years)	20	
AC Outlet Cost	$3,432.00	$3,465.00

Physical Space and Mounting Requirements

Retrofit of a rooftop unit requires ensuring that the building structure and space can support the proposed unit. One component of this process is ensuring that the proposed unit is compatible with the existing curb (a device used to support the weight of the rooftop unit and provide and opening to the building). Manufacturers appear to have made efforts to ensure that RTUs (both heat pump and gas-fired) are cross compatible with many existing curbs and provide literature to aid in determination. Daikin provides the *Daikin Light Commercial Rooftop Units Cross Reference Guide* for example.[12] In the event that the proposed unit is not compatible, curb adapters are available with equipment cost in the $2,000-$3,000 range.[13] Ultimately, this issue is not unique to heat pump RTUs, however, and must be overcome for retrofit with new gas-fired RTUs as well. Therefore, the cost of a curb adaptor was not included in the cost analysis.

Heating Performance and Climate

Heat pumps are more susceptible to weather conditions. Typical minimum efficiency heat pump capacities and efficiencies begin to drop significantly at lower temperatures and are often reported at several testing conditions (often 47°F and 17°F) to allow customers to determine the best fit. Trane reports that heat pump efficiencies begin to suffer at

[12] https://backend.daikincomfort.com/docs/default-source/product-documents/light-commercial/other/pf-rtu_curbfit.pdf

[13] https://hvacdirect.com/instantsearchplus/result?q=curb+adapter

temperatures below 25°F.[14] This threshold will depend on the specific equipment performance characteristics. While high performance heat pumps are available that maintain capacity and efficiency at cold climate conditions, this analysis focused on minimum efficiency heat pumps. Minimum efficiency heat pumps are often fit with a supplementary electric resistance heating coil to provide additional heating at low outside air temperatures, which may adversely impact energy performance. As a result of this performance limitation, heating dominated climates may not be the ideal climate for requirement of a minimum efficiency heat pump RTU, due to the energy use of the supplementary electric heat, as will be further examined with the modeling results in Section 2.1.4.

Further, heating capacity is not as customizable for heat pumps RTUs as for gas-fired RTUs. Since heating and cooling are provided using the same coils, the capacities are interconnected, whereas gas-fired units can simply be purchased with a heating section of the desired capacity. Looking at the sample specifications in

[14] https://www.trane.com/residential/en/resources/glossary/what-is-hspf/

Table 1 for example, the heat pump has a heating capacity of 33,200 Btu/h, while the gas-fired unit could be purchased with capacities of 40,000-80,000 Btu/h. As a result, in heating driven climates, care must be taken to select a heat pump capable of providing the correct capacity, with a potential outcome of being limited in heat pump application, running the supplementary heating system more, or oversizing of the cooling capacity (which would increase costs). This is something that should be considered further as this feasibility study is developed into a code proposal.

2.1.3 Cost-Effectiveness Analysis

An energy and cost analysis was performed to determine the potential cost effectiveness of requiring retrofit of commercial buildings with code-minimum heat pump RTUs as an alternative to code-minimum gas-fired RTUs.

Energy models were created using the California Building Energy Code Compliance (CBECC) 2025 software. Since offices are one of the primary use cases for heat pump RTUs, to provide a representative sample of energy impacts from a commercial heat pump retrofit, energy models were constructed using the Small Office prototype model provided with the software, which represents a single-story office of 5,502 conditioned square feet, served by five single zone packaged rooftop units. Model iterations were created for a building with T24 code-compliant gas-fired heat pump RTUs (baseline) and with code-compliant gas-fired RTUs (proposed), and a summary of the HVAC specifications used in the models is shown in Table 2. HVAC efficiencies used in the models are based on the upcoming Department of Energy's new minimum efficiency standards for commercial air conditioning and heat pump equipment that will go into effect on January 1, 2023. Since the feasibility study is examining an alteration measure, envelope details for the prototype were updated from Title 24 code compliance to values reflective of a typical existing office building based on our experience and engineering judgement, as summarized in Table 3.

Table 2 – CBECC Model HVAC Specifications – Small Office

Component	Baseline	Proposed
System Type	SZAC - Single Zone Air Conditioner	SZHP – Single Zone HP
Number of Units	5	5
Cooling Coil	Direct Expansion	Direct Expansion
Cooling Efficiency	14 SEER	14 SEER
Heating Type	Gas Furnace	Heat Pump
Heating Efficiency	78% AFUE	8.0 HSPF

Table 3 – Adjustments to CBECC Prototype - Small Office

Component	Type	CBECC Prototype Specs	Adjusted Values
Exterior Walls	Metal Frame Wall	U-Factor: 0.055 Cont. Insulation: R16.05	U-Factor: 0.076 Cont. Insulation: R11
Roof	Steep Wood Frame	U-Factor: 0.034 Cont. Insulation: R28.63	U-Factor: 0.047 Cont. Insulation: 20.54
Windows	Fixed	U-Factor: 0.340 SHGC: 0.220 VT: 0.42	U-Factor: 1.2 SHGC: 0.4 VT: 0.8
Door	Glazed	U-Factor: 0.45 SHGC: 0.23 VT: 0.17	U-Factor: 1.2 SHGC: 0.4 VT: 0.8
Below Grade Floor	Unheated Slab-on-grade	F-Factor: 0.730 Insulation Orientation: None R-Value: R0	F-Factor: 0.730 Insulation Orientation: None R-Value: R0
Exterior Floor	Other	U-Factor: 0.071 Cont. Insulation: 9.83	U-Factor: 0.071 Cont. Insulation: 9.83

To provide a representative overview of the potential statewide impacts, iterations of each HVAC type were created for a sample of five California climate zones – CZ03, CZ07, CZ09, CZ12, and CZ16. The climate zones were sampled based upon their varying geographic regions which span the southern coast (CZ07) to north central California (CZ16) and encompass a variety of climate conditions. A summary of the cooling and heating design days and degree days for each of the sampled zones is shown in Table 4.

Table 4 – Climate Zone Degree Days[15]

Climate Zone	Reference City	Summer Design Day[16] (°F)	Cooling Degree Days (Base 65)	Winter Design Day[17] (°F)	Heating Degree Days (Base 65)
CZ03	Oakland	80°F	128	35°F	2,909
CZ07	San Diego	80°F	984	44°F	1,256
CZ09	Los Angeles (Civic Center)	89°F	1,537	40°F	1,154
CZ12	Stockton	97°F	1,470	30°F	2,702
CZ16	Bishop	100°F	1,037	15°F	4,313

2.1.4 Modeling Results

The energy savings from the Small Office CBECC models are presented in Table 5, comparing the energy consumption of a code-minimum heat pump RTU to a gas-fired RTU baseline. Figure 6 presents a comparison of the total time dependent valuation (TDV) for the heat pump RTUs compared to the baseline in each of the five sampled climate zones. Figure 7 presents the same comparison for total time dependent source (TDS) energy consumption. From the estimated TDV savings, the data demonstrates that with the exception of Climate Zone 16, which is heavily heating dominated, the installation of heat pump RTUs is estimated to have a net positive impact at small offices in the state of California. Energy savings in the building are attributed primarily to decreased heating and fan consumption, driven by the change from gas heating to more efficient heat pump heating, and from the lower fan power allowance of heat pump RTUs (SZHP) compared to gas-fired RTUs (SZAC).[18] Notably, Climate Zones 3, 7, and 9 have an estimated net positive savings in electricity consumption. The low heating load in these CZ07 and CZ09, and low cooling load in CZ03, results in the increase in heating electric use of the heat pump system being offset by the fan savings from the reduced fan power.

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[15] https://www.pge.com/myhome/edusafety/workshopstraining/pec/toolbox/arch/climate/index.shtml

[16] Summer design days are reported here as temperatures for the 2.5 percent annual percentile.

[17] Winter design days are reported here as temperatures for the 97.5 percent annual percentile.

[18] According to the *2022 Nonresidential and Multifamily Alternative Calculation Method Reference Manual*, the fan power allowance for heat-pump RTUs (SZHP) is 0.744 W/cfm, while the allowance for gas-fired RTUs (SZAC) is 0.802 W/cfm.

Table 5 – Commercial Heat Pump RTU Savings Per Year – Small Office

Climate Zone	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)	TDV Energy Savings (kTDV/ft²/yr)
CZ03	91	219.0	10
CZ07	1,874	28.1	11
CZ09	1,370	85.0	11
CZ12	(1,188)	328.5	8
CZ16	(9,128)	939.9	(23)

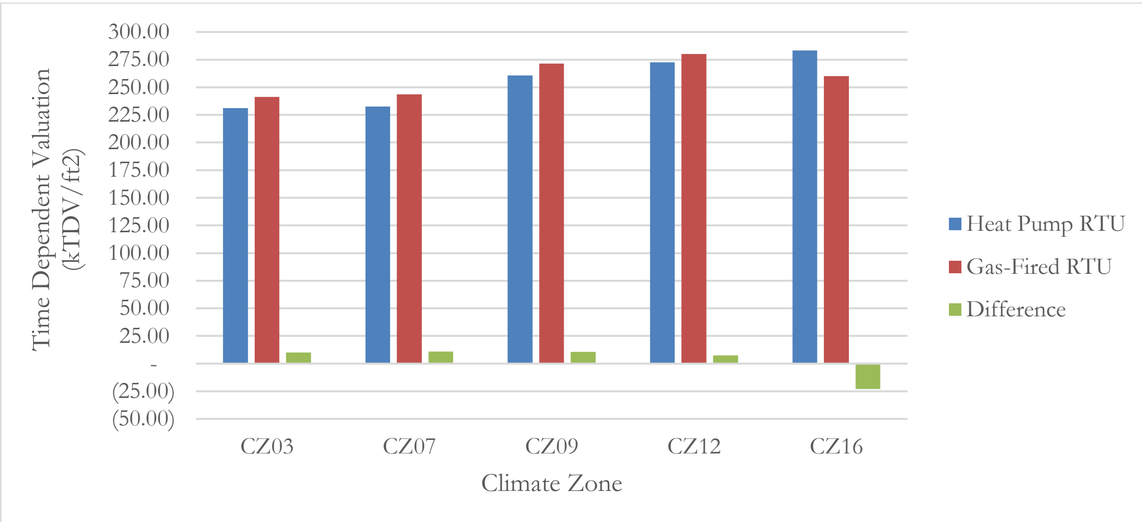

Figure 6 – Comparison of Baseline and Proposed CBECC Model TDV (kTDV/ft²) – Small Office

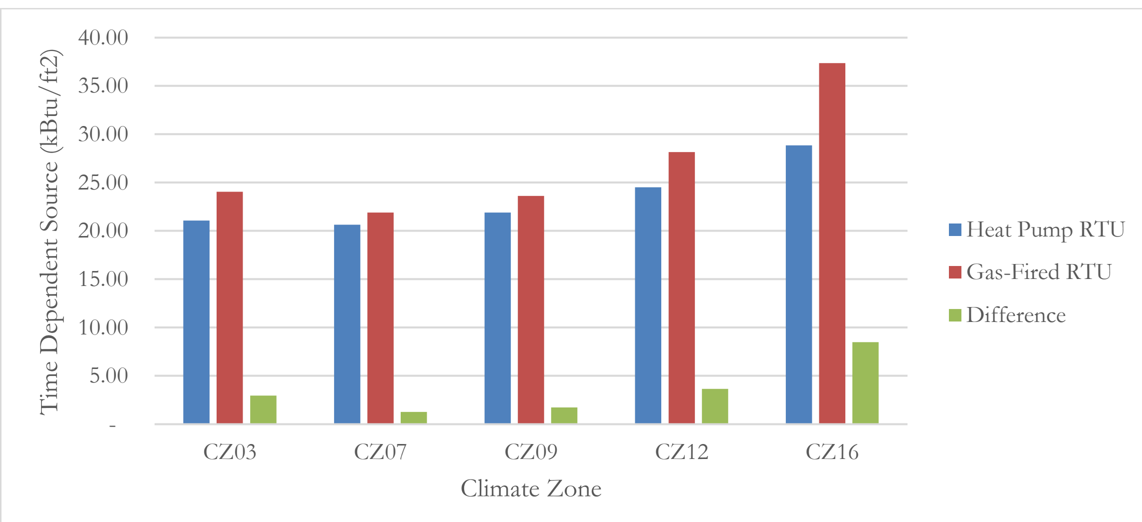

Figure 7 – Comparison of Baseline and Proposed CBECC Model TDS (kBtu/ft²) – Small Office

2.1.5 Cost Effectiveness

The estimated 2025 TDV energy costs per square foot for the energy models are presented in Table 6, determined by multiplying the TDV values in CBECC by the conversion factor from kBTU TDV to $ TDV.[19] The TDV results show the present value of costs across the assumed lifetime of the equipment (15 years for non-residential HVAC). The CBECC Small Office model demonstrates energy cost savings for each climate zone, again except for CZ16 due to the high heating requirements. Since the heat pump RTUs were found to have lower equipment costs on average than a code-minimum gas fired RTU, this measure is anticipated to be cost effective under most circumstances. Adverse impacts could occur in the case of alterations needing to be made to the facility to accommodate the proposed unit. However, as discussed many of the potential installation issues are not unique to heat pumps and would apply to the baseline code-minimum gas fired unit as well. A summary of the estimated equipment costs for retrofit of the five rooftop units in the small office prototype model is presented in Table 7. Variations in costs for each climate zone are the result of changes in unit cooling capacity required to serve the Small Office Prototype.

Table 6 – Commercial Heat Pump Estimated Cost Savings – Small Office

Climate Zone	TDV Energy Costs (TDV $/ft^2) - 2025 PV Non-Res 15-yr		TDV Savings (TDV $/ft^2)
	Heat Pump RTU	Gas Fired RTU	
CZ03	$20.57	$21.47	$0.90
CZ07	$20.71	$21.69	$0.98
CZ09	$23.20	$23.64	$0.95
CZ12	$24.26	$24.94	$0.68
CZ16	$25.20	$23.16	$(2.05)

Table 7 –Estimated RTU Equipment Costs for Prototype Retrofit - Small Office

Climate Zone	Equipment Costs ($/ft^2)		Incremental HP Cost ($/ft^2)
	Heat Pump RTU	Gas Fired RTU	
CZ03	$2.95	$3.03	$(0.09)
CZ07	$2.95	$3.03	$(0.09)
CZ09	$3.17	$3.27	$(0.09)
CZ12	$3.08	$3.22	$(0.13)
CZ16	$3.29	$3.42	$(0.13)

19 The kBtu TDV to $ TDV factor used in the analysis is the non-residential, 15-year, 2023 PV Adjustment factor of $0.089/kBtu TDV.

2.2 Residential Buildings –Replacing Split System ACs with Heat Pumps

For residential buildings, this study provides a high-level feasibility assessment of requiring existing split system air conditioners to be replaced with split system heat pumps at time of equipment change out. We analyzed scenarios both with and without the existing furnace being left in place. For simplicity and cost savings, the recommendation is to leave the existing furnace in place, with the potential to provide back-up/supplementary heat for the heat pump.

2.2.1 Market Potential

To gain market insights, we performed a targeted assessment of data provided in the *2019 California Residential Appliance Saturation Study (RASS)* performed by DNV GL Energy Insights USA, Inc. for the California Energy Commission.[20] ‘

Based on data from the RASS study, 63 percent of the 29,863 single family detached residences, townhomes, duplexes, or row houses surveyed report paying for central cooling. By applying this distribution to the California housing stock as reported by U.S. Census data, there are an estimated 5,578,365 single family detached or attached homes with cooling in the state of California.[21] The RASS survey also asked respondents to report the type – central air conditioning, central evaporative cooling, heat pump cooling, mini-split cooling, or room air conditioning – and number of air conditioning units at their residence. Applying this distribution to the estimated California residences with cooling yields an estimate of 5,554,852 central air conditioning units in the state of California. A summary of the methodology for this estimate is provided in Table 8 and

[20] https://webtools.dnv.com/CA_RASS/

[21] https://data.census.gov/table?q=year+structure+built&g=0400000US06&tid=ACSST1Y2021.S2504

Table 9.

Table 8 – Estimate of Number of CA Single Family Residences with Cooling

Pays for Cooling	**2019 California Residential Appliance Saturation Study (RASS)**				**Statewide Estimate**
	Single Family	**Townhouse, Duplex, or Row House**	**Total Single Family Detached or Attached**	**%**	**Single Family Detached or Attached**
Yes	**17,050**	**1,863**	**18,913**	**63%**	**5,578,365**
No Part of Rent	96	64	160	1%	47,192
No Cooling	7,571	1,423	8,994	30%	2,652,769
No Response	1,546	250	1,796	6%	529,728
Total Sample	26,263	3,600	29,863		8,808,054

Table 9 – Estimate of Number of Central Air Conditioning Units in CA

Number of Central AC Units	2019 California Residential Appliance Saturation Study (RASS)		Statewide Estimate	
	Total	%	Single Family Detached or Attached Homes	Estimated Number of Central AC Units in CA
0	1,829	13%	544,383	-
1	14,277	74%	4,249,404	4,249,404
2	2,055	9%	611,650	1,223,300
3	92	1%	27,383	82,149
No response	489	3%	145,546	-
Total	18,742		**5,578,365**	**5,554,852**

Further, the RASS study collected information on age of the existing heating and cooling equipment, as demonstrated in Figure 8. Note that the survey only collected the age of equipment from the total sample, not delineated by building type, and space heating equipment based on fuel type rather than equipment type. The May 2022 *California Heat Pump Residential Market Characterization and Baseline Study* performed by Opinion Dynamics for the California Public Utilities Commission (CPUC) utilized an independent targeted analysis of the RASS data.[22] According to the study, based on the RASS data, 35 percent of the 19,872 reported central air conditioning systems are greater than 14 years of age, near or exceeding the EUL of 15 years. The heating equipment was similarly aged, with 44 percent of natural gas heating equipment reported as greater than 14 years of age. Based on this data, a large share of the split system residential air conditioners in California are likely due for an upgrade in the near future. Applying the age distribution to the estimated total central air conditioners provides an estimate of 1,944,198 central air conditioners that are greater than 14 years of age.

[22] https://pda.energydataweb.com/api/view/2610/OD-CPUC-Heat-Pump-Market-Study-Report-final-4-2022.pdf

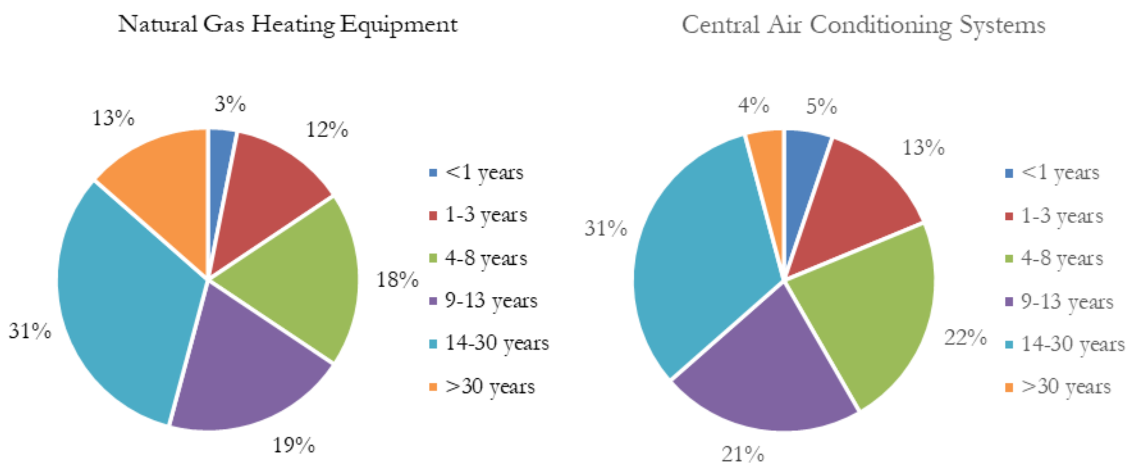

Figure 8 – Reported Age of Heating and Cooling Equipment in California Residences
Source: 2022 California Heat Pump Residential Market Characterization and Baseline Study

2.2.2 Product Details

2.2.2.1 Cost

One of the primary factors in considering requiring heat pumps would be the impact on installation costs incurred by the building owner. To represent this impact, we examined the incremental equipment cost between a code-minimum heat pump and a code-minimum direct expansion air conditioner, while assuming the existing gas-furnace would be left in place. Equipment costs were obtained from wholesale websites, with cost obtained for two manufacturers, Goodman and Rheem/Ruud.[23,24] Available cost information was available for residential units of 1-5 tons of cooling, typical for a residential home. Figure 9 shows a summary of the average costs for fifty code-minimum DX units and twenty-five code-minimum heat pump units. On average, the equipment costs for a 1-5 ton heat pump were found to be approximately 29 percent higher than that of a code-minimum DX unit (without a new furnace), which translates to an average cost of $706.

[23] https://www.theacoutlet.com/complete-ac-systems/split-systems.html
[24] https://www.acdirect.com/complete-systems

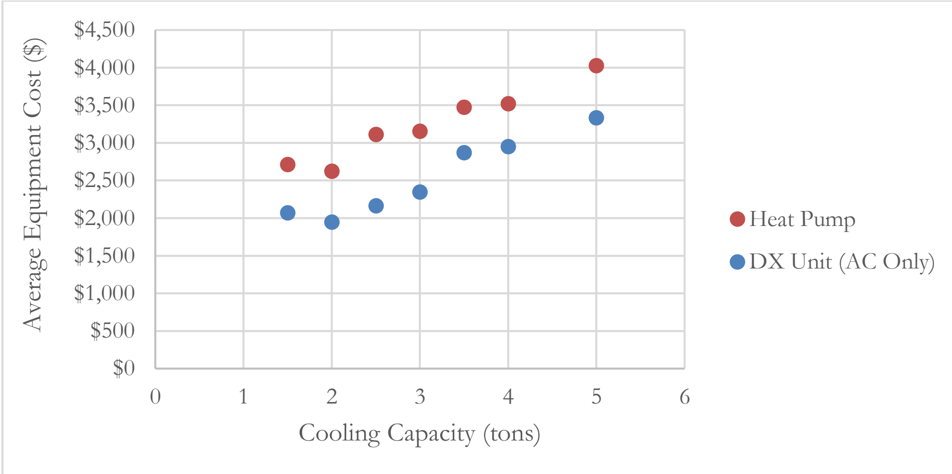

Figure 9 – Comparison of Equipment Costs for Code-minimum residential heat pump and DX units

2.2.2.2 Barriers

Electrical Requirements

Examination of specifications on units from the online HVAC wholesalers showed that most heat pumps had similar requirements to the split AC units, with little variations in amps required between units of the same cooling capacity. Since the infrastructure for the AC is already in place, this reduces the potential additional cost of installing a heat pump in its place. All residential DX units and heat pumps examined in the 3-5 ton capacity range were single phase, 240V units. TECH Clean California, a statewide initiative to accelerate the adoption of residential heat pump HVAC systems, has collected and published data for a sample of 9,471 heat pump projects between August 2021 and January 2023. A subset of 3,052 of these projects consisted of upgrades of existing central air-conditioning and gas furnaces to split system heat pumps. Of these projects, only approximately 3 percent included a panel upgrade, confirming that in most cases a heat pump retrofit does not require alterations to the electrical system. Projects that included a panel upgrade cost on average $2,221 more than projects that did not.

Table 10 shows an example of specifications for each a residential DX unit and heat pump of the same efficiency and cooling capacity, both of which require 30 Amps. Typical residences have an electrical panel rated at 100-150A, and if an existing air conditioning unit is already in place (the case for this feasibility study), it will likely be able to support a heat pump unit. If the electrical panel does need to be upgraded, additional costs would be incurred, however this is not necessarily unique to heat pump installations.

TECH Clean California, a statewide initiative to accelerate the adoption of residential heat pump HVAC systems, has collected and published data for a sample of 9,471 heat pump projects between August 2021 and January 2023.[25] A subset of 3,052 of these projects consisted of upgrades of existing central air-conditioning and gas furnaces to split system heat pumps. Of these projects, only approximately 3 percent included a panel upgrade, confirming that in most cases a heat pump retrofit does not require alterations to the electrical system. Projects that included a panel upgrade cost on average $2,221 more than projects that did not.

[25] https://techcleanca.com/public-data/

Table 10 – Comparison of Sample Residential HVAC Unit Specifications

	DX AC Unit	Heat Pump
GroupKit	Split System Kit (3.0 - 5.0 Ton)	Split System Kit (3.0 - 5.0 Ton)
Type	Air Conditioning	Heat Pump
Seer	15 Seer	15 Seer
Brand	Goodman	Goodman
Category	Split Systems	Split Systems
Model Number(s)	GSX160371 - CAPF4961D6 - TX3N4	GSZ160361 - CAPF3743C6 - MBVC1600AA-1 - TX3N4
SEER	15	15
HSPF		8.5
Cooling Btu	36,000	36,000
Heating Btu		36,000
Cooling Stage(s)	1	1
Heating Stage(s)		1
Compressor Stage	Single	Single
Blower Application		Multi-Position
Voltage	208/230V	208/230V
Electrical Phase(s)	1	1
Amp(s)	30	30
Hertz (Hz)	60	60
Decibel Level (dB)	73	73
Blower		Variable Speed
Maximum CFM		1,600.00
Refrigerant Type	R-410A	R-410A
Suction Valve Size (Inches)	7/8	7/8
Liquid Valve Size (Inches)	3/8	3/8
Outdoor Unit Height (Inches)	36.25	40
Outdoor Unit Width (Inches)	35.5	35.5
Outdoor Unit Depth (Inches)	35.5	35.5
Indoor Unit Height (Inches)		30
Indoor Unit Width (Inches)		21
Indoor Unit Depth (Inches)		21
Parts Warranty (Years)	10	10
Compressor Warranty (Years)	10	10
AHRI Certificate #	9103809	8601495
AC Outlet Cost	$2,607	$4,179

Space

A sample of units supplied by an online wholesaler shows that heat pump units typically have the same or similar footprints as a conventional DX unit of the same cooling capacity, thus should not require any specific accommodations for a retrofit.

Existing Infrastructure

Since this proposal is examining the retrofit of a home with an existing central air conditioning system, most of the existing home connections would be able to be used. Heat pump systems are typically able to use the existing ductwork which is often the largest additional cost when examining new HVAC systems. If ductwork upgrades are needed, this may be due to incorrect sizing of the ductwork originally or an aging duct system.

Analysis of the TECH Clean California heat pump project data demonstrated that of the 3,052 central AC and furnace to split system heat pump retrofits, only approximately 14 percent included a duct replacement.[26] As only 11 percent of these split system heat pump

[26] https://techcleanca.com/public-data/

retrofits included an ACCA Manual J residential load calculation, this assessment does not account for the fact that many projects may have had heat pumps installed without a proper HVAC and duct sizing analysis. Further analysis of the data shows, however, that of the 330 projects that did have a Manual J analysis performed, 22 percent included a duct replacement. Leaving the furnace in place also does not seem to prompt duct replacement, with only 9 percent of projects for which the existing gas furnace is used as emergency heating including a duct replacement.

Thus, for most heat pump installations, no alterations to existing air distribution infrastructure is anticipated compared to a code-minimum DX unit. When necessary, according to the TECH Clean California data, the average additional cost of a duct replacement is approximately $3,520.

Controls

Residential heat pumps can be used in tandem with existing furnaces left in place. Having the existing furnace remain both avoids furnace removal costs and provides an additional support of back-up heat for times when the heat pump may be unable to meet demand or operating inefficiently. Though many modern thermostats provide this functionality,[27] it is not a universal offering, and thus this setup may require installation and programming resulting in added costs compared to a code-minimum DX air conditioner installation. Typical thermostats cost in the range of $100-$250 with an estimated additional $100-$200 for labor. These costs are included in the cost-effectiveness analysis.

Heating Performance and Climate

Similar to commercial units, minimum efficiency residential heat pump capacities and efficiencies begin to drop significantly at lower temperatures. Heat pumps are often fit with a supplementary electric resistance heating coil to provide additional heating at low outside air temperatures, which may adversely impact energy performance. As a result of this performance limitation, heating dominated climates may not be the ideal climate for requirement of a minimum efficiency heat pump,[28] as will be further examined with the modeling results in Section 2.2.3.1. We are proposing here to allow for the existing heating system to stay in place as a supplementary heating system, which would mitigate these concerns in cold climates.

Cold weather performance also adds complications to load sizing for a heat pump. As the same unit provides heating and cooling, the heating capacity and cooling capacity are inextricably linked. As a result, houses with heating loads that differ drastically from the cooling loads can complicate product selection and can result in cooling systems that are oversized, or an over-reliance on supplementary heating systems. Again, since the existing heating system is allowed to remain in place, this can also help mitigate potential oversizing of the cooling system.

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27 https://www.honeywellhome.com/us/en/support/lyric-thermostat-compatibility-21/

28 There are cold climate heat pumps that can perform well in these climates but exceed the federal minimum efficiency requirements.

2.2.3 Cost-Effectiveness Analysis

An energy and cost analysis was performed to determine the potential cost effectiveness of requiring retrofit of residential buildings with code minimum heat pumps when replacing the existing direct expansion air conditioning unit.

Energy models were created using the California Building Energy Code Compliance Residential (CBECC-Res) 2025 software. Energy models were constructed using the 2-story residence prototype model provided with the software, which represents a two-story home of 2,700 conditioned square feet, served by a split system HVAC system with a direct expansion air conditioner and natural gas furnace. Model iterations were created for a building with T24 code-compliant DX/furnace split system (Baseline), a code-compliant heat pump with the existing gas furnace for supplementary heat (Proposed Iteration #1), and a code-compliant heat pump with electric resistance supplementary heat (Proposed Iteration #2). A summary of the HVAC specifications used in the models is shown in Table 11. HVAC efficiencies used in the models are based on the upcoming Department of Energy's new minimum efficiency standards for split system air conditioners and heat pumps that will go into effect on January 1, 2023.

Table 11 – CBECC-Res Model HVAC Specifications – 2-story Residence

Component	Baseline	Proposed – Iteration 1	Proposed – Iteration 2
System Type	Split System DX/Gas Furnace	Dual Fuel Heat Pump	Heat Pump
Number of Units	1	1	1
Cooling Coil	Direct Expansion	Direct Expansion	Direct Expansion
Cooling Efficiency	14.5/15 SEER[29]	15 SEER	15 SEER
Primary Heating Type	Gas Furnace	Heat Pump	Heat Pump
Heating Efficiency	80%	8.8 HSPF	8.8 HSPF
Supplementary Heating Type	N/A	Gas Furnace	Electric Resistance
Central Fan	Gas Furnace: 0.45 W/CFM	Heat Pump: 0.58 W/CFM	Heat Pump: 0.58 W/CFM

Since the feasibility study is examining an alteration measure, envelope details for the prototype were updated from Title 24 code compliance to values reflective of a typical residence. Based on the U.S. census data a majority of homes in California were constructed prior to 1990 (86 percent as of March 2000). To provide conservative estimates of potential savings in a typical home, however, building envelope details were adjusted to reflect values in the 1992 Title 24 residential building code, with the adjustments summarized in Table 12. As with the commercial models discussed above, iterations were created for a sample of five climate zones – CZ03, CZ07, CZ09, CZ12, and CZ16 – to provide a representative sample of potential statewide impacts. See Table 4 for details on each of the climate zones sampled.

Table 12 – Adjustments to CBECC Prototype – 2-story Residence

Component	CBECC Prototype Specs	Adjustments by Climate Zone				
		CZ03	CZ07	CZ09	CZ12	CZ16
Exterior Walls	R19 + R5 Stucco	R8+R5 Stucco	R8+R5 Stucco	R8+R5 Stucco	R8+R5 Stucco	R14+R5 Stucco
Roof	Insulation: R38 Attic	R30 Attic	R19 Attic	R30 Attic	R30 Attic	R38 Attic
Windows	U-Factor: 0.3 SHGC: 0.23	U-Factor: 1.1 SHGC: 0.4	U-Factor: 1.1 SHGC: 0.4	U-Factor: 1.1 SHGC: 0.4	U-Factor: 0.65 SHGC: 0.4	U-Factor: 0.65 SHGC: 0.4
Door	U-Factor: 0.3 SHGC: 0.23	U-Factor: 1.1 SHGC: 0.4	U-Factor: 1.1 SHGC: 0.4	U-Factor: 1.1 SHGC: 0.4	U-Factor: 0.65 SHGC: 0.4	U-Factor: 0.65 SHGC: 0.4
Below Grade Floor	R5, 16in	R7, 16in	R7, 16in	R7, 16in	R7, 16in	R7, 16in
Exterior Floor	U-Factor: 0.071 Cont. Insulation: 9.8	R13	R13	R13	R13	R19

[29] Depending on unit capacity.

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2.2.3.1 Modeling Results

The energy savings from the 2-story residential CBECC models are presented in Table 13 and Table 14. The savings represent the incremental savings comparing the two scenarios analyzed to a DX/gas-furnace baseline. Figure 10 presents a comparison of the total time dependent valuation (TDV) for both heat pump scenarios modeled compared to the baseline in each of the five sampled climate zones, and

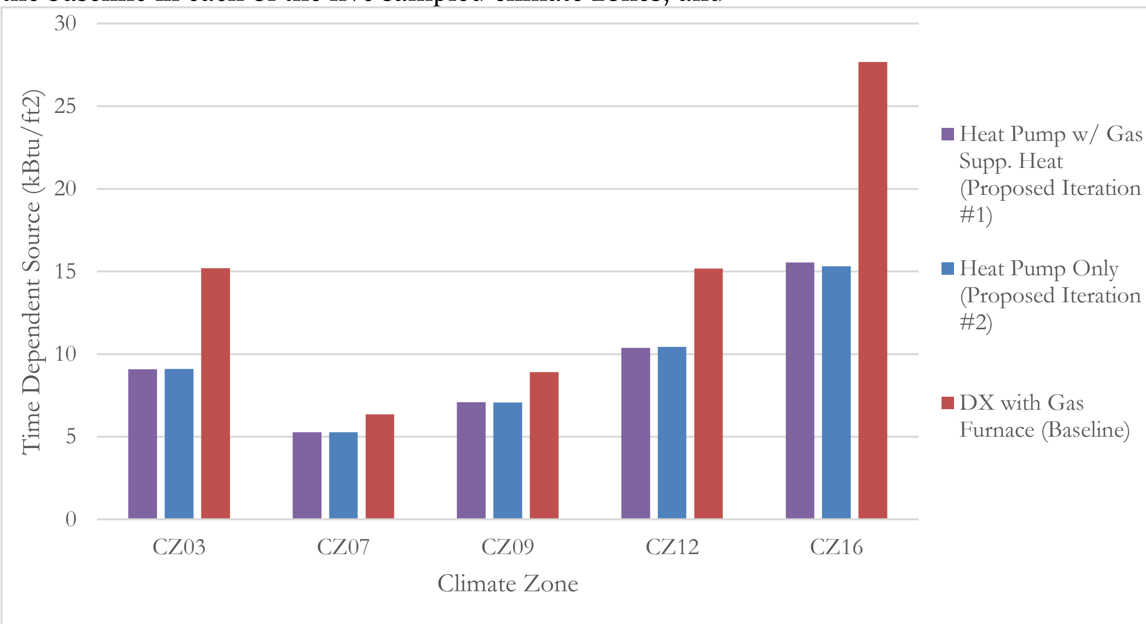

Figure 11 presents the same comparison for time dependent source (TDS). From the estimated TDV savings, the data demonstrates that the installation of a heat pump is estimated to have a net positive impact at residences in the state of California due to the potential for reduced gas consumption. Climate zones that have similar cooling and heating demands, such as climate zones 7 and 9, have the potential to have a lower impact on TDV savings, likely due to the higher use of cooling, which does not see the same efficiency benefits as heat pump heating.

Table 13 – Proposed Iteration #1 Residential Dual-Fuel Heat Pump Savings Per Year – 2-Story Residence

Climate Zone	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)	TDV Energy Savings (kTDV/ft^2/yr)
CZ03	(2,328)	292	15
CZ07	(503)	59	2
CZ09	(1,031)	105	1
CZ12	(2,255)	254	8
CZ16	(5,517)	600	6

Table 14 – Proposed Iteration #2 Residential Heat Pump Only (No Gas Backup) Savings Per Year – 2-Story Residence

Climate Zone	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)	TDV Energy Savings (kTDV/ft^2/yr)
CZ03	(2,591)	304	14
CZ07	(528)	60	2
CZ09	(1,185)	113	1
CZ12	(2,697)	273	5
CZ16	(6,924)	662	(3)

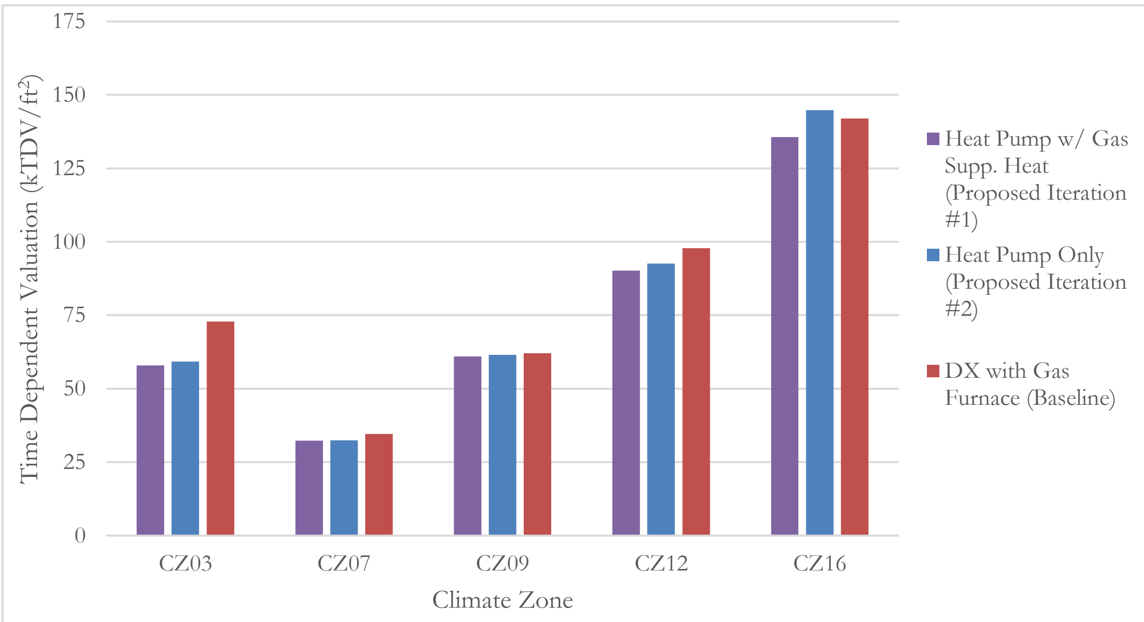

Figure 10 - Comparison of Baseline and Proposed CBECC-Res Model TDV (kTDV/ft^2) – 2-Story Residence

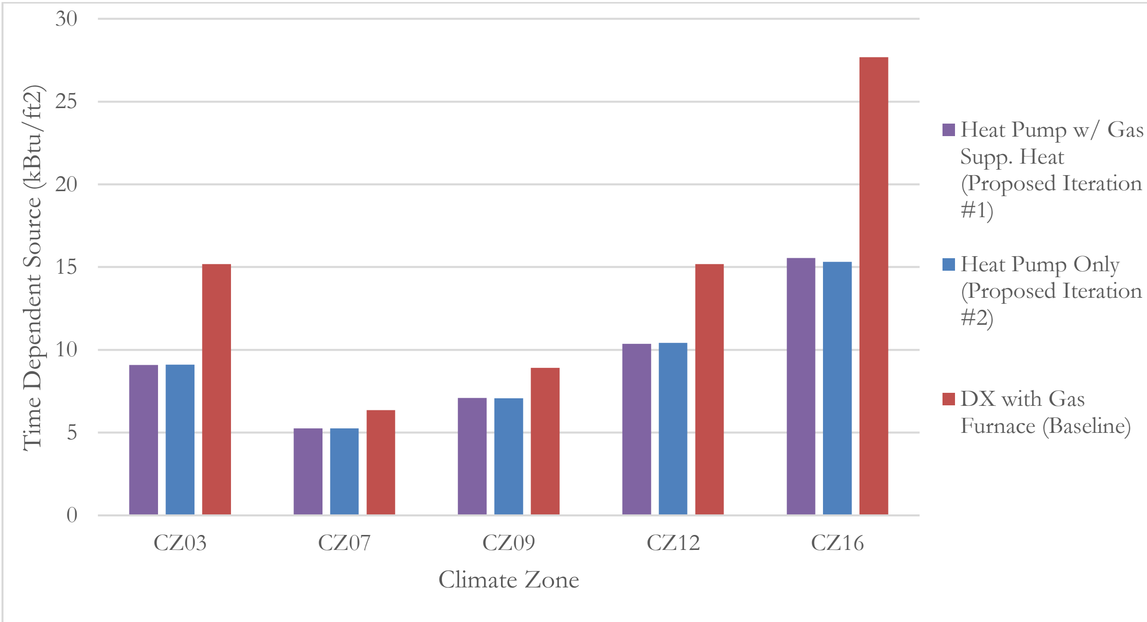

Figure 11 – Comparison of Baseline and Proposed CBECC-Res Model TDS (kBtu/ft^2) – 2-Story Residence

2.2.4 Cost Effectiveness

The estimated 2022 TDV energy costs for the energy models are presented in Table 15 and Table 16Table 15. The TDV results show the present value of costs across the assumed lifetime of the equipment (30 years for residential HVAC). The CBECC 2-story residential model demonstrates that for each climate zone, installation of a dual fuel heat pump to replace a conventional DX air conditioner and use of a natural gas furnace would result in TDV cost savings.

Table 15 – Proposed Iteration #1 Residential Dual Fuel Heat Pump Estimated Cost Savings – 2-Story Residence

Climate Zone	TDV Cost/ft^2 (2022 2025 PV Res-30 yr)		TDV Cost Savings ($/ft^2)
	Heat Pump w/ Gas Supp.	DX Cooling/Gas Furnace	
CZ03	$10.04	$12.62	$2.58
CZ07	$5.60	$6.00	$0.40
CZ09	$10.56	$10.75	$0.19
CZ12	$15.63	$16.94	$1.31
CZ16	$23.49	$24.60	$1.11

Table 16 – Proposed Iteration #2 Heat Pump Only Estimated Cost Savings – 2-Story Residence

Climate Zone	TDV Cost/ft^2 (2025 PV Res-30 yr)		TDV Cost Savings ($/ft^2)
	Heat Pump	DX Cooling/Gas Furnace	
CZ03	$10.26	$12.62	$2.36
CZ07	$5.62	$6.00	$0.38
CZ09	$10.65	$10.75	$0.09
CZ12	$16.03	$16.94	$0.91
CZ16	$25.08	$24.60	-$0.48

Table 17 presents a comparison of the cost savings per square foot (benefits) to the estimated installation costs per square foot (costs) for proposed iteration #1. Installation costs for the analysis include $450 for installation and programming of a new thermostat and a replacement cost due to the 30-year residential lifetime used for PV compared to a typical 15-year estimated useful life of a heat pump. The benefit to cost ratio is greater than 1 for all but Climate Zone 7 and 9, and thus heat pumps retrofits using natural gas supplementary heat are anticipated to be cost effective in most zones. As discussed above, Climate Zones 7 and 9 have a higher ratio of cooling to heating use than other zones, and thus produced a B/C ratio of less than 1 using the 2022 TDV values.

Table 17 – Proposed Iteration #1 Residential Dual Fuel Heat Pump Benefit to Cost Ratio – 2-Story Residence

Climate Zone	Benefits (TDV Cost Savings - $/ft^2)	Costs (Incremental Costs/ft^2)	B/C Ratio
CZ03	$2.58	$0.85	$3.05
CZ07	$0.40	$0.76	$0.53
CZ09	$0.19	$0.85	$0.22
CZ12	$1.31	$0.85	$1.55
CZ16	$1.11	$0.85	$1.31