Room Heat Pumps Market Transformation Initiative

Appendix B: Market Forecasting & Cost-Effectiveness Modeling Approach

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List of Abbreviations

Abbreviation	Definition
AC	Air-Conditioning
ACC	Avoided Cost Calculator
ACS	American Community Survey
BMA	Baseline Market Adoption
CalMTA	California Market Transformation Administrator
CE	Cost-Effectiveness
CEDARS	California Energy Data and Reporting System
CEER	Combined Energy Efficiency Ratio
CET	Cost-Effectiveness Tool
COP	Coefficient of Performance
CPUC	California Public Utilities Commission
DEER	Database for Energy Efficient Resources
DOE	Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EIA RECS	Energy Information Administration's Residential Energy Consumption Survey
EUL	Estimated Useful Life
EV	Electric Vehicle
GHG	Greenhouse Gas
GWP	Global Warming Potential
HEER	Heating Energy Efficiency Rating
HP	Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
IMC	Incremental Measure Cost
IOU	Investor-Owned Utility
MF	Multifamily
MTI	Market Transformation Initiative
NEEA	Northwest Energy Efficiency Alliance
PAC	Program Administrator Cost
PG&E	Pacific Gas and Electric
PHP	Portable Heat Pump
RA	Resource Acquisition
RASS	Residential Appliance Saturation Survey
RHP	Room Heat Pump
SCE	Southern California Edison
SCT	Societal Cost Test
SDG&E	San Diego Gas and Electric
SF	Single-Family
TMA	Total Market Adoption
TRC	Total Resource Cost
TSB	Total System Benefit
UEI	Unit Energy Impact
UES	Unit Energy Savings
WHP	Window Heat Pump

1 Purpose

Market Transformation Initiatives (MTIs) generate energy savings and related benefits by accelerating and increasing market adoption of energy-efficient technologies and practices. Estimating the energy impacts and cost-effectiveness of MTIs requires developing a forecasting model that uses a set of inputs based on well-documented sources, methods, and assumptions.

This appendix details the methodology used to estimate incremental impacts resulting from the Room Heat Pumps (RHP) MTI and summarizes findings from the analysis. These methods are consistent with the approach described in Appendix F: Evaluation Plan.[1]

2 Executive summary

To estimate incremental impacts for the RHP MTI, CalMTA developed models that forecasted Baseline Market Adoption (BMA) and Total Market Adoption (TMA) and, ultimately, the net incremental market adoption achieved by the MTI. Forecasted units of adoption are a key input to the calculation of Total System Benefit (TSB) and cost-effectiveness ratios: Total Resource Cost (TRC), Program Administrator Cost (PAC), and Societal Cost Test (SCT).

2.1 Market adoption forecasts

The section summarizes CalMTA's forecast of BMA, TMA, and net incremental market adoption of RHPs. BMA represents the expected "naturally occurring" market adoption, taking into account current and expected market, regulatory and technological trends. TMA includes the additional adoption forecasted to result from strategic interventions described in this MTI plan.
To estimate BMA and TMA for the RHP MTI, CalMTA employed an "S-curve" model, which is characterized by an initial slow growth phase, followed by a rapid growth phase, and eventually a plateau as the market reaches saturation.

CalMTA took a multifaceted approach to inform assumptions and parameters of the S-curve model. For baseline adoption, insights were drawn from various sources, including Delphi panel estimates, qualitative comments, surveys of property managers and households, and discussions with stakeholders such as manufacturers. For adoption influenced by the MTI, the model parameters were aligned with the market interventions, outcomes, and planned milestones specified in the MTI Plan.

[1] The MTI Evaluation Framework provides foundational guidance for the evaluation of CalMTA's MTIs: https://calmta.org/wp-content/uploads/sites/263/Market-Transformation-Evaluation-Framework-FINAL.pdf. The framework outlines the approach that will be used to measure incremental adoption of RHPs, including the high-level process to estimate incremental adoption and produce the necessary inputs to that model, such as BMA and TMA, and calculate TSB and cost-effectiveness ratios.

The S-curve model provides annual saturation levels throughout the forecast period, indicating the proportion of existing households expected to adopt RHPs through 2050. CalMTA developed separate forecasts for single-family and multifamily households. Figure 1 illustrates the estimated adoption in terms of proportions for single-family (left) and multifamily households (right), while Figure 2 presents the adoption numbers in thousands of households.

Figure 1. Estimated proportion of single-family and multifamily households adopting RHPs

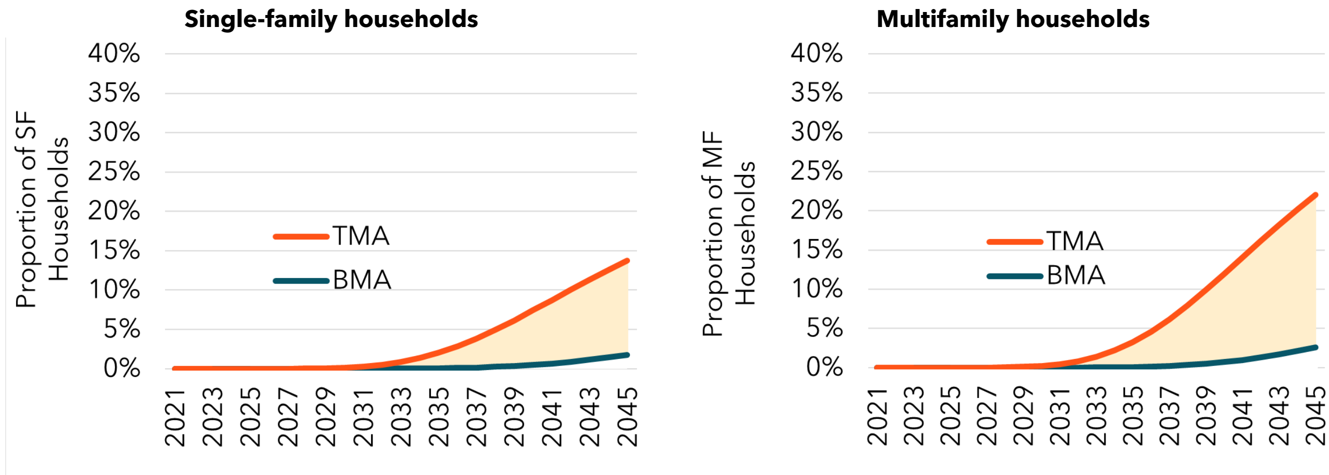
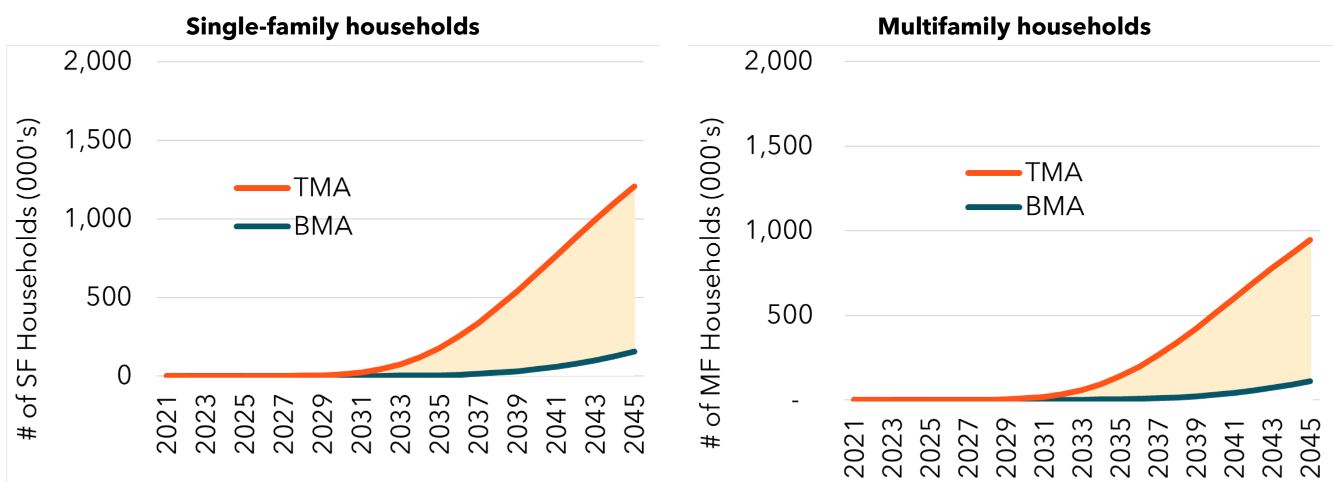


Figure 2. Estimated number of single-family and multifamily households adopting RHPs (in thousands)



After forecasting household saturation, CalMTA estimated the number of RHP units adopted based on assumed units per household and the assumed rate of product re-adoption in replacement scenarios.

In the final step of the adoption forecast process, CalMTA calculated the net incremental unit adoption, which is equal to TMA minus BMA, minus estimated adoption associated with Program Administrators' (PAs) verified savings (this included all PA programs statewide; for IOUs, this included programs reported in the California Energy Data and Reporting System or CEDARS).[2] The net incremental adoption is summarized in the equation below.

$$Y^{N.incremental} = Y^{TMA} - Y^{BMA} - Y^{PA}$$

Where Y represents cumulative adoption of RHPs over the forecast period of 2024 to 2045.[3] The superscripts $N.incremental$, TMA, BMA, and PA represent net incremental adoption attributed to the MTI, Total Market Adoption, Baseline Market Adoption, and PA-verified savings respectively. Table 1 below summarizes TMA, BMA, PA-verified units, and net incremental adoption in terms of RHP units adopted.

The approach described above was used to estimate BMA, TMA, and net incremental adoption at a statewide level. The last two columns of Table 1 show the adoption attributed to households outside the IOU service territories, and the adjusted adoption estimates included in TSB and cost-effectiveness estimates respectively.[4]

Table 1. Forecast of RHP adoption (in thousands, 2024-2045)

	TMA (Y^{TMA})	BMA (Y^{BMA})	PA-verified units (Y^{PA})	Net incremental ($Y^{N.incremental}$)	Adoption attributed to non-IOU territory	Adoption for TSB and CE estimation
Single-family households	1,838	242	196	1,400	372	1,028
Multifamily households	1,207	144	129	934	251	683
Total	**3,045**	**386**	**325**	**2,334**	**623**	**1,711**

Source: CalMTA estimates. PA verified units include adoption associated with PA programs statewide.

[2] https://cedars.cpuc.ca.gov/.

[3] CalMTA forecasted market adoption beginning in 2024 to reflect the fact that there are some RHP products in the market and CalMTA is already investing in preliminary market engagement; however, incremental market adoption prior to the start of Phase III (Market Deployment) is negligible – as illustrated in Figures 1 and 2.

[4] It is important to note that the state of California will realize electric system benefits from statewide incremental RHP market adoption, not only from adoption inside the IOU service territories. While the adjusted values may be the most appropriate values to use for the CPUC's cost-effectiveness tests, as a matter of policy, they do not fully represent the statewide benefits that will result from investment in the RHP MTI. This approach discounts statewide benefits by nearly 26%.

In addition to the net incremental adoption estimates attributed to households in the territories of the three IOUs, the TSB and cost-effectiveness calculations also considered initiative costs, incremental measure cost (IMC), avoided costs, load shapes, and unit energy impacts (UEI).

2.2 Total System Benefit & Cost-Effectiveness forecast

CalMTA estimated TSB and cost-effectiveness for the RHP MTI, including the TRC, PAC, and two SCT results. Table 2 below shows the MTI's TSB with energy, grid, and greenhouse gas (GHG) impacts.

The initiative will deliver an estimated $521 million in TSB. Most of these benefits come from GHG emission reductions associated with product efficiency and fuel substitution, especially in later years of the MTI after more California-appropriate RHP models become available and market adoption accelerates. The initiative is cost-effective over its lifetime under each test perspective (Table 3).

Table 2. RHP TSB estimates, 2024-2045

TSB ($M)	Energy ($M)	Grid ($M)	GHG non-refrigerant ($M)	GHG refrigerant ($M)
521	160	30	331	N/A

Table 3. RHP cost-effectiveness estimates, 2024-2045

	TRC	PAC	Base SCT	High SCT
Negative IMCs included[a]	330.15	8.29	(30.24)	(30.26)
Negative IMCs set to zero	5.46	8.29	11.20	11.21

[a] CalMTA calculated cost-effectiveness using negative Incremental Measure Costs (IMCs), per the guidance from the CPUC's Energy Division guidance memo that required negative IMCs to be entered into Cost-Effectiveness Tool (CET) and not set to zero.[5] Because use of the negative IMCs resulted in some counterintuitive results, CalMTA also calculated cost-effectiveness results with negative incremental costs set to zero.

3 MTI product definition

As described in the body of this MTI Plan, the RHP MTI seeks to transform the residential heating and cooling market by shifting consumers to a dual-purpose and more efficient product. CalMTA envisions an end state where consumers purchase RHPs over other competing products and where these products include air filtration and use of low global warming potential (GWP) refrigerants.

[5] Guidance for Deemed Measures History: CPUC Guidance on the use of Negative Incremental Measure Cost (IMC) in the Cost Effectiveness Tool - CEDARS.

To model market adoption and cost-effectiveness, CalMTA defined the RHP products included in the MTI as window and portable units that provide efficient heating and cooling for small spaces including single rooms, small apartments, and homes. They are similar in shape and size to typical window air-conditioning (AC) units and portable AC products. These products can be installed without a certified technician and plugged into a 120V outlet. The addressable market segments for this technology are existing California residential households.

4 Market adoption analysis

This section details CalMTA's approach to forecasting the adoption of RHPs by California households from 2024 to 2045, along with the forecast results.

4.1 Modeling approach

The team used an S-curve modeling framework to estimate the diffusion of RHPs among existing single-family and multifamily households in California. In this framework, diffusion follows three distinct stages: an initial slow growth phase, followed by a rapid growth phase, and finally, a plateau as the market becomes saturated.

Multiple S-curve models exist that are commonly used in diffusion modeling. The team used the Gompertz model framework to estimate adoption by existing households. The Gompertz model uses a mathematical equation with three parameters to generate an S-shaped curve that represents the product saturation or cumulative adoption of a product. Thus, the proportion of households Z who have adopted the product in year t may be written as the following equation:

$$Z_t = m\left(e^{-e^{-r(t-t_0)}}\right)$$

Where:

Maximum market potential (m)	=	The total number of households who will eventually or ultimately adopt the product. It represents the upper limit of the S-curve, beyond which further adoption is not possible under current assumptions of trends in technology and customer preferences (parameter #1).
Year of inflection (t_0)	=	The year when the adoption rate of RHPs reaches its peak growth. This is the turning point where the adoption curve transitions from accelerating growth to decelerating growth (parameter #2).

Rate of growth (r) = The speed at which the technology is being adopted. The parameter influences the steepness of the S-curve (parameter #3).

Euler's number (e) = Mathematical constant approximately equal to 2.71828

CalMTA took a multifaceted approach to develop model assumptions and parameters. For BMA, CalMTA considered insights from multiple sources, including Delphi panel estimates and qualitative comments; market research, including surveys of property managers and households; and discussions with stakeholders, including manufacturers. To forecast TMA in the presence of MTI interventions, CalMTA aligned the model parameters with the market interventions, outcomes and planned milestones in the MTI Plan.

CalMTA initially considered the Bass model framework, which was employed by CalMTA to develop its preliminary adoption forecast in the fall 2023. However, for this study, the team chose to use the Gompertz model for several reasons. Firstly, the Gompertz model has been widely applied across diverse fields such as population studies, epidemiology, and technology diffusion since its introduction in the 1800s. It is also prevalent in energy efficiency and climate change literature.[6]

The second and primary reason for selecting the Gompertz model over the Bass model is its ability to directly relate the interventions recommended in the MTI Plan and the planned market outcomes to model parameters. For example, as detailed in the next section, the introduction of RHP models compatible with the requirements of California's residential sector – a key outcome of the MTI's strategic market interventions - can be directly linked to the assumed Gompertz model parameters. Similarly, planned market milestones, such as program inclusion of RHPs as an incentivized measure, can be directly associated with the Gompertz model parameters. This direct linkage is not feasible with the Bass model, which is grounded in a sociological perspective, emphasizing the role of social interactions in driving technology adoption. It posits that adoption is influenced by two primary mechanisms: innovation and imitation. The model parameters specify the rate of adoption by innovators (early adopters who are not influenced by others) and imitators who adopt based on the influence of others. Consequently, the model parameters do not correspond as well with MTI market barriers and planned interventions.[7]

[6] For instance, the International Energy Agency's MoMo model employs the Gompertz model to assess the impact of various policies on transportation demand and emissions. See Yeh, S., Mishra, G. S., Fulton, L., Kyle, P., McCollum, D. L., Miller, J., ... & Teter, J. (2017). Detailed assessment of global transport-energy models' structures and projections. Transportation Research Part D: Transport and Environment, 55, 294-309.

[7] The output differences between the Bass and Gompertz models are minimal. For example, Kumar et al. (2022) compared the Bass, Gompertz, and logistic models on historical trends in the adoption of electric vehicles across

Base-year assumptions

The section summarizes the estimated number of existing single-family and multifamily households in California in the base year and the type of heating, ventilation, and air conditioning (HVAC) equipment used by these households.

Base-year population

For RHPs, CalMTA considered two residential segments: single-family and multifamily households. The team used data from the 2022 American Community Survey 1-Year Estimates, conducted by the U.S. Census Bureau for the number of single-family and multifamily households in California, as shown in Table 4.[8]

Table 4. Number of households in California

	Single-family households	Multifamily households
Number of households (millions)	8.79	4.29

Source: EIA RECS 2020; CalMTA recalibration of household population to the American Community Survey (ACS) 2022.

Base-year saturation of residential heating and cooling equipment

The base-year saturations of heating and cooling equipment in California in 2022 are given in Table 5 and Table 6. The data is based on The Energy Information Administration's Residential Energy Consumption Survey 2020 (EIA RECS 2020) estimates.[9] The EIA RECS 2020 is representative of California's residential sector in 2020, weighted based on household population estimates from ACS 2020. Given that the base year of this study is 2023, CalMTA calibrated the household population estimates in EIA RECS 2020 to ACS 2022, based on changes in household population between ACS 2020 and ACS 2022.

Table 5. Main heating equipment type in the residential sector in California by housing type

Main heating equipment	Number of housing units in millions	
	Single-family	Multifamily
Central furnace	6.64	1.48
Heat pump (central and mini-splits)	0.28	0.26
Portable electric heater	0.28	0.52

20 countries, including the United States. The study found negligible differences in model fit, with the Bass model providing a better fit for some countries and the Gompertz model for others.
Kumar, R. R., Guha, P., & Chakraborty, A. (2022). Comparative assessment and selection of electric vehicle diffusion models: A global outlook. *Energy*, *238*, 121932.

[8] U.S. Census Bureau. (2023). *American Community Survey 1-Year Estimates: 2022*. https://www.census.gov/programs-surveys/acs/technical-documentation/table-and-geography-changes/2022/1-year.html.

[9] U.S. Energy Information Administration. (2023). *Residential Energy Consumption Survey: 2020*. Retrieved from https://www.eia.gov/consumption/residential/data/2020/.

Main heating equipment	Number of housing units in millions	
	Single-family	Multifamily
Built-in electric units	0.12	0.46
Others +	0.88	0.55
Housing units with no heating++	0.59	1.02
Total	**8.79**	**4.29**

Source: EIA RECS 2020; CalMTA recalibration of household population to ACS 2022. Survey Question: What is the main type of heating equipment used to provide heat for your home? Notes: (+) Others Includes zonal gas and oil heaters, and wood/pellet stoves. (++) These households did not respond "Yes" to the survey question: Is your home heated during the winter?

Table 6. Main cooling equipment type in the residential sector in California by housing type

Main cooling equipment	Number of housing units in millions	
	Single-family	Multifamily
Central AC (including central heat pump)	5.49	1.45
Window or wall AC	0.61	1.00
Portable AC	0.24	0.28
Others +	0.26	0.12
Housing units with no cooling++	2.19	1.44
Total	**8.79**	**4.29**

Source: EIA RECS 2020; CalMTA recalibration of household population to ACS 2022. Survey Question: What is the main type of air conditioning equipment used to cool your home? Notes (+) Others include ductless heat pumps and evaporative or swamp cooler. (++) These households did not respond "Yes" to the survey question: Is any air conditioning equipment used in your home?

4.2 Baseline Market Adoption (BMA)

This section details the approach CalMTA used to forecast BMA: the estimate of RHP market adoption by existing households in the absence of the MTI.

Approach summary

CalMTA adopted a three-step process to forecast BMA:

1) Estimated the proportion of existing households projected to adopt RHPs in the absence of the MTI
2) Estimated the cumulative number of households and units of RHP adopted
3) Estimated the total units of RHPs adopted taking into consideration product failures and re-adoption during the forecast period.

Each step is further detailed below.

Step 1: Proportion of households adopting RHP

CalMTA used the Gompertz S-curve to estimate saturation in terms of the proportion of existing households that will adopt the product for each year in the 2024-2045 forecast period in absence of the MTI. CalMTA made the following assumptions about each of the three model parameters.

Parameter #1: Maximum market potential (m)

To estimate the market potential (*m*) in the baseline, CalMTA segmented the multifamily and single-family households in California based on attributes that influence propensity to adopt an RHP. These include urban versus rural location, the type of equipment currently used by the household for primary heating and/or cooling, and whether the household owns or rents their housing unit. These variables led to 40 mutually exclusive, collectively exhaustive subsegments of each of the two broad market segments: single-family and multifamily households.

Table 7 provides the number of households in each subsegment in the base year based on the criteria described above.

Table 7. Distribution of California households by primary heating and/or cooling equipment type (thousands)

Primary equipment type for heating and/or cooling	Single-family				Multifamily+	
	Urban		Rural		Both urban & rural	
	Own	Rent	Own	Rent	Own	Rent
1. Electric resistance heating (zonal)	261	128	11	-	98	886
2. Electric central furnace (ducted)	181	77	28	6	14	387
3. Gas, oil or wood stoves (zonal)	378	199	162	49	-	487
4. Central HP and/or mini-splits	183	59	40	-	28	228
5. Central gas furnace without any cooling and not counted above in #1 to #4	1,049	129	110	57	33	215
6. Central gas furnace and central cooling and not counted in #1 to #5	3,489	530	482	80	73	466
7. Window/wall/portable AC and not counted above in #1 to #6	224	151	26	15	15	636
8. No heating or cooling	200	102	-	20	27	391
9. Central cooling without any heating and not counted above in #1 to #8	115	75	-	-	46	191
10. Other households	86	61	32	-	-	64
Total	**6,166**	**1,511**	**890**	**227**	**333**	**3,952**

Source: Based on EIA RECS 2020; CalMTA recalibration of household population to ACS 2022. Notes: The data is based on the following two survey questions in EIA RECS 2020. Question 1: What is the main type of heating equipment used to provide heat for your home? Question: What is the main type of air conditioning equipment used to cool your home? (+) The data is aggregated over the Urban/Rural variable for multifamily households because only around 2% of such households are rural.

For each subsegment, the team assessed the maximum market potential in absence of the MTI – that is, the proportion of households who will eventually adopt the product assuming current market, regulatory and technological trends. CalMTA made the following assumptions to estimate m:

4) **High potential for adoption among households with existing inefficient zonal heating and/or cooling system.** These are households using systems like portable heaters, baseboard electric heaters, and window or wall ACs for primary heating and cooling. It also includes households with zonal gas, oil, and wood-based heaters. CalMTA assumes that high energy costs associated with such inefficient zonal systems and expected increases in energy costs going forward will motivate such households to eventually transition to zonal heat pumps (either mini-splits or RHPs).
5) **Low potential for adoption among single-family households with a centralized gas furnace and/or central cooling system; high adoption among multifamily households.** In the long term, single-family homes are more likely to upgrade to centralized heat pumps, while multifamily properties are more inclined to adopt zonal heat pumps. For single-family homes, the compatibility of centralized heat pumps with existing infrastructure, such as ductwork and electrical systems, can make them a more cost-effective option. Additionally, centralized heat pumps are less conspicuous (no indoor unit visible in rooms) and also provide air filtration. In contrast, multifamily properties may face challenges in retrofitting existing infrastructure for centralized heat pumps, making zonal systems a more practical and cost-effective choice.
6) **Single-family households choosing zonal systems will prefer mini-splits and RHPs equally.** In the long term, single-family households in the market for zonal heat pumps are equally likely to prefer RHPs and mini-splits. RHPs offer portability, flexibility, and ease of installation and appeal to those who prioritize these features, including households with limited outdoor space or restrictive building codes. Households willing and able to pay a premium for a permanent installation and longer lifespan, and who prefer the mini-split aesthetic, may choose mini-splits. CalMTA assumes these preferences are equally distributed among single-family households in California.
7) **Multifamily units choosing zonal heat pumps will prefer RHPs.** When considering zonal heat pump options, residents of multifamily units are more likely to RHPs over mini-splits compared to those in single-family homes. This preference is primarily due to the installation and visual impact of condenser units. RHP condenser units are integrated into the same unit that hangs out of a window, making them less visually intrusive in living spaces. This self-contained design is particularly advantageous in multifamily settings where exterior modifications may be restricted. In contrast, mini-splits have separate outdoor condenser units that need to be permanently mounted on a bracket or balcony, which can be more complex to install due to shared walls and building codes in multifamily settings. The simplified installation process of RHPs, which does not require

permanent exterior modifications, makes them a more practical and often more permissible choice for renters or condo owners in multifamily buildings.

8) **Lower potential for adoption of heat pumps in rental units compared to owned units.** Households who rent their property are less likely to install zonal heat pumps compared to households who own their property. This is primarily due to the split incentive problem: renters may have less incentive to invest in energy-efficient upgrades since they do not own the property, and property managers may be reluctant to invest in such upgrades due to the upfront costs and uncertainty about recouping the investment through higher rents.[10] CalMTA's survey of property managers indicated that some property managers see a benefit in investing in zonal heat pumps to increase potential rent and attract higher-quality tenants. However, given the financial uncertainty associated with this decision, CalMTA assumes that rental units will have a lower uptake of the product than owned units, in the absence of the MTI. However, CalMTA assumes this difference between renters and owners is small because the portability of the product allows renters to take the units with them when they move.

9) **Some potential for adoption of zonal HPs by households without HVAC systems currently.** As a result of climate change and the increasing number of cooling degree days (CDDs), some households that currently lack HVAC systems are expected to adopt heat pumps. These households, which may have previously relied on passive cooling methods or no cooling at all, will find heat pumps an attractive option due to their efficiency and ability to provide both heating and cooling. The growing frequency and intensity of extreme heat events will drive these households to invest in heat pumps to ensure comfort and safety. This trend is expected to be more pronounced among households in hot-dry climate conditions compared to those in marine climate conditions, where the demand for effective cooling solutions is higher. Additionally, government incentives and subsidies aimed at promoting energy-efficient technologies will further encourage adoption among these households.

10) **Lower adoption of heat pumps in rural households compared to urban households.** Rural households will avoid fuel substitution away from gas due to grid reliability concerns, resulting in lower heat pump adoption. Rural areas often experience less reliable electrical grids, making households hesitant to switch from gas furnaces to electric heat pumps. Additionally, the adoption of heat pumps in these areas is hindered by lower levels of communication infrastructure, limited availability of products, and a scarcity of technicians with the expertise for maintenance or installation. These factors collectively constrain the overall market potential for heat pumps in rural settings.

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[10] Davis, L. W. (2011). Evaluating the slow adoption of energy efficient investments: are renters less likely to have energy efficient appliances? In *The design and implementation of US climate policy* (pp. 301-316). University of Chicago Press. https://www.nber.org/system/files/chapters/c12130/c12130.pdf.

Table 8 shows CalMTA's estimate of the baseline maximum market adoption potential (m) – that is, the maximum potential adoption without the MTI.

Table 8. Estimated maximum baseline market potential of RHPs (without the MTI)

	Existing single-family households	Existing multifamily households
Percent of households	13%	19%
Number of households (thousands)	1,174	831

Source: CalMTA estimates. Note: The numbers in the table represent maximum market potential and not estimated baseline market adoption.

Parameter 2: Year of inflection (t_0)

The year of inflection in the Gompertz model is the point in time where the growth rate of technology adoption is at its maximum, or the inflection point. Before the inflection point, the adoption rate is increasing, starting slowly and then increasing. After the inflection point, the adoption rate slows down as the market approaches saturation. Technologies with earlier inflection points are considered more rapidly adopted compared to those with later inflection points.

Determining the year of inflection can be a complex task, typically necessitating extensive historical data and sophisticated statistical analysis. Since comprehensive historical data is not available for this relatively new technology, CalMTA estimated the year of inflection based on the estimated year of take-off and the estimated year of market saturation.

The year of take-off is the point in time when the adoption of the technology starts to accelerate significantly and there is a noticeable uptick in adoption rates. It may be construed as marking the transition from adoption by innovators and early adopters to a broader market acceptance by the early majority.[11] In the context of the RHP MTI, this represents the point where one or more major market barriers are overcome, or market opportunities are exploited. For RHPs, adoption is expected to take off in the year following availability of Type 2 and Type 3 RHPs that are compatible with sliding windows.[12] Based on discussions with manufacturers and subject matter experts, CalMTA assumes that in absence of the MTI, CA-appropriate RHPs would be introduced in 2036, and adoption would take off in 2037 for both single-family and multifamily households.

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[11] Rogers, Everett M., Diffusion of Innovations. New York, Free Press of Glencoe, 1962.

[12] **Type 1 heat pump**: A room heat pump that does not have active defrost or for which the specified compressor cut-in and cut-out temperatures are not both less than 40˚F. **Type 2 heat pump:** A room heat pump that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 40˚F but not both less than 17˚F. **Type 3 heat pump:** A room heat pump that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 17˚F but not both less than 5˚F. **Type 4 heat pump:** A room heat pump that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 5˚F.

The year of saturation is the point in time when the market for the technology is *close* to its maximum market potential (m). Most households have adopted the product, and any additional sale of the product may be attributed to product failures and re-adoption. CalMTA fitted a Gompertz model to the median estimates of RHP adoption provided by the Delphi panel for both single-family and multifamily households. From this fitted model, CalMTA extracted the estimated duration (in years) to reach market saturation. For both single-family and multifamily household models, saturation is estimated to take around 30 years after take-off, based on historical patterns of adoption for other emerging technologies. Based on the assumption for the year of take-off above, CalMTA estimates the year of saturation to be 2067 in the absence of the MTI.

CalMTA assumes that the year of inflection is the midpoint of the year of take-off and year of saturation. In other words, it is implicitly assumed that the adoption curve is symmetrical around this point. This means that the rate of adoption increases and decreases at similar rates before and after the inflection point as shown below in Table 9.

Table 9. Baseline forecast - year of inflection

	Existing single-family households	Existing multifamily households
Year of take-off	2037	2037
Year close to saturation	2067	2067
Year of inflection (t_0)	2052	2052

Source: CalMTA estimates.

Parameter 3: Rate of growth (r)

The rate of growth in the Gompertz model determines the shape and steepness of the adoption curve. This parameter controls the speed of transition from the initial slow growth phase through the rapid growth phase and finally to the saturation phase. A higher rate of growth indicates a faster adoption process, meaning the technology will reach its maximum market potential more quickly. Conversely, a lower rate of growth produces a more gradual S-curve, suggesting a slower adoption process spread over a longer period.

CalMTA used the rate of growth estimated from the Delphi panel median BMA adoption forecasts. CalMTA fit a Gompertz model to the median forecasts to identify these rates of growth (r): 0.095 for single-family; and 0.106 for multifamily households. To assess the reasonableness of these estimates, CalMTA reviewed the literature for diffusion of several other technologies. For example, Kumar R.R. et al. (2022) fit a Gompertz model to the diffusion of electric vehicles in 20 countries globally and found the rate of growth to range from 0.03 to 0.12.[13] Jha and Saha (2018) studied the diffusion of mobile networks in four European countries and estimated r of 0.04 to

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[13] Kumar, R. R., Guha, P., & Chakraborty, A. (2022). Comparative assessment and selection of electric vehicle diffusion models: A global outlook. *Energy*, *238*, 121932.

0.14 for the diffusion of 3G networks and 0.15 to 0.22 for the diffusion of 4G networks in the four countries.[14]

CalMTA assumed a 0.10 rate of BMA growth for both single-family and multifamily households. This growth rate is approximately the average of the growth rates estimated from fitting a Gompertz model to the median estimates from the Delphi panel.

Table 10 below summarizes the values adopted for the three parameters for single-family and multifamily households.

Table 10. Parameters of S-curve in the baseline - summary

	Single-family households	**Multifamily households**	**Sources**
Maximum market potential (m)	13%	19%	CalMTA estimates based on household attributes.
Year of inflection (t_0)	2052	2052	Market research including interviews of market players.
Rate of growth (r)	0.10	0.10	Inputs from Delphi Panel and literature review

Source: CalMTA estimates.

Step 2: Estimate cumulative baseline adoption of RHP

In Step #2, the forecasting model estimates the cumulative number of units of the room HP adopted based on saturation estimates from Step #1 ($Z_t^{baseline}$). It is important to note that the adoption is forecasted separately for single-family and multifamily households, although the equations presented here are simplified and do not differentiate by household type for ease of understanding.

$$Cumulative.Units_t^{baseline} = Z_t^{baseline} \times Total.Households_{2023} \times \omega$$

Where:

$Z_t^{baseline}$ = Proportion of households who have adopted RHP by t in baseline
$Cumulative.Units_t^{baseline}$ = Cumulative # of units adopted by year t
$Total.Households_{2023}$ = Number of households in base year
ω = Units per household (assumed constant over time)

For ω, CalMTA assumes 1.25 units per multifamily and 1.5 units per single-family household. These estimates are based on current ownership of portable heaters or coolers (including window ACs). EIA RECS 2020 shows that households owning zonal heating or cooling units have an

[14] Jha, A., & Saha PhD, D. (2018). Diffusion and Forecast of Mobile Service Generations in Germany, UK, France and Italy–A Comparative Analysis Based on Bass, Gompertz and Simple Logistic Growth Models.

average of 1.75 units in multifamily dwellings and 1.94 units in single-family homes. However, RHPs offer both heating and cooling functionality, potentially reducing the total number of units needed per household. Our downward adjustment reflects this dual functionality.

Step 3: Estimate annual adoption

The model then calculates the annual adoption at time t for each household type:

$$y_t^{baseline} = Cumulative.Units_t^{baseline} - Cumulative.Units_{t-1}^{baseline} + Product.Failures_t \times RPR_t$$

Where:

$y_t^{baseline}$	= Number of units adopted in year in the baseline in absence of the MTI
$Product.Failures_t$	= Units of products adopted until $t = t-1$ which fail in year t
RPR_t	= Repeat purchase rate. We assumed a repurchase rate of 75% that is constant over time.

To model product failure and re-adoption, CalMTA developed survival functions to estimate the percentage of heat pumps of a given age that would still be in operation each year. Consistent with analysis by U.S. Department for Energy (DOE EERE 2023) on product survival and failure of HVAC appliances,[15] CalMTA assumed that the survival function has the form of a cumulative Weibull distribution. The Weibull distribution is also used by the Energy Information Agency (EIA) to model residential and commercial equipment failure rates in their National Energy Modeling Systems.[16]

The cumulative Weibull distribution takes the following form:

$$F(t) = 1 - e^{-\left(\frac{t-\gamma}{\alpha}\right)^{\beta}}$$

Where:

$F(t)$:	= Probability that the appliance is still in use at age t in years

[15] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. (2023, March). *Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Room Air Conditioners* [Technical support document]. Retrieved from https://downloads.regulations.gov/EERE-2014-BT-STD-0059-0053/content.pdf.

[16] U.S. EIA. (2022). *Residential Demand Module of the National Energy Modeling System: Model Documentation* (DOE/EIA-M067). [Report]. Washington, DC: Retrieved from https://www.eia.gov/outlooks/aeo/nems/documentation/residential/pdf/RDM_2022.pdf.

t = Time or age at which the RHP product is evaluated

α = Scale parameter. Represents the time at which 63.2% of the population has failed, providing a measure of the overall scale or magnitude of the failure distribution. A larger scale parameter means that the failures are spread out over a longer period, indicating a more reliable product. Conversely, a smaller α means that failures occur more quickly.

β = Shape parameter, which determines the way in which the failure rate changes through time. Products with a larger β will have a shorter period of reliable operation before failures become common. Conversely, products with a smaller β will have a longer useful life before failures become frequent.

γ = Delay parameter, which allows for a delay before any failures occurs. CalMTA assumed a delay parameter of 0, indicating that failures can technically start from the first year.

Based on Department of Energy (DOE) analysis,[17] CalMTA adopted a scale parameter (α) of 9.36 and shape parameter of 2.49, leading to an equipment life of approximately nine years. This is consistent with estimated useful life (EUL) estimates per Database for Energy Efficient Resources (DEER).

BMA estimates

Table 11 summarizes the adoption forecasts in the BMA scenario. Results are presented for expected saturation at the end of the forecast period in terms of the percentage and the total number of households estimated to adopt the product by 2045. This is followed by the cumulative number of units expected to be adopted in the forecast period ($Y_t^{BMA} = \sum_{t=2024}^{t=2045} y_t^{BMA}$).

Table 11. BMA of RHPs

	Existing single-family households	Existing multifamily households
Saturation: Percent of households estimated to adopt by 2045	2%	3%
Number of households estimated to adopt in the forecast period (thousands)	157	111
Total units estimated to be adopted in the forecast period Y_t^{BMA} (thousands)	242	144

[17] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. (2023, March). *Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Room Air Conditioners* [Technical support document]. Retrieved from https://downloads.regulations.gov/EERE-2014-BT-STD-0059-0053/content.pdf.

The low forecasted baseline market adoption rates for RHPs reflect market conditions, and technology, market, and policy trends. These include an extremely low level of current market adoption, lack of California energy efficiency programs, and manufacturers' lack of awareness regarding needs for California-appropriate products, such as those designed for sliding windows and mild climates. RHPs will become eligible for IRA incentives once the ENERGY STAR certification – expected in 2027- is adopted. In the absence of the MTI, however, CalMTA estimates that manufacturers would not develop California appropriate products until 2036, substantially slowing adoption associated with California energy efficiency programs or IRA incentives. This delay, coupled with limited consumer awareness of the benefits and functionality of RHPs, unclear labeling, and higher costs compared to alternative technologies, are expected to limit adoption without the MTI's interventions to address these structural market barriers.

4.3 Total Market Adoption (TMA)

This section details the approach to forecast TMA, market adoption of qualified RHP products, assuming California invests in the MTI.

Approach summary

To forecast TMA, CalMTA adopted an approach that parallels the approach for BMA following the three steps mentioned in section for BMA. In this section, we highlight any additional or changed assumptions for each of the steps compared to BMA. Readers may refer to the BMA section for further details.

Step 1: Proportion of households adopting RHP in presence of the MTI

For the TMA forecast, CalMTA made the following assumptions about each of the three S-curve model parameters.

Parameter #1: Maximum market potential (m) in presence of the MTI

CalMTA estimated the maximum market potential in the presence of the MTI for each of the 80 mutually exclusive, collectively exhaustive subsegments of existing households in California.

The assumptions made for estimating m for BMA were also adopted for estimating m here, including these:

1) High adoption among households with existing inefficient zonal heating and/or cooling system
2) Low adoption rate among single-family households with a centralized gas furnace and/or central cooling system; high adoption among multifamily households
3) Low adoption rate among single-family households with a centralized gas furnace and/or central cooling system; high adoption among multifamily households with similar systems

4) Multifamily units choosing zonal heat pumps will prefer RHPs
5) Lower potential for adoption of heat pumps in rental units compared to owned units
6) Some potential for adoption by households without HVAC systems currently compared to baseline
7) Lower adoption of heat pumps in rural households compared to urban households

In addition to the assumptions above, CalMTA made the following assumptions for m in the presence of the MTI:

8. Higher potential for adoption among all household segments in the presence of the MTI relative to baseline. CalMTA assumes that the maximum market potential for zonal heat pumps will be higher among all household segments in presence of the MTI relative to the baseline. Multiple CalMTA interventions will lead to that outcome. First, the MTI will aggregate demand to influence manufacturers to produce RHPs appropriate for California's climate and its dominant window type (slider windows). Efforts to build market awareness of product benefits and improve labeling consistency and in-store product availability will lead to increased adoption. Additionally, the MTI efforts to increase product availability in low-income communities is likely to lead to broader access across various subsegments, leading to higher potential for adoption. The MTI will also influence manufacturers to produce California appropriate products with additional value-added features, such as air filtration systems. Increased production volume is expected to lead to economies of scale, lower prices, and an increased number of make/models compared to baseline, which in turn is expected to lead to higher adoption compared to baseline. This assumption impacts all the 40 sub-segments discussed above.

9. Increase in potential for adoption of heat pumps in rental units compared to baseline.

With targeted interventions by CalMTA, including negotiated bulk pricing as well as efforts to increase awareness of the benefits of heat pumps among property managers, an increase in the uptake of these products by property managers and owners of rental properties is anticipated. Additionally, MTI interventions aimed at enhancing the price competitiveness of RHPs relative to baseline technologies are expected to contribute to this increase. Consequently, CalMTA relaxed the initial assumption of lower adoption rates in rental units. While rental properties are still expected to have a lower uptake compared to owned properties, the uptake in rental properties is projected to be higher if the MTI is implemented than it would be in the baseline scenario.

10. Greater market potential for RHP relative to mini-splits in presence of the MTI.

The current availability of RHPs is limited to Type 1 units, and two very expensive Type 4 window units designed for cold climates and vertically hung windows. Existing units are suitable for only a small fraction of California households, because most households would require Type 2 or Type 3 products and/or units that fit sliding or casement windows. As a result, households seeking zonal heat pump solutions in the near future may opt for mini-splits. Given the initial investment and potential long-term use of mini-splits, such households will be less inclined to shift away from mini-splits and adopt RHPs in the future. CalMTA plans to actively engage with manufacturers to accelerate the development and availability of California-appropriate products. These interventions will accelerate the development and introduction of products that better suit the needs of California's residential market, reducing the number of households that might otherwise become locked into mini-split systems. In other words, a greater proportion of households will eventually adopt RHPs if the MTI is implemented than in the baseline scenario because of the faster introduction of California-appropriate products.

Given the above assumptions, CalMTA estimates the following maximum market potential for RHPs, assuming it implements the RHP MTI (Table 12).

Table 12. Estimated maximum market potential of RHPs among existing households in presence of the MTI

	Existing single-family households	Existing multifamily households
Percent of households	24%	38%
Number of households (thousands)	2,085	1,635

Note: The numbers in the table represent maximum market potential and not estimated market adoption.

Parameter 2: Year of inflection (t_0)

To address the key market barrier of limited products that are compatible with California's requirements, CalMTA plans interventions to encourage manufacturer development of window heat pumps (WHPs) that meet the needs of the California market through technology challenges, demand aggregation, and ongoing manufacturer engagement. CalMTA plans the following medium term (3-5 years) market milestone: three new RHP Type 2 or 3 products for sliding and casement windows become available for purchase. This milestone, along with others such as having at least five programs that offer RHP as an eligible measure in the medium term, is expected to lead to a take-off in adoption of RHPs.

In the presence of the MTI, CalMTA assumes the market will reach saturation after a shorter duration than the baseline scenario. The faster trajectory to saturation will be facilitated through engagement with market partners including manufacturers and retailers leading to increased product availability, marketing campaigns leading to enhanced product awareness among households and property managers, and engagement with program administrators (PAs) leading to multiple programs including resource acquisition programs to incentivize adoption of RHPs.

However, CalMTA does not have a specific basis to estimate by how many years the duration should be lower in the presence of MTI. In the absence of any available trends, we conservatively consider a 20% reduction, resulting in an estimated time to saturation of 24 years compared to 30 years in the baseline scenario. As with the baseline scenario, the year of inflection is expected to be the mid-point of year of take-off and year of saturation, as shown below in Table 13.

Table 13. Year of inflection in presence of the MTI

	Existing single-family households	Existing multifamily households
Year of take-off	2029	2029
Year close to saturation	2053	2053
Year of inflection (t_0)	2041	2041

Source: CalMTA estimates.

Parameter 3: Rate of growth (r)

As mentioned earlier, this parameter controls the speed of transition from the initial slow growth phase through the rapid growth phase and finally to the saturation phase. In the presence of the MTI, CalMTA assumes that the speed of this transition will be higher compared to the baseline. To contextualize our assumption, we can draw parallels from electric vehicle (EV) adoption studies. Kumar R.R. et al. (2022) estimated the rate of growth for the Gompertz curve fitted to EV adoption in the U.S. at 0.058. For Norway, a country with substantial policy interventions promoting EV adoption, the equivalent estimate is 0.113. The higher r-value for Norway (nearly double that of the U.S.) can be attributed to aggressive policy measures, resulting in EVs comprising around 86% of new car sales today.[18] Comparatively, less than 10% of cars sold in the U.S. are EVs.[19] Given the planned interventions in the RHP MTI, CalMTA conservatively assumes that the rate of growth will increase by 25% compared to the baseline scenario.

Table 14 below summarizes the values adopted for the three parameters for single-family and multifamily households.

Table 14. Parameters of S-curve in the presence of the MTI - summary

	Single-family households	Multifamily households	Sources
Maximum market potential (m)	24%	38%	CalMTA estimates based on household attributes, and assumed impacts of the MTI plan
Year of inflection (t_0)	2041	2041	Based on planned interventions and targeted milestones in the MTI plan
Rate of growth (r)	0.125	0.125	As above

Source: CalMTA estimates.

[18] Ryghaug, M., & Skjølsvold, T. M. (2023). How policies and actor strategies affect electric vehicle diffusion and wider sustainability transitions. *Proceedings of the National Academy of Sciences*, *120*(47), e2207888119.
[19] EIA (2024) https://www.eia.gov/todayinenergy/detail.php?id=62924.

Step 2: Forecast cumulative total market adoption of RHP

Parallel to the approach used to forecast BMA, in this step, CalMTA estimated $Cumulative.Units_t^{TMA}$ the cumulative number of units of RHP adopted by year t.

Step 3: Forecast annual adoption

Parallel to the BMA approach, in this step, CalMTA calculated y_t^{TMA} the annual adoption at time t for each household type.

TMA estimates

Table 15 summarizes the TMA forecasts, alongside BMA results for comparison. Results are presented for expected saturation at the end of the forecast period in terms of the percentage and the total number of households estimated to adopt the product by 2045. This is followed by the cumulative number of units expected to be adopted in the forecast period ($Y_t^{TMA} = \sum_{t=2024}^{t=2045} y_t^{TMA}$) , which includes re-adoption.

Table 15. Market adoption of RHPs

	Existing single-family households		**Existing multifamily households**	
	BMA	TMA	BMA	TMA
Saturation: Percent of households estimated to adopt by 2045	2%	14%	3%	22%
Number of households estimated to adopt in the forecast period (thousands)	157	1,205	111	945
Total units estimated to be adopted in the forecast period Y_t^{TMA} (thousands)	242	1,838	144	1,207

The presence of the MTI is expected to lead to a substantial increase in the adoption of RHPs. CalMTA forecasts that approximately 14% of single-family households and 22% of multifamily households will adopt RHPs. For comparison, current saturation levels for portable heaters stand at around 25% for both single-family and multifamily households, indicating their use for primary heating or supplemental heating. Similarly, in terms of air conditioning, approximately 15% of single-family households and 31% of multifamily households currently own portable, window, or wall-mounted air conditioning units (EIA RECS 2020).

Figure 3 illustrates the estimated adoption in terms of proportions for single-family (left) and multifamily households (right), while Figure 4 presents the adoption numbers in thousands of households.

Figure 3. Estimated proportion of single-family and multifamily households adopting RHPs

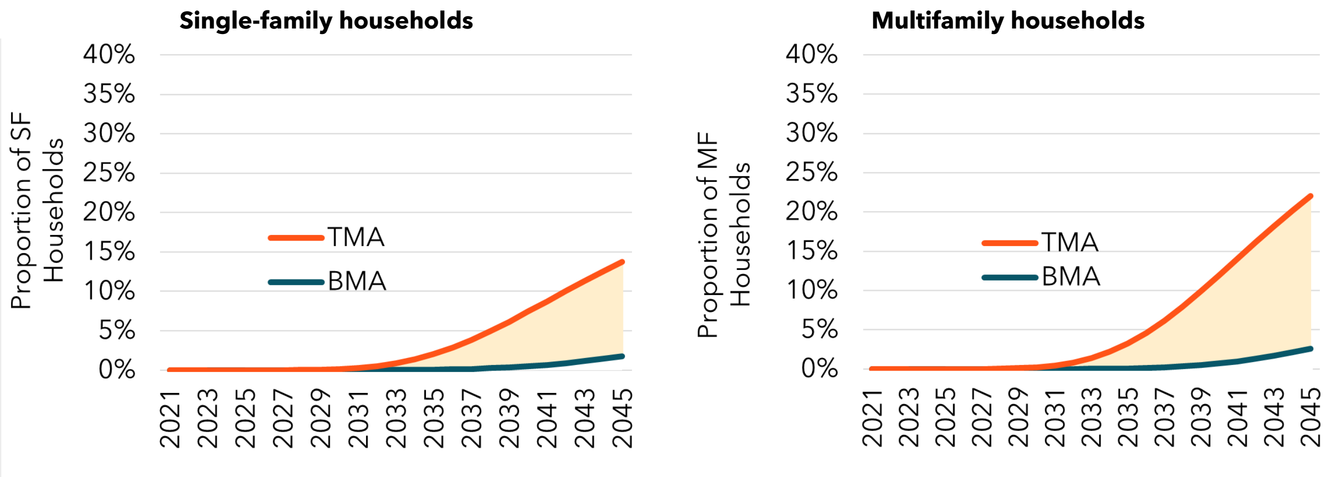
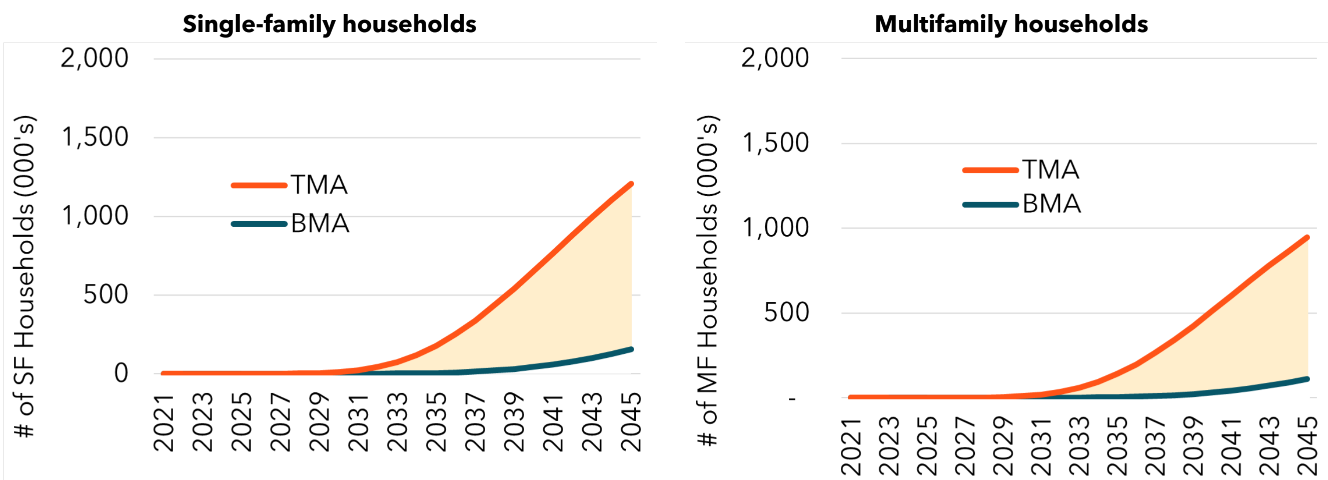


Figure 4. Estimated number of single-family and multifamily households adopting RHPs (in thousands)



4.4 Incremental impact

Per the attribution approach agreed upon in the MTI Evaluation Framework, net incremental adoption of RHPs attributed to the market transformation efforts by CalMTA may be written as:

$$Y^{N.incremental} = Y^{TMA} - Y^{BMA} - Y^{RA}$$

Where Y represents cumulative adoption of RHPs over the forecast period of 2024 to 2045. The superscripts $N.incremental$, TMA, BMA, and RA represent net incremental adoption attributed to the MTI, TMA, BMA, and PA-verified savings respectively.

This section details the approach to estimate verified units attributed to PA-led initiatives and calculates the incremental adoption of RHP.

Estimating IOU vs. non-IOU units

Prior to estimating net incremental, CalMTA considered adoption attributed to households in the IOU service territories. The approach summarized above estimated BMA, and TMA at a statewide level. To estimate the proportion of adoption by households in the IOU service territories, CalMTA considered three options: number of residential electricity customers, total electricity sales to the residential sector, and revenues from residential electricity sales. Ultimately, CalMTA selected revenue-based allocation as it comprehensively captures both customer numbers and electricity consumption patterns while accounting for factors like pricing that influence heat pump adoption decisions. Based on EIA data, and accounting for both bundled and unbundled customers for the three IOUs (PG&E, SDG&E, and SCE), CalMTA allocated around 74% of incremental adoption to the California IOUs with the remaining 26% representing customers outside of the IOU service territories.[20]

Approach to estimating units associated with verified PA savings

To forecast adoption associated with verified PA initiatives, CalMTA estimated the number of incremental units (TMA minus BMA) associated with such initiatives. There is no reliable source for an estimate of PA RHP savings claims in the future, therefore, the team used available historical information from two market transformation programs administered by the Northwest Energy Efficiency Alliance (NEEA) to inform its estimate of the proportion of market adoption above baseline that would be claimed by California PAs.

Estimated market adoption in year t associated with units from PA-verified savings or y_t^{PA} may be expressed as:

$$y_t^{PA} = \rho_t \times (y_t^{TMA} - y_t^{BMA})$$

Where:

y_t^{PA}:	= Number of units adopted in year t associated with PA-verified savings
ρ_t	= Fraction of the difference in adoption between TMA and BMA in year t that CalMTA estimates would be associated with PAs may claim from their RA programs.

[20] U.S. Energy Information Administration. (2023). *Residential Energy Consumption Survey: 2020*. Retrieved from https://www.eia.gov/consumption/residential/data/2020/.

CalMTA used two NEEA studies as points of reference to inform estimates of ρ_t. NEEA's Heat Pump Water Heater Market Progress Evaluation Reports #7 estimates that PA programs incented about 49% to 61% of units adopted in the years 2019 to 2021.[21] The Northwest Ductless Heat Pump Initiative: Market Progress Evaluation #8 estimates ρ_t about 42% for the mid-initiative period.[22]

Using these points of reference, CalMTA made the following assumptions about ρ_t (6). The segmentation of the program cycle reflects the IOUs Business Plan Cycle and Application Cycle, or four and eight years, respectively.

Table 16. Estimated PA program verified savings claims as percentage of incremental adoption[23]

MTI program years	Assumed ρ_t	Justification for assumption
2024-2027 (early initiative)	10%	No PA programs currently incentivize RHPs, and few are expected over the next several years; therefore, ρ_t is low early in the program cycle.
2028-2031 (mid-initiative)	40%	By 2028, programs promoting RHPs are assumed to be more widely available, providing downstream and midstream incentives.
2032-2045 (late initiative)	Decrease annually to 0% in 2045	As the technology matures, CalMTA assumes reduction in units associated with PA initiatives.

Table 17 summarizes the total number of incremental units estimated to be incentivized by Program Administrators, disaggregated by household type, from 2024 to 2045 ($Y_t^{RA} = \sum_{t=2024}^{t=2045} y_t^{RA}$).

Table 17. Estimated units attributed to PA-verified savings

	Existing single-family households	Existing multifamily households
Total units estimated to be adopted in the forecast period that are PA Incented (Y_t^{PA}, thousands)	196	129

[21] NEEA. November 2019. *Heat Pump Water Heater Market Progress Evaluation Report #7*. HPWH MPER 7 (neea.org).

[22] NEEA. November 2019. *Northwest Ductless Heat Pump Initiative: Market Progress Evaluation #8*. Northwest-Ductless-Heat-Pump-Initiative-Market-Progress-Evaluation-8.pdf (neea.org).

[23] The assumed PA-verified units will be reviewed and adjusted during the MTI Phase III deployment to reflect actual PA verified savings claims.

Table 18 summarizes the state-wide TMA, BMA, PA-verified units, and net incremental adoption in terms of RHP units adopted. The next-to-last column estimates adoption attributed to households outside the service territories of the three IOUs. The final column provides the adoption estimates included in the estimation of TSB and cost-effectiveness.

Table 18. Forecast of adoption of RHPs (in thousands, 2024-2045)

	TMA (Y^{TMA})	BMA (Y^{BMA})	PA-verified units (Y^{A})	Net incremental ($Y^{N.incremental}$)	Adoption attributed to non-IOU territory	Adoption for TSB and CE estimation
Single-family households	1,838	242	196	1,400	372	1,028
Multifamily households	1207	144	129	934	251	683
Total	**3,045**	**386**	**325**	**2,334**	**623**	**1,711**

Source: CalMTA estimates. PA verified units include adoption associated with PA programs statewide.

4.5 Allocation to counterfactual conditions in the baseline

This section describes CalMTA's approach to allocate net incremental adoption to a set of counterfactual conditions in the absence of the MTI (the baseline modeling scenario). These conditions, henceforth referred to as "installation conditions." represent the combination of MTI technologies and the counterfactual heating and cooling technologies that a household would have adopted in the absence of the MTI. The per-unit savings calculations and cost-effectiveness analysis are conducted by installation conditions.

CalMTA categorized the installation conditions into three broad decision types:

- **Replacement**: Households covered in this scenario are anticipated to use zonal systems for primary heating and cooling. In the absence of CalMTA's interventions, they are assumed to adopt one of the baseline technologies identified in Table 19, such as room air conditioners with electric resistance heat or gas wall furnaces.
- **Displacement**: Single-family households covered in this scenario are expected to use zonal systems to reduce the usage of their central HVAC systems. Without the MTI, they are expected to opt for other baseline technologies like room air conditioners or zonal heaters to supplement their central system. This scenario does not cover multifamily households where we do not expect a combination of central and zonal systems due to unit size.
- **No cooling**: In the absence of the MTI, some households would have installed only heating systems, such as gas furnaces, without any cooling systems.

CalMTA's approach to assigning net incremental RHP adoption considered two key aspects: the relative market share between PHPs and WHPs, and the allocation to baseline installation conditions. While portable heat pumps (PHPs) are currently assumed to dominate the market due to compatibility constraints with California's casement and sliding windows, WHPs are expected to become more prevalent over time as manufacturers develop products better suited to California window types, offering superior efficiency, improved aesthetics, and quieter operation compared to portable units. For assignment to installation conditions, CalMTA made three key assumptions: single-family households with central HVAC systems would have chosen inefficient electric zonal heaters and window AC units to supplement their central systems, households with only gas furnaces would have installed heating-only systems without any cooling, and the remaining households would have defaulted to inefficient electric heating combined with window/wall AC units.

Table 19 presents the allocation percentages of net incremental RHP adoption across these installation conditions, showing how adoption patterns differ between single-family and multifamily sectors for each decision type and equipment combination.

Table 19. Allocation of net incremental adoption of RHPs to various modeled installation conditions

Decision type	Efficient equipment	Counterfactual equipment	Sector: Single-family	Sector: Multifamily
Replacement	WHP	Window AC w/electric resistance heat	20%	52%
		Window AC w/gas wall furnace	4%	10%
	PHP	Portable AC w/electric resistance heat	12%	30%
		Portable AC w/gas wall furnace	2%	6%
Displacement	WHP	Window AC w/electric resistance heat	35%	n/a
	PHP	Portable air conditioner w/electric resistance heat	20%	n/a
No cooling	WHP	Gas wall furnace	5%	2%
	PHP	Gas wall furnace	3%	1%

Source: CalMTA estimates. Notes: The displacement decision type is only modeled for single-family households.

5 Cost-effectiveness analysis

Evaluating cost-effectiveness and determining the net incremental benefits for an MTI requires the appropriate application of net incremental adoption, initiative costs, incremental measure cost (IMC), avoided costs, load shapes, and unit energy savings (UES). This analysis considers the installation conditions (the combination of counterfactual and efficient technologies), fuel types, target sector, and costs incurred in MTI implementation. Attachment 2 (following this document) provides additional details regarding the installation conditions and assumptions used to determine per unit savings for each of these conditions.

Currently, the CEDARS Cost-Effectiveness Tool (CET) is the official publicly available tool used to assess cost-effectiveness of energy efficiency programs in California. The CET is used for programs from all utilities and climate zones, using approved 8,760 load shapes and defined avoided costs. However, since the analysis for this MTI involved custom 8,760 load shapes not currently supported by CET-16, the team developed an in-house Excel-based cost-effectiveness which allowed for full insight into how the model generated outputs based on dynamic and varying inputs.

5.1 Modeling approach/methodology

The team took a systematic approach to developing the cost-effectiveness model, beginning with determining all the necessary model inputs and outputs for the MTI. The approach is further described below.

The team calculated MTI cost-effectiveness based on six inputs: market adoption, UES, initiative costs, load shape, avoided costs, and IMC. The team developed each of these inputs using product and market definitions documented by the MTI team. For the RHP MTI, all per-unit inputs were in terms of RHP or PHP units.

UEI inputs were analyzed by the three IOUs: PG&E, SCE, SDG&E. Consequently, each installation condition for any MTI had three sets of utility-specific UEIs. The model paired UEI inputs with an 8,760 hourly load shape appropriate for each MTI technology that estimated how likely an end user would use the equipment in any given hour of the year.

All inputs were applied on a yearly basis, over the equipment EUL and Phases II and III of the MTI. The analysis used these assumptions for the RHP MTI:

1) Phase II: 2 years (2024 to 2025)
2) Phase III: 20 years (2026 to 2045)
3) EUL: Nine years

Input-specific assumptions are described in more detail in their related sections below.

There are four outputs for reporting on the MTI: TSB, TRC, PAC, and SCT, with SCT including two ratios for base social cost of carbon (SCC) and high SCC. The team evaluated and aggregated the TSB, TRC, PAC, base SCT, and high SCT for each MTI installation condition, respectively, to determine the MTI total TSB, TRC, PAC, and base SCT, and high SCT. To account for the time value of money, the team applied a discount rate of 7.30% (3% for base and high SCT) to discount benefits and incremental measure cost to the first year of the MTI, in line with current guidance from the CPUC. Initiative costs were in real terms and therefore were not discounted. Table 20 lists the terms (based on the CET) used by the model to determine the TSB, TRC, PAC, and SCT.

Table 20. Cost-effectiveness model parameters

Terms	Description	Units
Electric benefits	Net benefits generated through electric savings from the Avoided Cost Calculator (ACC)	Dollars/kWh and Dollars/kW and associated GHG avoided costs
Gas benefits	Net benefits generated through gas savings from ACC	Dollars/therms and associated GHG avoided costs
Other benefits	Benefits generated through non-electric or gas savings. Stage 2 analysis incorporated refrigerant benefits only	Dollars per unit
Refrigerant benefits	Measure benefits generated through refrigerant savings	Dollars/unit
Electric supply cost	Costs incurred in the supply of electricity	Dollars/kWh and Dollars/kW
Gas Supply Cost	Costs incurred in the supply of gas	Dollars/therms
Refrigerant Costs	Costs incurred through refrigerant losses; Stage 2 analysis incorporated refrigerant costs only	Dollars/unit
TRC Costs	Costs associated with the TRC test	Dollars (Initiative Admin/Marketing/Evaluation and Incremental Measure Costs)
PAC Costs	Costs associated with the PAC test	Dollars (Initiative Admin/Marketing/Evaluation and Flow Down Incentives)
SCT Costs	Costs associated with the SCT	Dollars (Initiative Admin/Marketing/Evaluation and Incremental Measure Costs)

5.2 Inputs

MTI-driven adoption

The team applied MTI-driven incremental adoption allocated to each of three IOUs (PG&E, SCE, and SDG&E) for the duration of the EUL of RHPs. For example, if 80,000 units were projected to be installed in 2027, these units contributed to the model for nine years (EUL for RHPs), combined with RHPs introduced in the following years.

Initiative costs

Initiative costs are related to the implementation of the MTI. This includes flow-down incentives (FDI) and non-incentive costs, such as administration, research and evaluation, marketing, and other related costs. The team applied initiative costs from 2024 to 2045. The total initiative cost for the RHP MTI was approximately $62.81 million. More details can be found in Appendix H: Phase III Cost Estimate of the MTI Plan.

Initiative costs are used as inputs for all cost-effectiveness tests. However, while the PAC test includes all initiative costs, the TRC and SCT tests exclude incentive costs.

Incremental Measure Cost

The team conducted secondary research to develop estimates of incremental costs, researching currently available counterfactual and proposed energy-efficient technology products. Products included window and portable ACs, WHPs and PHPs, gas wall furnaces, and portable electric space and baseboard heating (see Table 21 for further details). The product costs were sourced from California stores like The Home Depot and Lowe's.

In three of the installation conditions, the equipment cost of the proposed technology was lower than the counterfactual equipment it replaces, as this MTI envisions one dual purpose unit replacing separate space heating and cooling equipment. In these instances, incremental costs were negative. Table 21 lists the first-year incremental costs used in this analysis:

Table 21. First year IMCs

Segment	Counterfactual equipment	Efficient equipment	Decision type	First-year IMC
Multi-/ single-family	Window AC + electric resistance heat	WHP	Replacement	$245
Multi-/ single-family	Window AC + gas wall furnace	WHP	Replacement	($598)
Multi-/ single-family	Portable AC + electric resistance heat	PHP	Replacement	($180)
Multi-/ single-family	Portable AC + gas wall furnace	PHP	Replacement	($1,023)
Single-family	Window AC + electric resistance heat	WHP	Displacement	$481
Single-family	Portable AC + electric resistance heat	PHP	Displacement	$56
Multi-/ single-family	No cooling + central gas furnace	WHP	No cooling	$890
Multi-/ single-family	No cooling + central gas furnace	PHP	No cooling	$586

The team included IMCs in the TRC test, along with non-FDI costs for each year and installation condition. In line with CPUC guidance, IMCs in the TRC test are discounted to the first year of the initiative to determine the present value of future incremental costs.

Trends in Incremental Measure Costs

CalMTA adopted price trends assumed by an analysis by U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE) study on U.S.-wide impact of ENERGY STAR specifications for room ACs (DOE EERE 2023).[24] The study employed the "learning curve" approach to model historical price trends and forecast likely trends from 2025 to 2055. The learning curve, or experience curve, approach is based on the idea that as production volume increases, the cost per unit decreases due to efficiencies and learning over time. This method captures how cumulative experience and improvements in processes lead to cost reductions. In essence, the learning curve quantifies the rate at which costs decline (learning rate) as a function of increased production, often represented as a percentage reduction for each doubling of cumulative output (learning rate). In the DOE study, a fixed industry average markup is applied to these cost reductions to estimate the corresponding price trends for room ACs.

The DOE EERE 2023 report estimates three separate learning rates. The default rate considers all available shipment and pricing data. A high learning rate considers price and shipment trends during the early part of product introduction (revolutionary phase). Finally, a low learning rate considers the mature stages of a product diffusion. Selection of the three stages involves subjectivity and analyst discretion.

In this report, CalMTA applies a high learning rate for the RHP products given the early stage of product introduction, and a low learning rate for the counterfactual technologies including zonal resistance heaters and central gas furnace given their maturity and large cumulative adoption over last several decades.

Room & portable AC

CalMTA adopted the DOE EERE 2023 study for price trends of room AC units. The DOE study considered both price trends of AC units with single-speed compressors based on historical price trends of room AC and combined that with learning rate associated with the electronic controls used in variable-speed units. DOE estimates price trends disaggregated by "efficiency levels." For this analysis, CalMTA chose the intermediate efficiency level which represents higher efficiency

[24] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Appliances and Commercial Equipment Standards. (2023, March). *Technical support document: Energy efficiency program for consumer products and commercial and industrial equipment: Room air conditioners*. https://www.regulations.gov/document/EERE-2014-BT-STD-0059-0053.

than the current ENERGY STAR Version 4.2 level but below the levels reached by units with variable-speed compressors currently on the market.

For portable AC units, DOE considered the similarities and dissimilarities with room AC units. Given that portable ACs and room ACs (wall and window units) share similar core technologies, it is reasonable to expect comparable price trends. Both types of ACs utilize compressors to circulate refrigerant and facilitate the cooling process, including the adoption of variable speed compressors, which adjust the compressor speed based on cooling demand to enhance energy efficiency. They also use similar refrigerants to absorb and release heat, essential for the cooling cycle, and have comparable heat exchange systems with evaporators and condensers. Additionally, both types of ACs employ electronic control systems to regulate temperature and fan speed, and benefit from advancements in energy efficiency technologies such as improved insulation, better airflow management, and smart thermostats. Given these shared components, CalMTA anticipates similar cost reductions and technological improvements over time.

However, portable ACs differ from room ACs in some critical ways. Sales of portable ACs took off only in the 1990s. Based on DOE EERE analysis in 2016[25], less than 5 million units had been cumulatively shipped through 2014 compared to nearly 250 million units for room AC (U.S.-wide shipments).

Central furnace and portable heaters

Given that portable heaters and central furnace heaters are mature products, CalMTA assumes there are limited prospects for further efficiency advancements within the supply chain. Consequently, CalMTA does not anticipate any price reductions for these products.

Room Heat Pumps

To establish price trends for WHPs and PHPs, CalMTA applied high learning rates derived from the analysis of room ACs by the DOE EERE 2023 study. This reflects cost trends during the early stages of product introduction (revolutionary phase) when manufacturers optimize production processes and scale up. In absence of data for heat pumps, CalMTA applied the learning rates from room ACs. Both products share similar core technologies, such as compressors and refrigerants, and often come from the same manufacturers. This technological overlap and shared production expertise suggests that RHPs can benefit from similar efficiency improvements and cost reductions observed in room ACs.

Portable Heat Pumps

PHPs are likely to experience a flatter price decline compared to WHPs due to several factors. First, PHPs are expected to have lower market demand and smaller market share relative to WHPs because of lower efficiencies, poorer aesthetics, and limited operability in temperatures below 40F, leading to limited economies of scale. Further, PHPs are unlikely to benefit from

[25] https://www.energy.gov/eere/buildings/articles/issuance-2016-12-28-energy-conservation-program-energy-conservation-2.

technological advancements in WHPs due to the need for portability. These factors are expected to collectively slow down the rate of cost reductions for PHPs compared to the more established and standardized WHPs. Given above, CalMTA assumes that PHPs will have a flatter price trajectory compared to RHP; the slope of price decline is assumed to be 75% of that of WHP for first 10 years and then 50% through 2045. Assumed price trends for each HVAC technology is provided in Table 22.

Table 22. Assumed Price Trends of HVAC Technologies

Equipment	Price trend - 2024 to 2035	Price trend - 2024 to 2045
Window AC	(8%)	(14%)
Portable AC	(10%)	(16%)
Central furnace	0%	0%
Resistance heating	0%	0%
WHP	(32%)	(46%)
PHP	(24%)	(32%)

Note: The values represent the percentage decrease in the price of the product from 2024 to 2035 and 2045 respectively.

Avoided costs

Avoided costs are defined as the marginal costs of energy that the state would avoid in any given hour through lower energy consumption. The electric avoided costs include cap and trade, GHG adder, GHG rebalancing, energy, generation capacity, transmission capacity, distribution capacity, ancillary services, losses, and methane leakage. Gas-avoided costs include transmission and distribution, commodity, nitrogen oxides, carbon dioxide, and methane leakage.

The team developed avoided costs using the E3 2024 Avoided Cost Calculator (ACC) for PG&E, SCE, and SDG&E. CalMTA developed avoided costs from 2024 to 2054 in each utility's territory and used these to determine the TSB, as well as TRC and PAC ratios. The team applied avoided costs to the incremental adoption for PG&E, SCE, and SDG&E for each installation condition in each year. The team aggregated and discounted these benefits to determine the MTI TSB in 2024 dollars.

While the methodology of calculating unit impacts were identical for TRC, PAC, base SCT, and high SCT, SCT analysis required the following additional factors to be included in the avoided costs:

1) Social cost of carbon (SCC)
    a. Base SCC (50th percentile of possible climate impacts)
    b. High SCC (95th percentile of possible climate impacts)
2) Base value of methane leakage: 2.3% of gas consumption

3) Statewide air quality adder: $14/MWh

4) Societal test specific discount rate: 3%

The ACC incorporates these societal benefits in their avoided costs. The team applied the base and high SCT specific avoided costs to the incremental adoption for PG&E, SCE, SDG&E. Like the TRC, and PAC analyses, the team aggregated and discounted these benefits to determine the base and high SCT TSB in 2024 dollars.

Load shape

A load shape is defined as the hourly probability of activity for RHPs based on a set of variables including equipment runtimes, operating characteristics, and other factors, such as occupancy patterns. To develop load shapes for this technology, multiple DEER based multifamily and single-family HVAC load shapes were used to create an average HVAC load shape representing California homes. A more detailed description of the load shape used for this analysis can be found in Attachment 2 following this document.

Unit Energy Savings

To determine the unit energy savings, estimates were developed through a set of energy models comparing different base and efficient cases for each climate zone. A detailed description of these models and their supporting assumptions can be found in Attachment 2 following this document. Table 23 provides electric savings (in kWh) and gas savings (in therms) by segment, installation condition, decision type, and IOU. Under certain installation conditions average annual kWh savings are negative, as gas heating equipment is replaced with electric equipment, resulting in additional electric consumption.

Table 23. Unit Energy Savings

Segment	Counterfactual equipment	Efficient equipment	Decision type	IOU	Average annual electric savings (kWh)	Average annual gas savings (therms)
Multifamily	Window AC + electric resistance heat	WHP	Replacement	SDG&E	152.4	0.0
				SCE	337.3	0.0
				PGE	563.8	0.0
Multifamily	Window AC + gas wall furnace	WHP	Replacement	SDG&E	(58.5)	10.3
				SCE	(196.9)	26.0
				PGE	(358.9)	45.0
Multifamily	Portable AC + electric resistance heat	PHP	Replacement	SDG&E	103.0	0.0
				SCE	204.2	0.0
				PGE	348.8	0.0
Multifamily		PHP	Replacement	SDG&E	(108.0)	10.3

Segment	Counterfactual equipment	Efficient equipment	Decision type	IOU	Average annual electric savings (kWh)	Average annual gas savings (therms)
	Portable AC + gas wall furnace			SCE	(330.0)	26.0
				PGE	(573.9)	45.0
Single-family	Window AC + electric resistance heat	WHP	Replacement	SDG&E	1447.6	0.0
				SCE	597.9	0.0
				PGE	1215.2	0.0
Single-family	Window AC + gas wall furnace	WHP	Replacement	SDG&E	(521.1)	96.0
				SCE	(317.4)	44.6
				PGE	(657.0)	91.3
Single-family	Portable AC + electric resistance heat	PHP	Replacement	SDG&E	1038.8	0.0
				SCE	386.4	0.0
				PGE	812.5	0.0
Single-family	Portable AC + gas wall furnace	PHP	Replacement	SDG&E	(930.0)	96.0
				SCE	(528.9)	44.6
				PGE	(1059.8)	91.3
Single-family	Room AC + electric resistance heat	WHP	Displacement	SDG&E	424.1	0.0
				SCE	393.7	0.0
				PGE	698.1	0.0
Single-family	Portable AC + electric resistance heat	PHP	Displacement	SDG&E	292.0	0.0
				SCE	278.2	0.0
				PGE	428.6	0.0
Multifamily	No cooling + central gas furnace	WHP	No cooling	SDG&E	(249.4)	15.1
				SCE	(233.4)	20.0
				PGE	(329.2)	47.7
Multifamily	No cooling + central gas furnace	PHP	No cooling	SDG&E	(459.8)	15.1
				SCE	(428.0)	20.0
				PGE	(561.5)	47.7
Single-family	No Cooling + Central Gas Furnace	WHP	No cooling	SDG&E	(607.6)	85.2
				SCE	(663.2)	98.5
				PGE	(1244.8)	183.9
Single-family	No Cooling + Central Gas Furnace	PHP	No cooling	SDG&E	(1097.5)	85.2
				SCE	(1191.7)	98.5
				PGE	(2164.2)	183.9

5.3 Outputs

Total System Benefit

TSB is a function of the inputs described in earlier sections. For the RHP MTI, the team disaggregated the total TSB into three components: energy, grid, and GHG benefits (categorized as refrigerant and non-refrigerant). The team used the following CET-based formula to determine TSB:

$$(Electric\ Benefits + Gas\ Benefits + \ Refrigerant\ Benefits)$$

$$-\ (Electric\ Supply\ Cost + Gas\ Supply\ Cost + \ Refrigerant\ Costs)$$

Total Resource Cost

The TRC test compares the life cycle benefits that the MTI will deliver to the costs associated with achieving those benefits from the perspective of the MTI administrator and the participant. Net benefits, initiative costs (not including FDIs), and IMC are used to determine TRC. The non-FDI initiative costs are summed together with the IMC and discounted over the period of the MTI's implementation. The discounted net life cycle benefits for all installation conditions are divided by the sum of the discounted IMC and non-FDI Initiative costs to determine the MTI TRC ratio. Below is the CET-based formula used by the tool to determine TRC.

$$(Electric\ Benefits\ +\ Gas\ Benefits\ +\ Other\ Benefits)\ /\ TRC\ Cost$$

Program Administrator Cost

The PAC test compares the life cycle benefits that the MTI will deliver to the costs associated with achieving those benefits from the perspective of the MTI administrator. Net benefits and Initiative costs (including FDIs) are used to determine PAC. The initiative costs are discounted over the lifetime of the MTI's implementation. The discounted net life cycle benefits for all installation conditions are divided by the sum of the initiative costs to determine the MTI PAC ratio. Below is the CET-based formula used by the tool to determine PAC.

$$(Electric\ Benefits\ +\ Gas\ Benefits\ +\ Other\ Benefits)\ /\ PAC\ Cost$$

Societal Cost Test

The SCT compares the life cycle benefits the MTI will deliver to the costs associated with achieving those benefits from the perspective of California as a whole. Net benefits, initiative costs (not including FDIs), and IMC are used to determine TRC. The non-FDI initiative costs are summed together with the IMC and discounted over the period of the MTI's implementation. The discounted net life cycle benefits for all installation conditions are divided by the sum of the respective discounted IMC and non-FDI Initiative costs to determine the MTI SCT ratio. Below is the formula used by the tool to determine the base SCT ratio.

$$(Base\ SCT\ Electric\ Benefits\ +\ Base\ SCT\ Gas\ Benefits\ +\ Other\ Benefits)\ /\ SCT\ Cost$$

Below is the formula used by the tool to determine the high SCT ratio.

$$(High\ SCT\ Electric\ Benefits\ +\ High\ SCT\ Gas\ Benefits\ +\ Other\ Benefits)\ /\ SCT\ Cost$$

Results

Total System Benefit (TSB)

Table 24 shows the TSB estimates disaggregated for energy, grid, and GHG impacts.

Table 24. TRC, PAC, base SCT, and high SCT TSB estimates, 2024-2045

MTI Approach	TSB ($M)	Energy ($M)	Grid ($M)	GHG non-refrigerant ($M)	GHG refrigerant ($M)
TRC (standard)	521	160	30	331	n/a
SCT base	1,417	344	68	1,005	n/a
SCT high	1,419	334	68	1,017	n/a

The RHP MTI will generate approximately $521 million in TSB using TRC assumptions. The largest share of the benefit can be attributed to mitigated non-refrigerant GHG emissions, with an estimated $331 million in TSB. The smallest share of the TSB is driven by grid benefits, with $30 million in TSB. Finally, energy benefits driven by savings related to electricity and natural gas reductions generate nearly $160 million in TSB. SCT based TSB shows substantially higher benefits, largely driven by smaller overall discount rates and greater benefits attributed to GHG emissions reductions. In both SCT TSB approaches, the contribution of GHG benefits is significantly higher to overall TSB than it is under that standard TRC based approach. The primary driver in the difference in TSB between standard and base and high SCT is the significantly lower discount rate and the added benefits attributed to greenhouse gas reductions. The SCT discount rate of 3% affords greater value to benefits accrued in the latter years of the MTI.

Cost-effectiveness ratios

Table 25 provides the cost-effectiveness estimates for the MTI over the period 2024-2045.

Table 25. MTI cost-effectiveness estimates, 2024-2045

	TRC	PAC	Base SCT	High SCT
Negative IMCs included [a]	330.15	8.29	(30.24)	(30.26)
Negative IMCs set to zero	5.46	8.29	11.20	11.21

[a] CalMTA calculated cost-effectiveness using negative Incremental Measure Costs (IMCs), per the guidance from the CPUC's Energy Division guidance memo that required negative IMCs to be entered into Cost Effectiveness Tool (CET) and not set to zero.[26] Because use of the negative IMCs resulted in some

[26] Guidance for Deemed Measures History: CPUC Guidance on the use of Negative Incremental Measure Cost (IMC) in the Cost Effectiveness Tool - CEDARS.

counterintuitive results, CalMTA also calculated cost-effectiveness results with negative incremental costs set to zero.

Table 26 provides the schedule of total system benefits and cost-effectiveness estimates for the RHP MTI.

Table 26. Cost-effectiveness schedule

Forecast metric	2030	2035	2045
TSB	$ 5M	$ 79M	$ 521M
TRC ratio (negative IMCs included)	0.14	1.72	330.15
TRC ratio (negative IMCs set to zero)	0.13	1.21	5.46
PAC ratio	0.12	1.28	8.29
Estimated incremental investment	$40M	$22M	$1M
Approximate breakeven year for TRC (negative IMCs included): 2034			
Approximate breakeven year for TRC (negative IMC set to zero): 2035			

Co-created and statewide TSB

- **Co-created TSB:** Co-created impacts refer to the total impacts (including utility-reported savings) influenced by the MTI. CalMTA estimated market adoption associated with PA-verified savings (described in the section: Approach to estimating units associated with verified PA savings) and subtracted it from incremental market adoption to calculate net incremental adoption for each year of the forecasting period in accordance with guidance in the MTI Evaluation Framework. While the TSB reported in this plan was calculated applying net incremental adoption, CalMTA conducted an additional analysis to estimate "co-created" TSB that included adoption from PA-verified programs, for the three IOUs and on a statewide basis as shown in Table 27.
- **Statewide TSB:** The RHP MTI is a California-wide effort. Because avoided costs for PG&E, SCE, and SDG&E do not fully represent the entire state, CalMTA conducted an additional analysis to estimate statewide TSB. The team developed adoption estimates for "non-IOU" territories (described in the section above Estimating IOU vs. non-IOU units) and developed avoided costs for non-IOU adoption by applying population-weighted average avoided costs for the three utilities. The resulting Statewide TSB estimates are shown in Table 27.

Table 27. Co-created and statewide TSB

Scenario	TSB
Co-created TSB (IOU service territory only)	$ 605M
Statewide TSB (excluding PA verified savings)	$ 700M
Co-created Statewide TSB	$ 813M

Attachment 1: Delphi Panel methods and findings

This attachment details the methodology and findings of the Delphi panel conducted by CalMTA to inform the Baseline Market Adoption (BMA) forecast for Room Heat Pumps (RHPs) in California's residential sector. Panelists, selected for their expertise in California's energy efficiency programs and appliance markets, provided adoption forecasts based on market conditions, technological advancements, and regulatory trends. CalMTA analyzed the panelists' qualitative and quantitative inputs to inform assumptions and parameters within the BMA forecast.

Methodology

Recruitment: criteria and qualifications

CalMTA selected candidates based on three criteria: their knowledge of California energy efficiency programs, or their knowledge of residential appliance markets in California or their experience with similar market transformation efforts outside of California. Candidates had to satisfy at least one criterion. To construct a panel that encompassed a range of perspectives while mitigating the risk of bias from any one organizational type, CalMTA recruited panel members from three categories: manufacturers or trade groups; subject matter experts (SMEs) from universities, Department of Energy (DOE) labs, or nonprofits; and utility and Regional Energy Network (REN) program managers (PMs). Ten candidates accepted invitations to participate; however, three panelists dropped out, leaving a final composition of seven (see Table 1).

Table 1. Composition of RHP Delphi Panel

	Manufacturers	SMEs	Utility/REN PMs
Number of panelists	1	4	2

For their time and effort, each panelist was offered a $500 gift card for participating in two rounds of forecasting. Panelists could accept, decline, or elect to donate their compensation to a charity of their choosing.

Confidentiality

To ensure the flow of ideas and mitigate the risk of cognitive biases based on groupthink and perceived pressure to change one's opinions, CalMTA maintained confidentiality throughout the process. Data presented for analysis and reporting could not be linked to any panelist.

The Delphi Panel process

The Delphi panel consisted of two rounds. In Round #1, panelists received a survey link that contained two sections: background information and forecasting.

Background information

To help guide panelists in generating their market adoption forecasts, CalMTA provided background information that focused on technology description, the regulatory landscape, the state of the market today, technology trends, and key market players.

Round #1 panel forecasts

Panelists were asked to consider the background information along with any additional insights they had based on their experiences in the field to provide their forecast of the naturally occurring (i.e., without CalMTA interventions) market adoption for RHPs in California households. Panelists estimated the proportion of households that they believed would have a RHP installed in their home starting in 2025 and then every five years through 2050. They also provided spccrate forecasts for single-family and multifamily households and a brief explanation describing the factors that influenced their decisions. Finally, panelists were asked to estimate the proportion of households that they believed will ultimately adopt an RHP, which could occur any year during or beyond the forecasting period (i.e., market potential).

Panelists turned in their forecasts over the course of approximately two weeks. CalMTA collected the data and proceeded to review and summarize the data to present the anonymized Round #1 forecasts and qualitative rationale from all panelists for Round #2.

Round #2 panel forecasts

In Round #2, CalMTA provided data to each panelist that included their own Round #1 forecast and the anonymized Round #1 forecasts and qualitative rationale from all panelists. The panelists then had the option to submit revised forecasts of adoption up to 2050 as well as their maximum market forecast, along with additional rationale for their Round #2 estimates.

Delphi Panel findings

This section describes the quantitative analysis for Round #2 forecasts. The rates of adoption for both single-family and multifamily households generally follow a similar pattern of a steady increase from 2025 to 2050. As depicted in Figure 1 and Figure 2, most panelists predicted slow uptake in saturation for RHPs in the first five to 10 years, followed by a slightly more upward trajectory from 2035 to 2050. Panelists were more optimistic in their saturation assessments for the future of RHPs in multifamily housing (median = 33%) compared to single-family housing (median = 20%) in 2050.

Figure 1. Forecast of adoption of RHPs by existing single-family households (saturation)

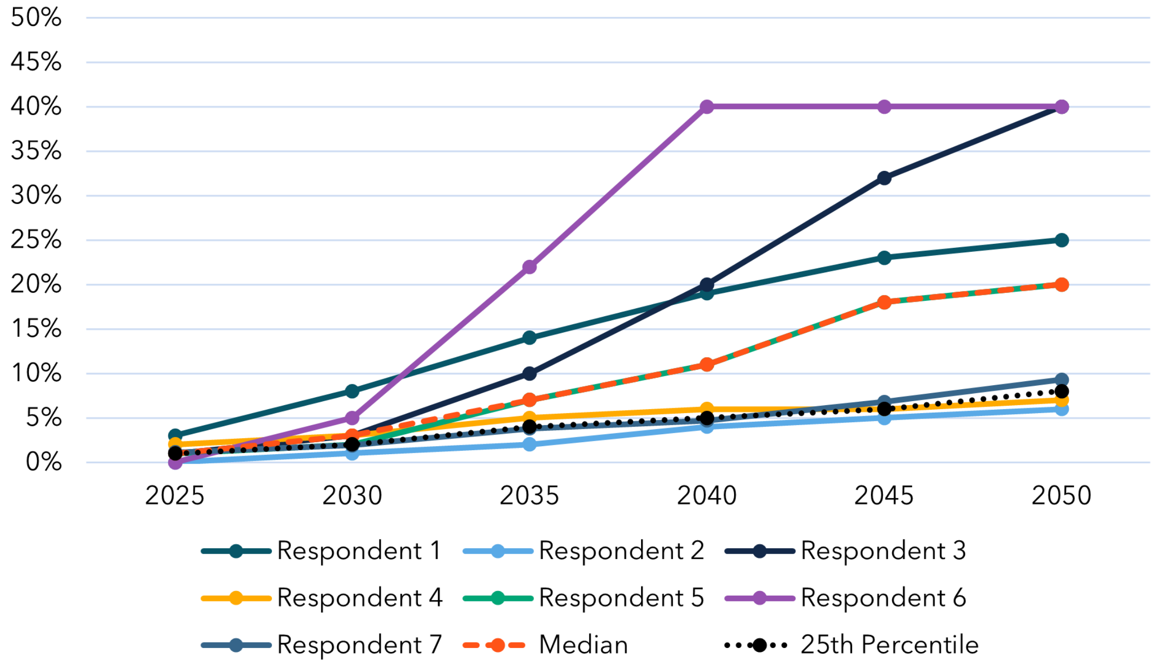
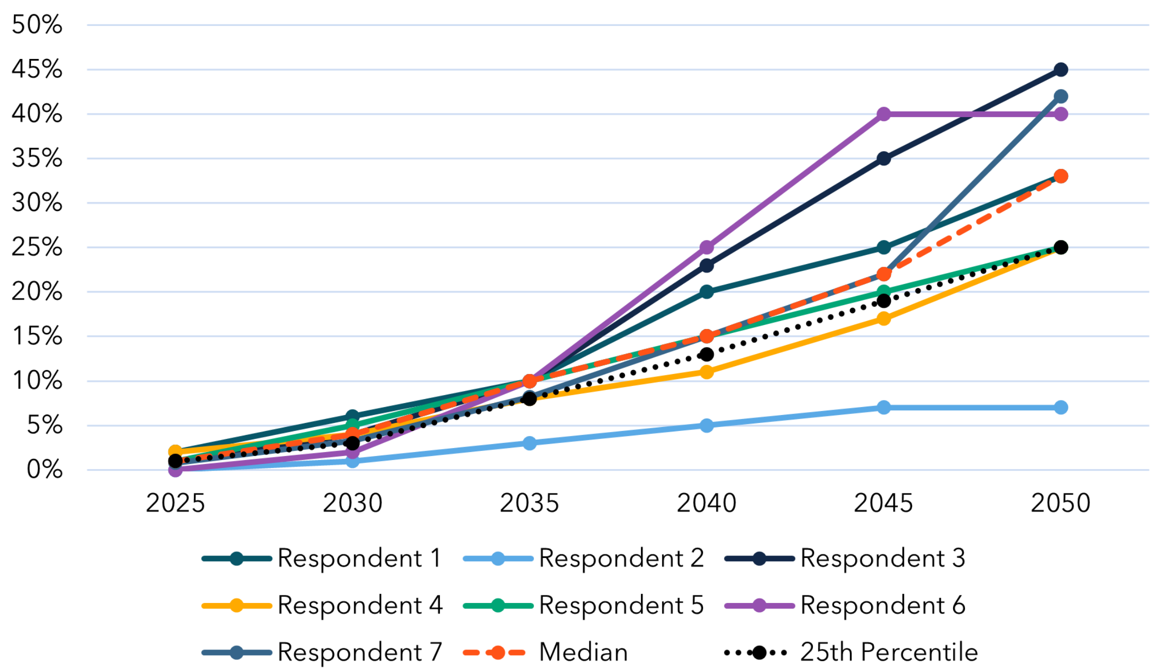


Figure 2. Forecast of adoption of RHPs by existing multifamily households (saturation)



Panelists forecasted stronger market potential in multifamily housing compared to single-family housing (see Table 2).

Panelists were asked what percentage of households would ultimately adopt RHPs. Three panelists predicted less than 10% saturation among single-family households by 2050, with one predicting ultimate market potential of 22%, whereas the other two did not predict such a jump above 10% at any point in time. The 25th percentile for market potential in single-family households was 15%, and the median was 29%. Only one panelist projected less than 10% saturation in multifamily households at any point by 2050 or beyond. The 25th percentile for market potential in multifamily households was 38%, and the median was 40% for maximum market potential.

Table 2. Market potential for RHPs across housing segments

	Single-family		Multifamily	
	Round 1	Round 2	Round 1	Round 2
Minimum	5%	6%	7%	8%
25th percentile	17%	15%	49%	38%
Median	**30%**	**29%**	**50%**	**40%**
Maximum	50%	40%	71%	50%

Note: Panelists were asked to estimate the proportion of single-family and multifamily households in California that they believed would ultimately install a RHP or PHP, given the existing and projected market, technology, and regulatory trends (i.e., naturally occurring market adoption) without any CalMTA market transformation investment. Panelists were asked to consider a long-term perspective that may extend beyond 2050.

Factors that drive adoption

The team analyzed the panelists' qualitative comments and rationale for their forecasts and observed several themes across housing segments. Panelists highlighted multiple arguments that suggested optimism toward the overall market potential of RHPs in both single-family and multifamily California households. The most prominent factors mentioned by panelists were related to California regulation and policy matters, increased technological improvements specific to heat pump technology, and consumer desire for cost-effective and efficient options, each described in more detail below.

Regulation and policy will strongly influence the future of the space conditioning market.

Panelists' rationales included the view that as California continues to push policies that support the adoption of efficient technologies and seeks to reduce the carbon footprint left by archaic technologies, RHPs will likely benefit from this advantage. One panelist said, "the regulatory and programmatic landscape in California is heavily emphasizing heat pump technology and will likely continue to into the future." Three panelists explicitly mentioned the California Air Resources Board's (CARB) zero-emissions appliance rules as an example of a policy that will influence the push for efficient technologies, such as RHPs in California.

Technological advancement and product maturity will facilitate the adoption of room and portable heat pumps.

Panelists' rationales included the view that improvements in heat pump technology will make these systems more efficient and attractive. In other words, as heat pump technology matures and distinguishes itself generally from competitors, adoption of heat pump technologies, including RHPs should increase. One panelist said, "heat pump technology will achieve a tipping point in about 10 years and become the default for small homes as they replace gas units." Another panelist said, "as more people become familiar with heat pump technology, they'll be more likely to seek it out." Panelists also thought that new product options and features would play a role in increasing RHP adoption, with one specifically stating "later heat pump iterations will address the window issue."

Consumers will seek efficient and cost-effective space conditioning to replace existing products.

Multiple panelists pointed to the need to replace old or outdated equipment as a reason that RHPs may prove attractive options for space conditioning needs. People will stop installing or will ultimately need to replace their gas wall furnaces leaving "mini-split heat pumps or portable/window heat pumps as the only alternative." The cost-effectiveness of RHPs will likely interest people who are seeking relief from high installation and energy costs. One panelist said, "California policies and electricity prices will drive customers to more efficient options," while another panelist noted, "many multifamily building owners looking for a cost-effective way to comply with regulations will heavily favor heat pump retrofits in California and may turn to these products because they're more plug and play."

Factors that temper adoption

Panelists also highlighted several factors that could temper adoption, with many questioning the market impact that heat pump technology could truly have without the presence of notable intervening forces. These factors are detailed below.

Uptake could be slow given the current lack of awareness and low product availability.

Heat pump technology in some form has existed for years, yet awareness remains relatively low. One panelist said, "heat pumps are an established technology that has thus far seen little penetration in the room/portable market." Others predicted limited growth without concerted outreach efforts on account of low consumer awareness. Low awareness is related to low product availability—as production capacity remains limited and retail inventory is scarce. One panelist said, "uptake will be very slow without concerted outreach efforts given low consumer awareness, low market availability, confusing labeling, and purchasing inertia." Thus, current awareness levels, limited production and availability, and a lack of clarity as to what a heat pump is and what it does remain significant barriers.

Competition from alternative products and systems could temper the market potential for room and portable heat pumps.

Even if RHPs achieve greater levels of awareness and product availability, and if confusion related to product definition and labeling is mitigated, there are several competing options that may present challenges toward breaking into the space conditioning market in a significant way. Some panelists predicted that as temperatures continue to rise, people will replace their systems with a central heat pump option rather than a portable one. Further, new construction codes will require cooling and will likely lead to installation of central systems. Aside from competition from central space conditioning systems, RHPs still face considerable competition from mini-splits. Three panelists explicitly pointed to mini-splits as attractive alternatives for people who plan to replace their old or outdated units.

Housing segment-specific considerations

Although the rationale for panelists' forecasts were similar for single-family and multifamily households, there were a few discernible differences between the housing segments.

Single-family considerations

Central systems will still be the more popular choice for single-family households who are either seeking to install new units or replace old ones. For heating specifically, two panelists predicted that as heating systems fail in single-family homes, central heat pump systems will likely be the preferred choice. This insight may help explain why single-family forecasts were lower than multifamily forecasts.

However, for cooling, portable units may play a larger role in the future. One panelist said that RHPs will be viewed primarily as air conditioners and secondarily as heating units—as temperatures continue to rise, the need for cooling options will too. As extreme heat becomes more prevalent, households without cooling will find their situation increasingly unsustainable. Portable units will be an attractive option for these homes, specifically for those who are affected by low income, as they seek affordable cooling options.

Multifamily considerations

Panelists had a more optimistic outlook for RHPs in multifamily housing than single-family housing, in part due to factors such as renter influence, cooling load capacity, cost-effectiveness, and regulatory compliance.

Renters are limited in the choices they can make regarding system changes, as one panelist explained, "renters have little say in large system upgrades, and as temps continue to rise, a portable or RHP will become a choice that a renter can make for their space conditioning needs." Multifamily units tend to be smaller and therefore more compatible with the cooling capacity provided by portable units compared to larger areas, thus making them a slightly more sensible option for multifamily households. Retrofitting large multifamily buildings with centralized systems is costly, thus making portable units a more viable option. Related to cost considerations is the fact that multifamily building owners and landlords have to comply with California building regulations and will seek the most cost-effective way to do so, as one panelist said, "many multifamily building owners looking for a cost-effective way to comply with regulations may turn to these products."

Observed rationale issues and omissions

The insights provided by the Delphi panel inform CalMTA's BMA forecast. CalMTA considered the qualitative and quantitative inputs provided by the panelists in its analysis for the development of the BMA forecast.

CalMTA noted that there were several key considerations that may not have been fully accounted for by some Delphi panel members. Qualitative feedback from some of the panel members indicated a conflation of RHPs with mini-split heat pumps, which are commonly available currently, and other currently available. A review of qualitative comments also suggested potential oversight of current product limitations, particularly the limited availability of cost-competitive Type-2 and Type-3[27] versions and products compatible with the prevalent window types in California, such as sliding and casement windows. Discussions with manufacturers and experts indicated that products suitable for the California market are likely to be introduced only in the mid-2030s. Because panel members did not consider the above insight about the introduction of California-appropriate products, they expected adoption to take off right away instead of the mid-2030s.

CalMTA's BMA forecast, developed using an S-curve model, took a multifaceted approach to inform model assumptions and parameters. This approach considered insights from multiple sources, including Delphi panel estimates and qualitative comments; market research, including surveys of property managers and households; and discussions with stakeholders, including manufacturers. The Delphi panel's estimates of the shape and steepness of the adoption curve (i.e., the speed at which the market transitions from early adoption to saturation), which represents the number of years for adoption of RHPs to reach saturation once the biggest market barriers to adoption are addressed, were used in the model.

[27] **Type 1 heat pump:** A room heat pump that does not have active defrost or for which the specified compressor cut-in and cut-out temperatures are not both less than 40˚F. **Type 2 heat pump:** A room heat pump that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 40˚F but not both less than 17˚F. **Type 3 heat pump:** A room heat pump that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 17˚F but not both less than 5˚F. **Type 4 heat pump**: A room heat pump that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 5˚F.

Attachment 2: Documentation of unit energy savings and avoided cost calculations for room heat pumps

This document is a reference of the scenarios developed and methodology used to develop unit energy savings shapes and avoided cost calculations that serve as inputs to the cost-effectiveness and total system benefit models for the Room Heat Pump MTI.

Product information

The MTI-proposed products considered are RHPs, defined as window and portable units that provide efficient heating and cooling for small spaces including single rooms, small apartments, and homes. They are similar in shape and size to typical window air-conditioning (AC) units and portable AC products. A wide variety of baseline equipment combinations, with different combinations of heating and cooling capabilities, exist in this product category.

Baseline equipment

For normal replacement, we consider window air conditioners and portable air conditioners as the baseline cooling technologies. The baseline heating technologies are electric resistance zonal heating and gas zonal heating.

A representative window air conditioner has a combined energy efficiency ratio (CEER) value of 16.0, and a cooling capacity of 9,000 BTU/h.[28] A representative portable air conditioner has dual hoses, a CEER of 8.6, and a cooling capacity of 9,000 BTU/h.

A representative zonal electric resistance heater is a pair of 1,500W electric baseboards that run on 120V 15A circuits. Although there are some small variations in energy consumption, we use this heating technology to represent electric baseboards, electric wall furnaces, and electric space heaters.

A representative gas zonal heating is a 11,000 BTU/h natural gas wall furnace with direct vent with an annual fuel utilization efficiency (AFUE) of 70%. We intend for this category of zonal gas heating to represent vented and unvented gas wall furnaces that are both passive/natural convection and forced air.

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[28] Based upon the active start date of 2026, we consider the updated room air conditioner efficiency standards which set the CEER for room air conditioner with louvered sides without reverse cycle and a capacity of 9,000 BTU/h to be 16.

Proposed equipment

A representative window heat pump (WHP) is Type 4 saddlebag heat pump that is variable speed with a CEER of 6 and a cooling capacity of 9,000 BTU/h. This unit will have a heating energy efficiency ratio (HEER) of 9.3 and a heating capacity of 9,000 BTU/h at 47°F and 17°F.[29] The WHP will operate in heat pump mode down to -5°F, covering all heating mode operation for the weather files used in this analysis.

A representative PHP has a CEER of 8.7 and a cooling capacity of 9,000 BTU/h. This product operates in heat pump mode down to 40°F and, at lower temperatures, uses backup electric resistance heat. For simplicity, we modeled this as integrated backup resistance heat, although this would likely be a separate portable electric resistance space heater that would be operated at lower outdoor temperatures.

Energy modeling software

The open-source U.S. Department of Energy (DOE) building energy modeling software, EnergyPlus was used in this work. Version 9.5 was used for compatibility with the ModelKit software and the DEER residential building prototypes. EnergyPlus simulates whole-building energy consumption on sub-hourly timesteps and can output hourly energy consumption of HVAC equipment on an hourly basis, which is used here as the basis of the generated savings shapes. Each savings shape is an 8760 profile of electricity consumption (in kWh) and gas consumption (in therms) that is the difference between the baseline and proposed HVAC equipment for different building models.

Building models

Building energy modeling was performed using EnergyPlus, the open-source DOE software, with building models developed by the DEER and DOE to represent both single and multifamily California homes with comparable energy consumption. The DEER prototype buildings are single-family attached (1 story), single-family detached (2 story), and multifamily with 12 units (2 story).[30] These models have been calibrated to match the energy use intensity from RASS 2019 survey data and are similar to the vintage of 1975 to 1985. The models are shown in Figure 1. Each model contains two separate buildings aligned orthogonally to capture orientation effects, especially related to solar heating.

The two buildings are run in the model simultaneously in each case and averaged to minimize orientation effects. In all cases, there is an exterior wall surrounding the building that affects shading on the first floor, but these have been removed in one building in each rendering to show the geometry of the building. Some additional information about the buildings is included

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[29] At the time of writing, there are two room heat pumps with active defrost and publicly available specifications. We use these specifications as representative: https://cdn.shopify.com/s/files/1/0558/4925/5070/files/Sales_Brochure_AW120V_Final_9324.pdf?v=1725378323

[30] https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M398/K072/398072858.PDF.

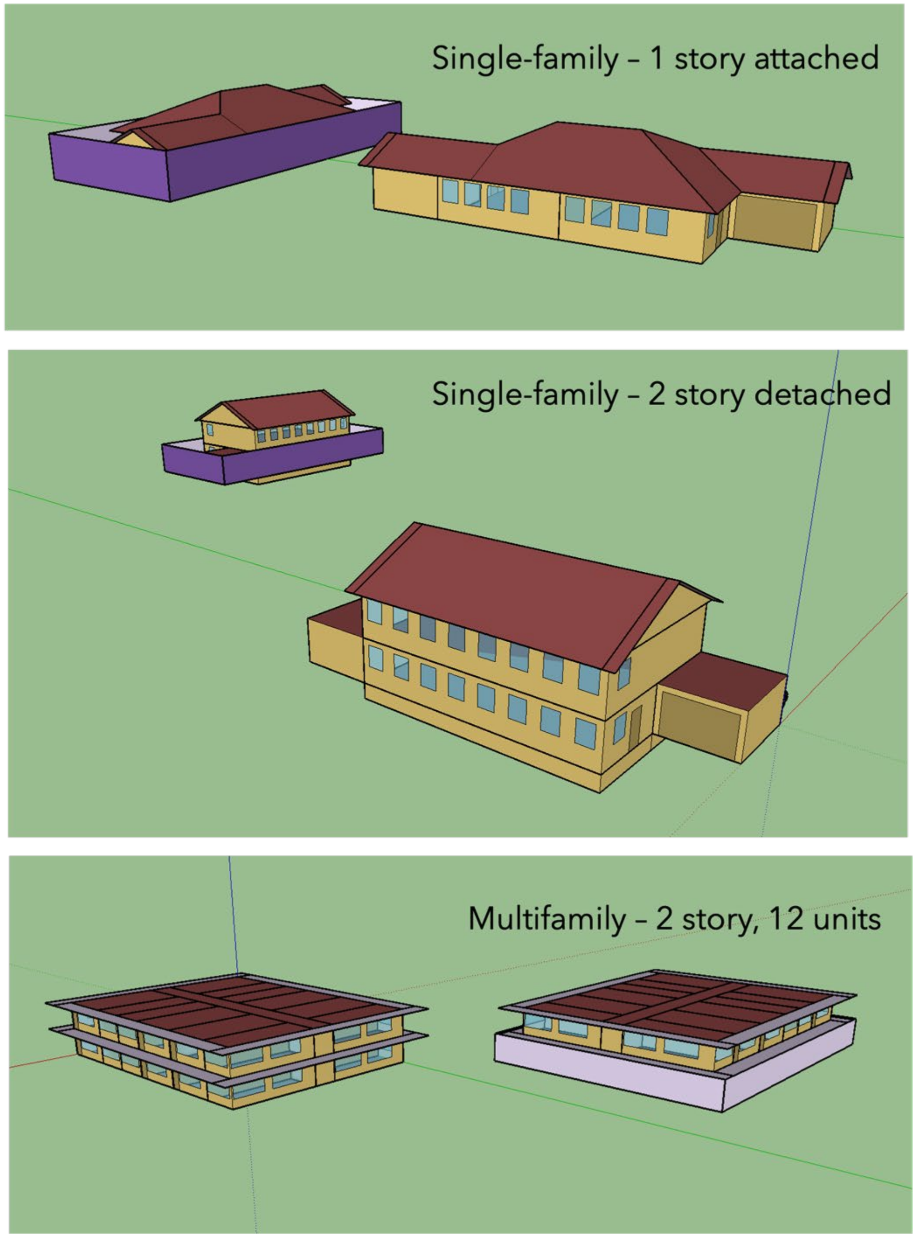
in Tables 1-4. More information on the prototype models can be found in the DEER Building Prototype System User Guide.[31]

The models are taken from the DEER Github repository[32] and the Measure for Package Terminal Air Conditioner or Heat Pump, Under 24 kBTU/h[33] (Measure ID SWHC027) is used as the basis of the prototype models, with some modifications mentioned in this documentation.

To create a blended load shape, the average load shape across all conditioned zones for each building is used in all normal replacement and no cooling scenarios. This means the multifamily load shapes are an average of 48 individual profiles, and the single-family load shape is an average of 4 individual profiles. Using a large number of individual zones to average the multifamily load shape is very important to account for all of the various combinations of orientation with respect to the sun and all of the different combinations of shared walls/floor/roof.

[31] DEER Building Prototype System User Guide https://cedars.sound-data.com/deer-resources/tools/energy-plus/file/3085/download/.
[32] https://github.com/sound-data/DEER-Prototypes-EnergyPlus.
[33] Statewide Measure ID SWHC027 https://www.caetrm.com/measure/SWHC027/05/.

Figure 1. Buildings used for energy modeling[34]



[34] EnergyPlus IDF building models visualized in Sketchup.

Table 1. Description of buildings used for energy modeling

Source	Vintage	Type	Stories	Units[35]	Area/Unit [ft²]
DEER	1985	Multifamily	2	24	1,024
DEER	1975-1985	Single-family attached	1	4	727
DEER	1975-1985	Single-family detached	2	2	2,906

The DEER California-specific buildings were developed with characteristics representative of the state's existing building stock and have slight adjustments in insulation, windows, and other properties based on climate zone. The performance of the buildings is calibrated using the 2019 California Residential Appliance Saturation Survey (RASS), and the stock values for building envelope insulation, infiltration, and fenestration performance were used. The thermostat setpoints were set to a constant year-round dual setpoint. The setpoints were 70°F for heating and 77 °F for cooling, except for the setback scenario, which is discussed in detail in a subsequent section.

Table 2. Selected vintage for each climate zone of single-family

CZ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SF Vintage	1975	1975	1975	1975	1975	1975	1975	1975	1975	1985	1985	1985	1985	1985	1985	1985
MF Vintage	1985	1985	1985	1985	1985	1985	1985	1985	1985	1985	1985	1985	1985	1985	1985	1985

[35] The number of units is per energy model. Each model has two separate buildings to account for orientation effects.

Table 3. Detailed multifamily envelope characteristics

Climate zone	Avg floor area per zone[36]	Infiltration air changes per hour	Ceiling R-Value	Wall R-Value	Floor R-Value	Window to wall ratio	Fenestration U-factor	Fenestration SHGC
1	512	0.350	20.0	16.5	4.5	35.42	0.66	0.52
2	512	0.350	20.0	16.5	4.5	35.42	0.59	0.46
3	512	0.400	20.0	16.5	4.5	35.42	0.66	0.50
4	512	0.350	20.0	16.5	4.5	35.42	0.60	0.47
5	512	0.400	20.0	16.5	4.5	35.42	0.68	0.51
6	512	0.550	20.0	15.5	4.5	35.42	0.69	0.51
7	512	0.500	20.0	15.5	4.5	35.42	0.68	0.51
8	512	0.400	20.0	15.5	4.5	35.42	0.71	0.53
9	512	0.350	20.0	15.5	4.5	35.42	0.71	0.53
10	512	0.350	20.0	15.5	4.5	35.42	0.68	0.52
11	512	0.350	21.8	15.5	4.5	35.42	0.61	0.49
12	512	0.350	21.8	15.5	4.5	35.42	0.61	0.47
13	512	0.500	21.8	15.5	4.5	35.42	0.74	0.56
14	512	0.350	20.0	15.5	4.5	35.42	0.69	0.54
15	512	0.350	20.0	15.5	4.5	35.42	0.65	0.49
16	512	0.350	20.0	16.5	4.5	35.42	0.64	0.50

[36] Each dwelling is 1,024 ft^2 with two conditioned zones each of which has a zonal HVAC system.

Table 4. Detailed single-family envelope characteristics

Climate zone	Avg floor area per zone, ft² (1 / 2 story)	Infiltration air changes per hour	Ceiling R-value	Wall R-value	Floor R-value	Window to wall ratio (1/2 story)[37]	Fenestration U-factor	Vertical fenestration SHGC
1	727 / 1,453	0.350	8.3	6.1	3.65	12.0 / 12.7	0.66	0.52
2	727 / 1,453	0.350	8.3	6.1	3.65	12.0 / 12.7	0.59	0.46
3	727 / 1,453	0.350	8.3	6.1	3.65	12.0 / 12.7	0.66	0.50
4	727 / 1,453	0.350	8.3	6.1	3.65	12.0 / 12.7	0.60	0.47
5	727 / 1,453	0.350	8.3	6.1	3.65	12.0 / 12.7	0.68	0.51
6	727 / 1,453	0.500	9.0	8.7	3.65	12.0 / 12.7	0.69	0.51
7	727 / 1,453	0.500	9.0	8.7	3.65	12.0 / 12.7	0.68	0.51
8	727 / 1,453	0.350	9.0	8.7	3.65	12.0 / 12.7	0.71	0.53
9	727 / 1,453	0.600	9.0	8.7	3.65	12.0 / 12.7	0.71	0.53
10	727 / 1,453	0.350	20.0	13.1	4.45	12.0 / 12.7	0.68	0.52
11	727 / 1,453	0.400	21.4	12.8	4.45	12.0 / 12.7	0.61	0.49
12	727 / 1,453	0.350	21.4	12.8	4.45	12.0 / 12.7	0.61	0.47
13	727 / 1,453	0.400	21.4	12.8	4.45	12.0 / 12.7	0.74	0.56
14	727 / 1,453	0.350	20.4	13.1	4.45	12.0 / 12.7	0.69	0.54
15	727 / 1,453	0.350	20.4	13.1	4.45	12.0 / 12.7	0.65	0.49
16	727 / 1,453	0.350	26.0	16.3	4.45	12.0 / 12.7	0.64	0.50

All building types had the lighting loads adjusted in line with the levels in ResStock to 4.3 W/m². This had a small impact on reducing the heating load and increasing the cooling load due to the waste heat from the lighting. Because the cooling loads are equal in baseline and proposed, this had the net effect of a slight reduction in the savings shape.

The plug and process loads were set to an average of 7.2 W/m² in conditioned zones of the multifamily building, which had a similar small effect on reducing the savings shape due to an increase in waste heat.

[37] Gross window to wall ratio for one- and two-story buildings.

Case descriptions

Fourteen different cases of proposed versus baseline equipment for different building types were created to represent the target market in California for RHP adoption. Eight cases were normal replacement, where we assume an old HVAC system is being replaced at end of life and a choice is made between a proposed equipment (WHP or PHP) and a baseline equipment (room or portable AC combined with zonal electric or gas heat). The normal replacement scenario uses multifamily or single-story attached single-family buildings.

Table 5. Savings scenarios

Savings shape[38]	Climate zones	Sector	Segment	Decision type	Proposed equipment type	Baseline equipment type
1, 2, 3	7, 10, 12	Res	MF	NR	WHP	WAC + Elec. Res. Heat
4, 5, 6	7, 10, 12	Res	MF	NR	WHP	WAC + Zonal Gas Heat
7, 8, 9	7, 10, 12	Res	MF	NR	PHP	PAC + Elec. Res. Heat
10, 11, 12	7, 10, 12	Res	MF	NR	PHP	PAC + Zonal Gas Heat
13, 14, 15	7, 10, 12	Res	SF	NR	WHP	WAC + Elec. Res. Heat
16, 17, 18	7, 10, 12	Res	SF	NR	WHP	WAC + Zonal Gas Heat
19, 20, 21	7, 10, 12	Res	SF	NR	PHP	PAC + Elec. Res. Heat
22, 23, 24	7, 10, 12	Res	SF	NR	PHP	PAC + Zonal Gas Heat
25, 26, 27	7, 10, 12	Res	SF	Displacement	WHP	WAC + Elec. Res. Heat
28, 29, 30	7, 10, 12	Res	SF	Displacement	PHP	PAC + Elec. Res. Heat
31, 32, 33	7, 6, 3	Res	MF	TBD	WHP	NC + Central GF
34, 35, 36	7, 6, 3	Res	MF	TBD	PHP	NC + Central GF
37, 38, 39	7, 6, 3	Res	SF	TBD	WHP	NC + Central GF
40, 41, 42	7, 6, 3	Res	SF	TBD	PHP	NC + Central GF

Abbreviations used in the table: Res = Residential, MF = multifamily, SF = single-family, NR = normal replacement, WHP = window heat pump, PHP = portable heat pump, WAC = window air conditioner, PAC = portable air conditioner, Elec. Res. = electrical resistance, NC = no cooling, GF = gas furnace.

[38] The savings shape is dependent upon the weather for an individual case (one building type, one proposed and baseline equipment combination) there will be three savings shapes generated, one for each climate zone.

Replacement scenario

Each replacement scenario is a direct comparison of proposed and zonal heating equipment over the entire year with a constant thermostat setpoint of 70°F for heating and 77°F for cooling.[39] The same setpoints are used for both baseline and proposed cases. As mentioned previously, the PHP only operates in heat pump mode down to 40°F, below that using supplemental electrical resistance heating. The room heat pump operates in heat pump mode throughout the entire temperature range.

Displacement scenario

In this scenario, we consider the two-story single-family detached home, with approximately 2,906 ft^2 of conditioned space. We look at two scenarios where a 500 ft^2 zone is conditioned, and the rest of the house is set back to run the main heating and cooling system less.

- **Conditioned space setpoints:** 70°F for heating, 77°F for cooling
- **Setback setpoints:** 64°F for heating, 81°F for cooling
- **Setback 1:** Work from home in a single office, main house setback from 8:00 AM to 5:00 PM, weekdays only
- **Setback 2:** Nighttime bedroom, main house setback from 10:00 PM to 8:00 AM, all days
- **Equipment scenario 1:**
    a) Baseline zone equipment: Window AC + electric space heater
    b) Proposed zone equipment: WHP
- **Equipment scenario 2:**
    a) Baseline zone equipment: Portable AC + electric space heater
    b) Proposed zone equipment: PHP with electric resistance heat below 40ºF

The savings in this scenario (baseline – proposed) is coming from the zone heating equipment (the switch from space heater to heat pump). We are not claiming the savings from the reduced energy consumption of the central HVAC system, and we assume the central HVAC system has been closed off in the area with zonal HVAC. Modeling the effects of parallel central and zonal HVAC within the same area with two different thermostat setpoints was beyond the scope of this analysis. This could be refined in future versions of modeling analysis. The logic is that setbacks are a user behavior choice (not an efficiency equipment improvement), and these scenarios were already possible using the baseline equipment outlined above. This is also consistent with the baseline and proposed equipment scenarios we are using for replacement for MF and small SF homes. The one key difference is that we are not considering a gas baseline. We do not think it is

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[39] The heating thermostat setpoint was 67°F for climate zones 1, 2, and 16, which better matches the RASS energy use intensity for heating. These climate zones were only used for general data reporting in the product assessment report and not for the CE and TSB calculations.

likely that users will purchase a new gas space heater or install a gas wall furnace to condition a single zone.

The single-family two-story model has two zones per household (and the model contains two houses at perpendicular orientations, each with two conditioned zones (on the first and second floors). Each zone has an area of 1,453 ft^2. This scenario uses three different thermostats within the model: 1) combined daytime and nighttime setback in the two ground level zones, 2) nighttime setback only in top zone 1, and 3) daytime setback only. This combines both setback scenarios into a single energy model for efficiency. The two setbacks are in separate buildings within the same model, so they do not affect each other. The proposed and baseline scenarios use the same thermostat but different HVAC equipment. The final savings shape was scaled by a factor of 0.34 to represent 500 ft^2 of conditioned space for a more realistic case of single room conditioning with whole-house setback.

No cooling scenario

Scenarios are included to cover households that currently have heating only and are adding a heat pump. The assumption is that these households will now have an increased energy consumption from using cooling when they previously had none. This will offset much of the savings achieved by adding more efficient heating. The climate zones used for this case were adjusted to be consistent with areas of California that have higher numbers of households without cooling. Climate Zones 10 and 12 have peak temperatures around 100 and significant cooling degree days. These were exchanged for Climate Zones 6 (coastal Los Angeles) and 3 (Oakland) in Southern California Edison (SCE) and Pacific Gas & Electric (PG&E) service territory, respectively. It should be noted that Climate Zone 1 is in PG&E territory where there are very low cooling loads, but Climate Zone 3 was chosen because of the higher population to be more representative.

This scenario has a thermostat setpoint of 70°F for heating and 77°F for cooling. The heat pump is conditioning an area of 500 ft^2 which is scaled linearly from a conditioned zone of 1,453 ft^2. The cooling is only added to this zone and the previous central gas furnace is assumed to be closed off to this area so that the heat pump is fully supplanting the central gas furnace within this smaller zone.

Any version of this scenario has multiple user behavior assumptions embedded, more so than a simple replacement case. It is likely that a household that never previously used air conditioning would not maintain the same setpoint and constant cooling that a household that is replacing existing air conditioning; in this case we may be overestimating the newly added cooling load. It is also likely that the household may set up the heat pump in such a way that the central gas furnace is not fully shut off in the heat pump zone (e.g., conditioned air leakage through closed vents), which would cause an over-estimation of the heating savings. Without a source of field data to better fine tune this scenario, we do not attempt to correct for assumptions that to some degree will work in opposition of each other. Future modeling could refine these scenarios with field data.

HVAC properties

Within the three types of building models considered, we vary the heating and cooling systems to mimic the various cases listed in Table 5. We model the room and PHPs as packaged terminal heat pumps and the room and portable air conditioners as packaged terminal air conditioners, consistent with the eTRM measure for portable air conditioners and heat pumps.[43] This models zonal space conditioning that will provide energy consumption results comparable with room heat pumps and room air conditioners.

Proposed system: window and portable heat pumps

WHPs and PHPs are modeled as packaged terminal heat pumps with different performance levels. This MTI focuses on variable-speed heat pumps, but detailed data on the part load performance of target products was not available. To simplify, we use single-speed heating and cooling and adjust the coefficient of performance (COP) to achieve comparable performance to a variable-speed unit. Future revisions will likely include modeling true variable speed performance with the inclusion of lab or manufacturer performance data. All heat pumps are set to auto-size for heating and cooling capacity as well as air flow. This is intended to allow the single speed operation to operate more efficiently and closer to variable speed. The sizing factor was 1.2 for both heating and cooling. In all cases, the average capacity was below 9,000 BTU/h, indicating a variable speed heat pump of this capacity was sufficient for the zones considered.

We use a gross COP of 4.69 for heating efficiency. In Climate Zone 12 (with the most significant heating season used for avoided costs), this results in a Heating Seasonal Performance Factor (HSPF) of 9.2 as calculated by EnergyPlus, which is comparable to the HEER of 9.4 published by one manufacturer of an all-weather saddlebag product. We adjust the temperature-dependent efficiency to achieve a COP of 2.5 at 17°F and maintain heat pump only operation to -5°F. The PHP gross heating COP was set to 2.6 which translated to an average HSPF of 5.9. The PHP was set to turn off heat pump mode at 40°F and use backup electrical resistance heating, consistent with PHPs without active defrost. The effective total heating COP in climate zone 12 was 2.6 for the RHP and 1.6 for the PHP based upon the heating performance for the entire year.

Baseline zonal cooling: window and portable air conditioners

The air conditioner performance is set to be identical in the baseline scenario (with PTAC) and the proposed equipment (with PTHP). For RHPs and room ACs, cooling is modeled with a single-speed air conditioner with gross rated cooling COP of 4.7. It is important to note in all scenarios except for the no cooling baseline, the same cooling energy is consumed in the proposed and baseline scenarios, so the details of the cooling performance are not affecting the savings shape. The portable air conditioner and PHP are modeled as single-speed air conditioners with gross rated cooling COPs of 2.5. The cooling capacity and air flow rate were auto-sized with a factor of 1.2.

Baseline zonal heating: electric resistance and gas

Electrical resistance heat is modeled as an electric heating coil in a packaged terminal air conditioner. The heating coils were allowed to autosize with a factor of 1.2. The efficiency of electric resistance heating was set to 100%, consistent with the default model settings. As mentioned previously, the baseline heating scenarios are intended to represent zonal heating both with and without forced air. There are small differences in total energy consumption due to the fan energy. Zonal heating without forced air often results in uneven heat within the target conditioning zone and may overheat a portion of the zone to achieve the needed setpoint. The EnergyPlus model assumes all zones are well-mixed and does not take into account this stratification, which would lead to more energy consumed. We therefore feel that incorporating the small additional fan energy for all cases of zonal heating is a reasonable approximation. The fan energy was less than 2% of the total heating energy for electrical resistance and zonal gas. Zonal gas heating was post-processed using the energy model from electric resistance heating, applying an efficiency of 70% and converting the energy source to natural gas instead of electricity for hourly heating energy consumption.[40]

Baseline central HVAC

Central HVAC systems are only used in a single case: where a WHP is added to a home that previously had only a central gas furnace and no cooling.

The only case where a central HVAC system contributes to the savings shapes is for the case of no cooling with central gas furnace. This HVAC was taken from the eTRM for residential furnaces[41] and the AFUE was adjusted to achieve an effective overall delivered efficiency of 70%. This assumes an existing central gas furnace AFUE of 80% with 10% duct losses.[42] This resulted in a entered efficiency of 92% for the gas furnace in EnergyPlus. Since this is a baseline technology, this is a more conservative approach compared with using the lower burner efficiency (80%) in the model.

Effective Useful Life

Effective Useful Life (EUL) is the estimated median life in years that a measure is still in operation. We adopt the same approach as the Portable Air Conditioner and Heat Pump eTRM and adopt the EUL for room air conditioners from the DEER database, which is 9.0 years.[43]

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[40] Typically, the AFUE of gas wall furnaces are lower than central gas furnaces, but it is important to note that zonal heating with an AFUE of 70% actually consumes less total energy than a central furnace with an AFUE of 80% when accounting for heating losses through ductwork and increased fan energy.

[41] Furnace, Residential. SWHC031. https://www.caetrm.com/measure/SWHC031/03/.

[42] An AFUE of 80% is the most common efficiency value for existing central gas furnaces in California, according to the ResStock database.

[43] Portable Air Conditioner and Heat Pump, Residential. SWAP020. https://www.caetrm.com/measure/SWAP020/01/.

Climate zones

We analyze energy consumption and bill impacts across all 16 climate zones in California. However, we focus on just three climate zones for inputs to the cost-effectiveness and total system benefit modeling. We choose one climate zone per investor-owned utility (IOU), representing a range of California weather. The CZ2022 weather files are used, which represent 20 years of weather from 1998 to 2017 and were adopted for Title 24 Version 2022.[44] The weather files used are shown in Table 6.

Table 6. Weather files for energy modeling in each climate zone

Climate zone	Weather file	Included in TSB Calculations
1	CA_EUREKA_725940S_CZ2022.epw	No
2	CA_NAPA-CO_724955S_CZ2022.epw	No
3	CA_OAKLAND-METRO-AP_724930S_CZ2022.epw	Yes – NC only[45]
4	CA_SAN-JOSE-IAP_724945S_CZ2022.epw	No
5	CA_SANTA-MARIA-PUBLIC-AP_723940S_CZ2022.epw	No
6	CA_LOS-ANGELES-IAP_722950S_CZ2022.epw	Yes – NC only[45]
7	CA_SAN-DIEGO-LINDBERGH-FLD_722900S_CZ2022.epw	Yes
8	CA_LONG-BEACH-DAUGHERTY-FLD_722970S_CZ2022.epw	No
9	CA_LOS-ANGELES-DOWNTOWN-USC_722874S_CZ2022.epw	No
10	CA_RIVERSIDE-MUNI_722869S_CZ2022.epw	Yes
11	CA_RED-BLUFF-MUNI-AP_725910S_CZ2022.epw	No
12	CA_STOCKTON-METRO-AP_724920S_CZ2022.epw	Yes
13	CA_FRESNO-YOSEMITE-IAP_723890S_CZ2022.epw	No
14	CA_DAGGETT-BARSTOW-AP_723815S_CZ2022.epw	No
15	CA_EL-CENTRO-NAF_722810S_CZ2022.epw	No
16	CA_BISHOP-AP_724800S_CZ2022.epw	No

[44] https://www.calmac.org/weather.asp

[45] Climate zones 3 and 6 replace 10 and 12 for the case where the baseline is no cooling because the cooling season weather is more mild, making these zones more likely for a scenario where there is no existing cooling.

Avoided cost calculations

The CPUC's Avoided Cost Calculator (ACC)[46] provides a robust framework for evaluating the benefits of distributed energy resources such as energy efficiency and fuel switching measures. The ACC estimates system-level costs of providing electric or gas service on an hourly basis in $/kWh and $/therm.[47] The calculator is comprised of three parts: an electric avoided cost calculator, a natural gas avoided cost calculator, and a refrigerant calculator. Since the calculator converts gas and electricity consumption to dollars of avoided cost, it provides a metric to calculate the impact of fuel switching measures' and pure efficiency measures' technology value from the baseline value to calculate the avoided costs for how much money is saved in the electrical grid and associate emissions through the adoption of one unit. The avoided cost factors (in $/kWh and $/therm) are applied to a unit energy savings shape on an hourly basis to calculate the avoided cost benefit per scenario, which is an input for the estimate of the MTIs cost-effectiveness and total system benefit (TSB). The previous TSB calculations for RHPs in the CalMTA advancement plan used the 2022 version of the avoided cost calculator workbook. Since then, the 2024 version has been released, all calculations in this analysis use the newly updated version. There are significant changes in the factors between the 2022 and 2024 ACC workbooks, including the following, per E3:[48]

- Energy value is more time-dependent (lower midday and higher overnight and early morning)
- Higher GHG value concentrated in evenings and early mornings
- Lower annual generation capacity value spread out over more hours
- Gas avoided costs are slightly higher, with the largest increases in winter months

We use both the electric and gas workbooks. We do not attempt to calculate any avoided cost benefit due to refrigerants since we are only considering normal replacement, and it is assumed that the proposed RHP products and baseline room AC products will have similar refrigerant characteristics. The ACC workbook settings used to produce hourly factors are shown in Table 7.[49]

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[46] Per the CPUC, "The primary benefits of demand-side resources are the avoided costs related to generation and distribution of energy. The avoided costs of electricity are modeled based on the following components: generation energy, generation capacity, ancillary services, transmission and distribution capacity, and decarbonization policy compliance. The Avoided Cost Calculator was established in 2005 and is updated biennially to improve the accuracy of how the benefits of demand-side resources are calculated."

[47] 2024 Distributed Energy Resources Avoided Cost Calculator Documentation. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-side-management/acc-models-latest-version/2024-acc-documentation-v1b.pdf.

[48] https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/cost-effectiveness/2024-draft-acc-workshop---final.pdf.

[49] The final air quality adders for both electric and gas are FALSE for TRC and TRUE for SCT, as these are hard-coded settings in the workbook that adjust based on the chosen cost test.

Table 7. Avoided cost workbook settings

Cost test	Total Resource Cost (TRC)	Societal Cost Test (SCT)
ACC workbook version	2024	2024
Discount rate	7.30%	3%
Social cost of carbon	-	Base and high
Start year	2024	2024
End year	2054	2054
IOU climate zones		
PG&E	12	12
SCE	10	10
SDG&E	7	7
Electric components to include		
Cap & trade	TRUE	TRUE
GHG adder	TRUE	TRUE
GHG rebalancing	TRUE	TRUE
Energy	TRUE	TRUE
Generation capacity	TRUE	TRUE
Transmission capacity	TRUE	TRUE
Distribution capacity	TRUE	TRUE
Ancillary services	TRUE	TRUE
Losses	TRUE	TRUE
Methane leakage	TRUE	TRUE
Air quality adder	TRUE	TRUE
Final air quality adder	FALSE	TRUE
Gas main inputs		
Class	Residential	Residential
End use	Residential furnace	Residential furnace
Emission control	Uncontrolled	Uncontrolled
Gas components to include		
Market	TRUE	TRUE
Transmission & distribution (T&D)	TRUE	TRUE
Environment	TRUE	TRUE
Upstream methane leakage	TRUE	TRUE
Behind-the-meter methane leakage	TRUE	TRUE
Air quality adder	TRUE	TRUE
Final air quality adder[50]	FALSE	TRUE

[50] The final air quality adder is controlled by the cost test and is automatically FALSE for TRC and TRUE for SCT.

Attachment 3: Sensitivity analysis

This attachment summarizes analysis conducted to assess the impact of removing market adoption associated with fuel substitution on TSB and cost-effectiveness.

Methodology

CalMTA ran a sensitivity analysis assuming zero adoption for the two use cases that assume end users install an RHP instead of a gas wall furnace:

1. **Assumed counterfactual HVAC equipment: gas wall furnace and window AC**
   In CalMTA's RHP MTI market adoption model, this use case accounts for 4% of total incremental adoption in the single-family sector and 10% for incremental adoption multifamily sector.
2. **Assumed counterfactual HVAC equipment: gas wall furnace and portable AC**
   In CalMTA's RHP MTI market adoption model, this use case accounts for 2% of the total incremental adoption in the single-family sector and 6% for the multifamily sector.

Results and implications

The sensitivity analysis resulted in lower TSB and TRC and PAC benefit-cost ratios (Table 1). Eliminating market adoption by end users who would otherwise install gas equipment combined with room or portable A/C lowers TSB by $51 million (10%) over the MTI lifetime and reduces TRC by 0.53 (Table 2).

Table 1. Summary of changes in TSB and cost-effectiveness results by scenario

Scenario	TSB ($M)	TRC	PAC	ΔTSB ($M)	ΔTRC	ΔPAC
Reported in MTI plan	521	330.15	8.29	-	-	-
No incremental adoption for use cases involving fuel substitution from gas heating	470	8.72	7.49	(50.31)	(321.43)	(.80)

Table 2. Summary of changes in TSB and cost-effectiveness results by scenario (negative IMCs set to zero)

Scenario	TSB ($M)	TRC	PAC	ΔTSB ($M)	ΔTRC	ΔPAC
Reported in MTI plan	521	5.46	8.29	-	-	-
No incremental adoption for use cases involving fuel substitution from gas heating	470	4.93	7.49	(50.31)	(0.53)	(0.8)

The RHP MTI Risk Management Plan (Appendix G) identifies a slower rollout of electrification enabling rates as an initiative risk (Risk #12). This analysis suggests that while this risk would lower market adoption of RHP, the MTI would still be highly cost effective.