Commercial Rooftop Units Market Transformation Initiative

Appendix B: Market Forecasting & Cost-Effectiveness Modeling Approach

December 17, 2025

Prepared by:
Karen Horkitz, Market Research and Evaluation Lead, CalMTA
John Walczyk, Principal, The Cadmus Group
Jason Christensen, Senior Associate, The Cadmus Group
Matt Wisnefske, Senior Associate, The Cadmus Group
Tom Bougher, Associate Director, 2050 Partners

Resource Innovations
719 Main Street, Suite A
Half Moon Bay, CA, 94019
(888) 217-0217
info@calmta.org

CalMTA is a program of the California Public Utilities Commission (CPUC) and is administered by Resource Innovations.

Contents

List of Abbreviations

Abbreviation	Definition
AC	Air-Conditioning
ACC	Avoided Cost Calculator
ACS	American Community Survey
AFDD+	Enhanced automated fault detection and diagnostics
BMA	Baseline Market Adoption
CalMTA	California Market Transformation Administrator
CCC	Connected Commissioning and Controls
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	Effective 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
IVEC	Integrated Ventilation, Economizing, and Cooling
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
VSD	Variable Speed Drive
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 market adoption forecasting model and using model outputs to estimate incremental system benefits and cost-effectiveness.

This appendix documents the approach, methods, assumptions, and data sources CalMTA used to estimate incremental impacts resulting from the Commercial Roof-Top Unit (CRTU) MTI and summarizes findings from the analysis. These methods are consistent with the approach described in the CalMTA Market Transformation Initiative Evaluation Framework.[1]

2 Executive summary

The CRTU MTI seeks to accelerate market adoption of efficient Commercial Rooftop Units. CalMTA defines a CRTU as a single-zone, packaged, forced-air, HVAC system with between 3 and 20 tons of cooling capacity that is installed on the roof of a non-residential building.

CalMTA's CRTU Initiative will promote increased adoption of three tiers of efficient CRTUs:

- **Tier 1:** Code-minimum heat pump (HP) RTU equipped with connected commissioning and controls (CCC), which is comprised of factory-installed sensors and integrated controls that allow for app-based startup routines, AFDD+,[2] and remote connectivity, including demand response to:
    - Increase installed efficiency through improved startup, commissioning, and compliance with Title 24 Acceptance Testing 3 requirements
    - Optimize long-term operational efficiency through predictive analytics and machine learning
    - Increase load flexibility and occupant comfort through integration of weather data, utility demand-response signals, and thermal load data

[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 impacts of MTIs.

[2] CalMTA defines AFDD+ as automated fault detection and diagnostics beyond current Title 24 requirements, which require economizer faults only.

[3] Title 24 Acceptance Testing is required during installation and replacement of single-zone HVAC systems, including CRTUs. Requirements include field verification and documentation of Outdoor Air Ventilation, Air Economizer Controls, AC and HP Controls, and Supply Fan Variable Flow Controls.

    - Remotely monitor RTU performance to detect, diagnose, and resolve faults by providing alerts to owners and actionable information to HVAC technicians
- **Tier 2:** HP RTU with a cooling efficiency at least 20% above the federal minimum standard.
- **Tier 3:** Variable speed HP RTU with CCC and a cooling efficiency at least 20% above the federal minimum standard.

To estimate incremental market adoption, Total System Benefit (TSB), and cost effectiveness of the CRTU MTI, CalMTA developed these inputs:

- Net Incremental Market Adoption
    - Baseline market adoption (BMA) forecast
    - Total market adoption (TMA) forecast
    - Program-verified units forecast
- Measure load shape
- Unit energy impacts
- Effective Useful Life (EUL)
- Avoided costs
- Costs required to calculate benefit-cost ratios using the TRC, PAC, and SCT tests, as prescribed by the CPUC:
    - Initiative costs
    - Incremental measure costs (IMCs)

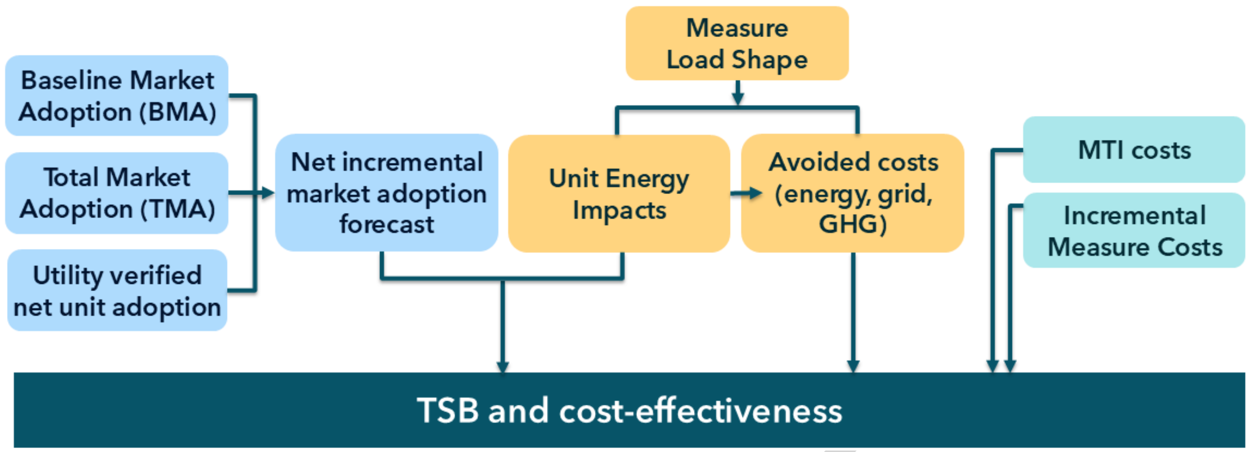
Throughout this appendix, "efficient CRTUs" will refer to these three tiers of efficient commercial rooftop units promoted through the MTI. "RTUs" will refer to all single-zone RTUs, including code-minimum HP RTUs and gas pack RTUs, which are not promoted through this MTI.

CalMTA used the inputs above to calculate TSB and cost effectiveness using the TRC, PAC, and SCT tests, as prescribed by the CPUC's Standard Practice Manual.[4]

Figure 1 illustrates the relationship among these input components and the resulting outputs. The remainder of this document describes the approach and sources for each of these components and summarizes the outputs of the TSB and cost-effectiveness analyses.

[4] The equations CalMTA used to calculate TRC, PAC, and SCT are specified in https://www.cpuc.ca.gov/-/media/cpuc website/files/uploadedfiles/cpuc_public_website/content/utilities_and_industries/energy_-_electricity_and_natural_gas/cpuc-standard-practice-manual.pdf. The input values for the SCT calculation were specified in https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M535/K822/535822173.PDF.

Figure 1. MTI incremental impact forecasting components



Detailed explanations of input and output calculation methods are provided in Section 3.

2.1 Net incremental market adoption forecast

2.1.1 BMA forecast

The BMA forecast represents the expected "naturally occurring" market adoption, factoring in current and expected market, regulatory, and technological trends.

Modeling approach

To estimate BMA for the CRTU MTI, CalMTA employed a modified discrete choice model with constraints and a nested logit structure. The constraints reflect two key market barriers – lack of product awareness and limited availability - which are unrelated to product preference. The nested structure separates the product selection decision into two stages, where the first stage represents the choice of heating fuel and the second stage represents the choice of technology when a heat pump is chosen in Stage 1. The following equation summarizes CalMTA's approach to forecast baseline market adoption of CRTUs in any given year:

$$s_i = \frac{\alpha_i * e^\wedge(c_i) * \gamma}{\sum_{i=1}^{I} \alpha_i \, e^\wedge(c_i) * \gamma}$$

Where:

s_i = market share for product i

α_i = share weight of product i

c_i = total cost of ownership of product i, which includes the upfront cost of equipment, permitting, labor, and other installation costs, plus discounted energy bill and operating costs, relative to total cost of a code-minimum HP RTU.

γ = logit exponent parameter which defines the sensitivity of product market share to the magnitude of the price ratio of product alternatives.

e = Euler's number, denoted as "e," is a mathematical constant approximately equal to 2.71828. It is the base of natural logarithms and is widely used in mathematics, particularly in calculations involving exponential growth and compound interest.

The α_i share weights are coefficients that represent barriers to market entry (i.e., lack of awareness of the product's value proposition and product availability) as a value between zero and one. If they are set to one or removed from the model, the modified logit produces an estimate of the unconstrained or latent demand for a given product alternative. Latent demand is the expected market share under hypothetical circumstances whereby contractors and consumers are fully aware of the characteristics of efficient heat pump products, and the products are readily available on the market with lead time equivalent to the baseline alternative. Conversely, if set to zero, the model produces an estimated market share of zero for a given product because the market is fully constrained, regardless of potential economics, if the product is not available or no decision makers are aware of the value proposition, resulting in zero market adoption. The α_i share weights are included to account for constraints on product availability and awareness that might prevent a consumer from choosing an efficient product in an unconstrained setting. CalMTA's CRTUs Market Characterization Report found that these two market barriers currently limit market adoption of efficient CRTUs and would be expected to persist without market intervention.

Consumer decisions are modeled as a two-stage decision process. First, the consumer chooses between a gas-fired packaged CRTU (gas pack) or a HP RTU, which is assumed to be a code-minimum model – the most prevalent type currently available. Conditional on the selection of the HP alternative, consumers face a secondary choice between the minimum code and higher efficiency HP, or CRTU, alternatives.

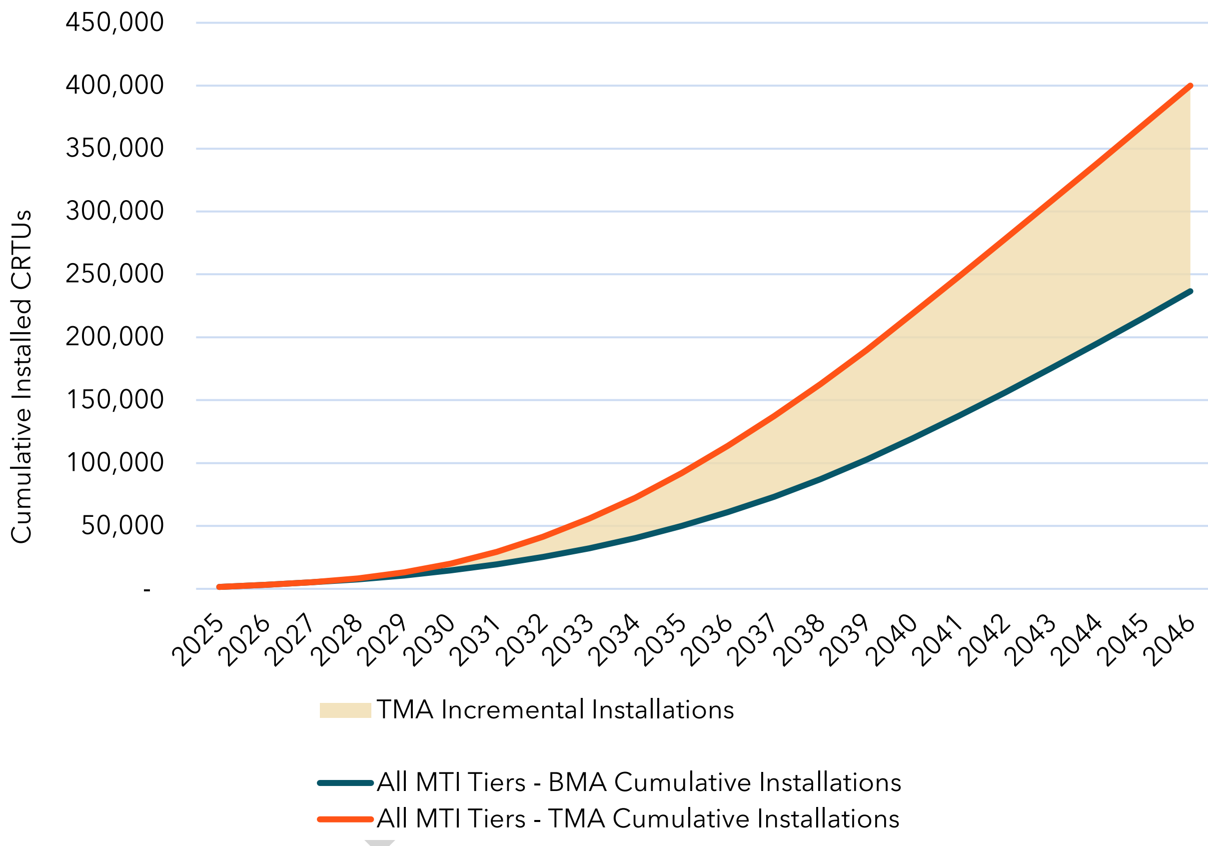
Assumptions and Parameters

CalMTA used a multifaceted approach and various sources to inform assumptions and parameters of the choice model. There are limited published studies on consumer preferences for CRTUs, so CalMTA relied on data on current market conditions including the CalMTA CRTUs Market Characterization Report, ComStock, the DOE's technical support document for Air-Cooled Commercial Unitary Air Conditioners and Commercial Unitary Heat Pumps, DEER2026 Update Resolution, and various academic papers, for which citations are provided in the relevant sections below.

CalMTA modeled adoption under three scenarios of policy-driven phase-out of natural gas commercial space heating. The policy scenarios (discussed in more detail in Section 3.1.2) reflect California Energy Commission's (CEC) proposed Additional Achievable Fuel Substitution (AAFS) Replace On Burnout Scenario Adoption Curves in the *2025 Integrated Energy Policy Report* proceeding.[5] CalMTA assumed the AAFS2 Gradual Transformation to 100% by 2040 Scenario to develop its primary market adoption, TSB, and cost-effectiveness forecasts. Results from the AAFS1 and AAFS3 scenarios are presented in 3.0.- of this appendix.

The model forecasts market share and saturation levels throughout the forecast period, indicating the cumulative proportion of existing commercial building square footage expected to adopt CRTUs through 2046. Figure 2 illustrates the estimated adoption.

Figure 2. Cumulative CRTU adoption



2.1.2 TMA forecast

The TMA forecast represents adoption predicted from the strategic interventions described in this MTI plan.

The TMA forecast model approach and structure are identical to the BMA forecast approach. The model modifies key parameters – product costs, availability, and value proposition awareness - to

[5] https://www.energy.ca.gov/sites/default/files/2025-08/Additional_Achievable_Energy_Efficiency_%28AAEE%29_and_Additional_Achievable_Fuel_Substitution_%28AAFS%29_ada.pdf. Accessed online October 6, 2025.

reflect the expected impact of MTI interventions in the TMA forecast. To forecast TMA, CalMTA aligned model parameters with the market interventions, outcomes, and planned milestones specified in the MTI Plan.

2.2 Net incremental market adoption

After developing the BMA and TMA forecasts, CalMTA calculated the net incremental unit adoption, which is equal to TMA minus BMA, minus estimated adoption associated with Program Administrators' (PA) verified savings, as specified in the MTI evaluation framework and summarized in the equation below:

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

Where Y represents cumulative adoption of CRTUs over the forecast period of 2025 to 2046.[6] 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. See Section 3.3 for CalMTA's approach to estimating PA-verified adoption.

Table 1 below summarizes TMA, BMA, PA-verified units, and net incremental adoption in terms of CRTU units.

The team used the approach described above 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.[7]

Table 1. Forecast of CRTU adoption (2025-2046)

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**
398,890	236,587	29,106	133,196	36,476	96,721

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

[6] CalMTA forecasted market adoption beginning in 2025 reflects CalMTA's preliminary investment in market engagement and the presence of CRTU products currently in the market; however, incremental market adoption prior to the start of Phase III (Market Deployment) is negligible – as illustrated in Figures 1 and 2.

[7] Note that the state of California will realize electric system benefits from statewide incremental CRTU market adoption, including from outside the IOU service territories. While the adjusted values may be the most appropriate 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 CRTU MTI. This approach discounts statewide benefits by nearly 26%.

2.3 Measure load shape

The team completed 1,600 full building energy model simulations representing a range of HVAC equipment, faults, building types, and climate zones (CZ). These were blended using weighting factors that account for proportion of building type and CZ population to represent six different installation scenarios, each with two load shapes (one for the baseline equipment and one for the proposed equipment). The team then calculated the difference between load shapes to arrive at unique 8,760 kWh and therm savings shapes for each installation scenario, which were used as inputs for avoided cost calculations. More details can be found in Attachment 2: Documentation of unit energy savings and avoided cost calculations for commercial rooftop units.

2.4 Unit energy impacts

CalMTA used a series of energy models to develop unit energy impact (UEI) estimates for six different base and efficient cases for all 16 California climate zones (CZ), five different commercial building types, and for each of the three IOUs: PG&E, SCE, SDG&E. We used weighting factors to combine the CZs and building types in one load shape per installation condition per IOU (30 total for three IOUs over 10 installation scenarios). More details can be found in Attachment 2.

2.5 Avoided costs

CalMTA developed 2025 to 2054 avoided costs using the latest E3 2024 Avoided Cost Calculator (ACC) for PG&E, SCE, and SDG&E. The avoided costs were then used to calculate the TSB, as well as TRC and PAC ratios. For CRTUs in operation from 2055 to 2065 (i.e., beyond the range of estimated avoided costs in the ACC), the analysis used the 2054 avoided cost value as a proxy. Further details on how the team applied the factors in the calculation of avoided costs can be found in Section 7.

2.6 Cost inputs

The cost-effectiveness model requires two types of cost inputs to develop TSB estimates and assess cost effectiveness: initiative costs (including incentives, if applicable) and incremental measure costs.

2.7 Initiative costs

Initiative costs are realized through the implementation of the MTI. These include costs of managing the MTI, research and evaluation, marketing, product development, manufacturer engagement, policy development, and data collection. Details on the total costs and how they were applied in cost effectiveness can be found in Section 8.

2.8 Incremental measure costs

Incremental measure costs (IMCs) represent the cost borne by the participant and include technology costs, add-on technology costs, electric system upgrade costs, labor costs, and permitting costs.

2.9 Total system benefit & cost-effectiveness forecast

CalMTA estimated TSB and cost-effectiveness for the CRTU MTI, including the TRC, PAC, and two SCT results. Table 2 shows the MTI's TSB with energy, grid, and greenhouse gas (GHG) impacts for the default scenario (AAFS2, middle case) for incremental adoption.

The initiative will deliver an estimated $594,807,318 in TSB. Approximately 25% of the TSB is attributed to energy, 25% attributed to grid, and 50% to GHG. The initiative is cost effective over its lifetime under each test perspective (Table 3.)

Table 2. CRTU Estimated TSB, 2025-2046

TSB ($M)	Energy ($M)	Grid ($M)	GHG non-refrigerant ($M)
$595	$148	$147	$300

Table 3. CRTU cost-effectiveness estimates, 2025-2046

TRC	PAC	Base SCT	High SCT
2.65	20.52	3.23	3.47

3 Market adoption forecast

This section details CalMTA's approach to forecasting the adoption of CRTUs by California households from 2025 to 2046, along with the forecast results.

3.1 Baseline market adoption (BMA)

The BMA forecast represents the expected "naturally occurring" market adoption, factoring in current and expected market, regulatory, and technological trends.

To estimate BMA for the CRTU MTI, CalMTA modeled consumer choice between gas-fired packaged CRTU (gas pack), code-minimum heat pump CRTU, and additional high efficiency heat pump alternatives. The modeling methodology is based on a discrete choice, nested logit framework and forecasts annual CRTU alterations, excluding new construction.[8]

We modeled the total CRTU market with segments for planned vs unplanned replacements (i.e., those triggered by an unexpected failure).

[8] While there are potential MTI impacts in the new construction market, the MTI is targeting the retrofit market.

3.1.1 Methodology

To forecast CRTU adoption, CalMTA employed a modified logit discrete choice model with constraints and a nested structure. The choice of model structure is well-established in economic decision-making literature.[9] The constrained choice model has also been used to forecast new technologies in the electrification space.[10]

The logit model predicts a customer's choice of CRTU as a function of product cost (c), price sensitivity (γ), share weight (α), and an alternative specific coefficient (ρ). Share weights impose constraints to reflect barriers to adoption, such as lack of product awareness and limited availability, which are not directly related to product preference or the comparative economic benefits of one option relative to another.

The product selection decision is separated into two stages. First, the consumer chooses between a gas-fired packaged (gas pack) or a HP CRTU. Conditional on the selection of the heat pump alternative, consumers face a secondary choice between the code minimum and higher efficiency HP alternatives. The first stage decision was not modeled via the equation above: CalMTA-specified BMA fuel substitution decisions based on the AAFS gas phase out trajectories. For TMA, CalMTA manually specified incremental fuel substitution based on collective judgment (described in further detail in Fuel substitution scenarios).

The efficient CRTU products targeted by the MTI were divided into three tiers to compete with code-minimum HP and gas pack CRTUs:

- Tier 1: Code-minimum HP RTU equipped with connected commissioning and controls (CCC), which is comprised of factory-installed sensors and integrated controls that allow for app-based startup routines, AFDD+, and remote connectivity, including demand response.
- Tier 2: HP RTU with a cooling efficiency at least 20% above the federal minimum standard.
- Tier 3: Variable speed HP RTU with CCC and a cooling efficiency at least 20% above the federal minimum standard.

The adoption model, therefore, considers choice between a total of four heat pump RTU options: code-minimum HPs and Tier 1, Tier 2, and Tier 3 HPs. Although the adoption model represents consumer choice across all of these technologies, CalMTA's CRTU MTI is focused *only* on increasing and accelerating adoption of efficient CRTUs – not code-minimum CRTUs. Thus, the

[9] Mariel, P., Campbell, D., Sandorf, E.D., Meyerhoff, J., Vega-Bayo, A., Blevins, R. (2025). *Random Utility Models: Theoretical Background. In: Environmental Valuation with Discrete Choice Experiments in R*. The Economics of Non-Market Goods and Resources, vol 17. Springer, Cham. https://doi.org/10.1007/978-3-031-89338-4_3.
[10] Wolinetz, M. and Axsen, J. (2017). *How policy can build the plug-in electric vehicle market: Insights from the Respondent-based Preference and Constraints (REPAC) model*. Technological Forecasting & Social Change. Volume 117, 2017. https://doi.org/10.1016/j.techfore.2016.11.022.

incremental market adoption, TSB, and cost-effectiveness analyses that follow reflect adoption of *only* efficient CRTUs (Tiers 1, 2, and 3).

The following equation summarizes CalMTA's approach to forecast baseline market adoption of CRTUs each year within the forecast period:

$$s_i = \frac{\alpha_i * e^{(c_j) * \gamma}}{\sum_{j=1}^{J} \alpha_j * e^{(c_j) * \gamma}}$$

Where:

s_i = market share for product i

α_i = share weight of product i

c_i = total cost of ownership of product i relative to the baseline product (i.e., the code-minimum heat pump or gas pack)

γ = logit exponent parameter, which defines the sensitivity of product market share to the magnitude of the ratio of preference characteristics, including cost and ASC, of product alternatives

J = total number of product alternatives in the choice set

The logit exponent, γ, also referred to as the logit coefficient, determines the magnitude of cost difference needed to produce a given change in market share. Holding α constant, the difference in market share depends on cost variation between product alternatives. The logit coefficient defines the sensitivity of market share to changes in relative costs.

The team modeled total cost of ownership as the ratio of the efficient equipment relative to the baseline equipment, including both first year and lifetime operating costs. First year costs are composed of equipment cost, installation labor costs, permitting costs, and other fixed costs (e.g., panel upgrade or related electrical work, subscription services for remote monitoring). Lifetime operating costs include expected energy bills, as well as any additional operating and maintenance costs over the 20-year expected useful life[11] for all CRTUs.

In addition to cost, the model included constraints represented by the α share weight parameter to account for limitations in product availability and awareness of value proposition (AVP). The share weight constraint parameter for each product alternative is a coefficient valued at between 0 and 1.

AVP represents the share of contractors that are aware of the value proposition for each of the efficient technologies and their willingness to convey the value proposition via recommendation

[11] CPUC E-5350. DEER2026 Attachment A. Table A-3.3

to the customer or decision maker. The underlying assumptions and sources for the baseline trends for BMA AVP are detailed in Section 3.1.2.

Availability represents the share of contractors and distributors that can install a given efficient technology within a reasonable timeframe such that the lead time for installation would not be a barrier relative to the standard code-minimum option. The underlying assumptions and sources for the baseline trends for BMA Availability are detailed in the following section.

The forecast considered incorporating an alternative specific coefficient (ASC) into the model equation. ASCs can represent the inherent market inertia or status-quo bias such that, even at price parity, decision makers would prefer to continue using the same technology or type of product already in use or that they are most familiar with.

For example, the ASC could be reasonably applied in fuel substitution choices. However, CalMTA found that the ASC parameter was negligible relative to the assumed "forced" policy-driven phase out of gas systems anticipated by the CEC in AAFS2 (described in the following section: Fuel substitution scenarios). Rather than include an ASC in the stage 1 decision (that is, consumer choice between gas and electric fuel), CalMTA applied an exogenous incremental fuel substitution factor to each of the AAFS scenarios, to represent fuel substitution choices incremental to policy impacts and resulting from MTI market interventions. Details on these incremental fuel substitution assumptions are described in Additional TMA fuel substitution.

3.1.2 Inputs and assumptions

This section describes the key assumptions, data sources, and methodologies used to develop the inputs for BMA analysis. These inputs form the basis for modeling CRTU market size, segmentation, cost estimates, and adoption constraints under different policy and technology scenarios. Each subsection summarizes the data sources, rationale, and adjustments applied, drawing primarily from CalMTA's CRTUs Market Characterization Report, DOE's Technical Support Document (TSD) for commercial unitary equipment, and related market research, to ensure consistent and transparent assumptions across all modeled scenarios.

Market size and segments

The BMA forecast assumes that the relative importance of decision-making criteria, represented by the model parameters, varies among different types of decision makers representing different market segments identified in the CRTU market characterization.[12] Specifically, the BMA forecast segments the CRTU market into the following combinations:

- Planned replacements of electric systems,
- Unplanned replacements of electric systems,

[12] CalMTA. (2025). CRTUs Market Characterization Report. Market-Characterization-Report-Commercial-Rooftop-Units1.pdf

- Planned replacements of mixed fuel systems, and
- Unplanned replacements of mixed fuel systems.

Using findings from the market characterization, the size of each of these segments is derived from the annual CRTU market size of 37,484 *replacement* units. The market characterization also estimated that a total of 4.8 billion square feet of commercial building space is conditioned by single-zone CRTUs (Section 2.3) and a total of 749,696 single-zone CRTUs are in service statewide (Table 5 of the Market Characterization Report). From there, the corresponding square footage is estimated using a ratio of total conditioned commercial floor space and the total number of single-zone CRTUs. Each CRTU serves 6,403 sq. ft.[13]

To allocate the units to each of the four segments, the following shares were applied (based on the CRTUs Market Characterization Report):[14]

- HPs are estimated to be 23% of the floor space while gas packs represent 65%. The remainder is composed of other types of RTUs (e.g., dual fuel HP or cooling-only units).
- Unplanned replacements comprise 80% of the market.

Table 4 shows the resulting allocation of the 37,484 annual replacement CRTUs by segment and conditioned floor space associated with the alterations.

Table 4. Annual CRTU alterations and commercial floorspace conditioned by single-zone CRTUs, by market segment

Market Segment	Counterfactual equipment fuel	Units	Conditioned Building Space (sq. ft.)	Percentage of Conditioned Space (sq. ft.)
Planned	Electric	2,624	6,586,307	7%
Unplanned	Electric	10,496	66,345,228	28%
Planned	Natural Gas	4,873	30,803,142	13%
Unplanned	Natural Gas	19,492	123,212,566	52%
Total – All Segments		**37,484**	**226,947,243**	**100%**

[13] CalMTA. (2025). CRTUs Market Characterization Report. Market-Characterization-Report-Commercial-Rooftop-Units1.pdf

[14] CalMTA. (2025). CRTUs Market Characterization Report. Market-Characterization-Report-Commercial-Rooftop-Units1.pdf

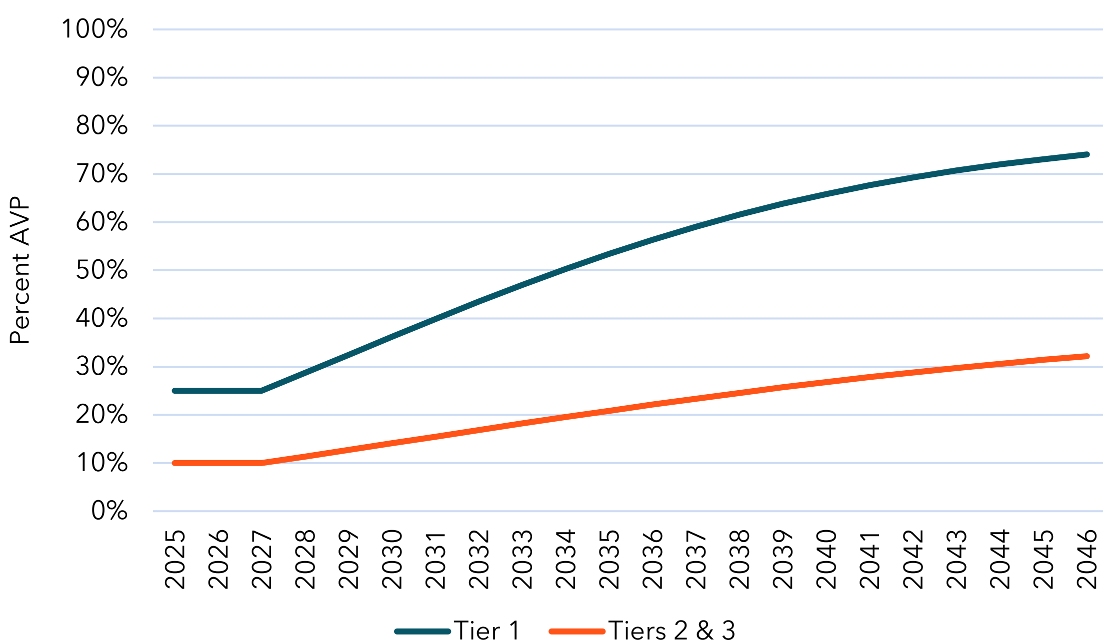
Market constraints – AVP and availability

Awareness of value proposition

Awareness of Value Proposition (AVP) represents the share of contractors that are aware of the value proposition for the CRTU elements (CCC, variable speed, and/or increased cooling efficiency) and that convey the value proposition and recommendation to a building owner or facility manager as a matter of standard practice. The baseline trends for AVP are informed by input from the CRTU strategy manager, logic model, and Market Characterization Report, and are as follows.

- Most contractors (nearly 75%) were familiar with internet-enabled RTUs with onboard sensors that allow for remote monitoring and fault detection. However, of those who were familiar with remote monitoring systems for RTUs, less than 25% recommended them.
- A third of contractors interviewed reported selling variable speed HPs. It is assumed that these contractors target buyers of high-performance systems, which would include CRTUs. Only two of 18 contractors said they recommend variable speed products.

Figure 3. BMA AVP constraint for Tier 1, Tier 2, and Tier 3 products by year



Because the CalMTA Market Characterization Report findings did not provide precise estimates of current market shares, nor precise trajectories or end-state market shares over time for products with CRTU elements, CalMTA applied professional judgement with specific values for the AVP constraint for each of the tiers. The constraints do not equal market shares and should not be interpreted to suggest that market shares of Tier 1 products are 25% in 2025 and 10% for Tiers 2 and 3 products. Rather, the AVP constraint represents the share of market influencers – including installers - who are sufficiently aware of the benefits and value proposition of these systems to include them in their bids, regardless of whether the decision-maker ultimately chooses one of the efficient CRTUs.

AVP would likely be constrained throughout the forecast period without MTI market intervention due to limited availability and substantial cost premiums associated with high-efficiency CRTUs, which factor into the value proposition. The Market Characterization Report found that 36% of facility managers and 44% of building owners were hypothetically willing to purchase higher efficiency units at a higher price, though they were only willing to pay approximately 2.5% to 7.3% more for efficient units. The reported percentage of building managers and owners willing to consider higher efficiency units informed the ceiling for Tier 2 and Tier 3 AVP. However, given that the current price premium for Tier 2 and 3 units is substantially higher than 7.3% - approximately 60% greater than code-minimum heat pump CRTUs - and the limited availability of Tier 2 and Tier 3 CRTUs for replace-on-burnout installations, the ceiling for AVP was set slightly below the reported willingness to consider, at 32% absent MTI intervention.

CalMTA expects the AVP for Tier 1 units will increase substantially as the market matures – albeit more slowly without MTI intervention. CalMTA assumed that contractor AVP would grow over the forecast period to a high point of 74% by the end of the forecast period.

Availability

Availability represents the share of contractors and distributors that can deliver a given efficient technology for installation within a timeframe that is comparable to and competitive with standard, code-minimum options. The CalMTA Market Characterization study estimates that 80% of RTU retrofits are unplanned replacements and finds that long lead times are a barrier to the CRTU market.

The baseline trends for availability are informed by input from the CRTU strategy manager, product assessment, and market characterization.

- **Tier 1.** CCC and its components are commercialized technology; however, availability varies. CCC may be a default feature on higher performance product lines, but it is optional on others, and not available on most entry level product lines.
- **Tier 2.** Five manufacturers currently offer products that meet 20% improved cooling efficiency relative to code; however, it is unclear how the 2029 shift to the Integrated Ventilation, Economizing, and Cooling (IVEC) metric will impact availability given the new IVEC metric is expected to increase minimum efficiency by roughly 10%.[15]

[15] For units less than 65,000 Btu/h (5.4 tons), the metric used for cooling efficiency is SEER2. For units 65,000 Btu/h (5.4 tons) or greater, the metric used for cooling efficiency is IEER, which will change to IVEC in 2029.

- **Tier 3.** Variable speed compressors are gaining market share in the residential market (a recent study estimates market share to be greater than 40% in the Pacific Northwest),[16] but market share remains significantly lower for commercial CRTUs.[17] Currently AAON's alpha class and Daikin's Rebel have this feature, but these are special-order high-performance products with limited market share.

The Availability constraint functions as a multiplier in the model equation and takes values from zero to 100%. A value of zero results in zero market share regardless of the relative cost of a given CRTU tier and the AVP. A value of 100% means the market is unconstrained by availability. Any value between zero and 100% discounts the expected market share given relative price alone.

The Market Characterization Report found that most unplanned replacements (replace-on-burnout) typically opt for equipment that is readily available. Additionally, available stock from most distributors is typically code-minimum RTUs. Most high-efficiency CRTUs must be special ordered through manufacturer representatives.

Given the ready availability of code-minimum HPs and gas packs, the market for those products is unconstrained by availability across all market segments.

In the planned market segment, replacements are unconstrained by availability because decision makers can account for lead times when planning ahead. The Availability constraint for this segment was set to 100% for all CRTUs, including Tier1, 2, and 3 products.

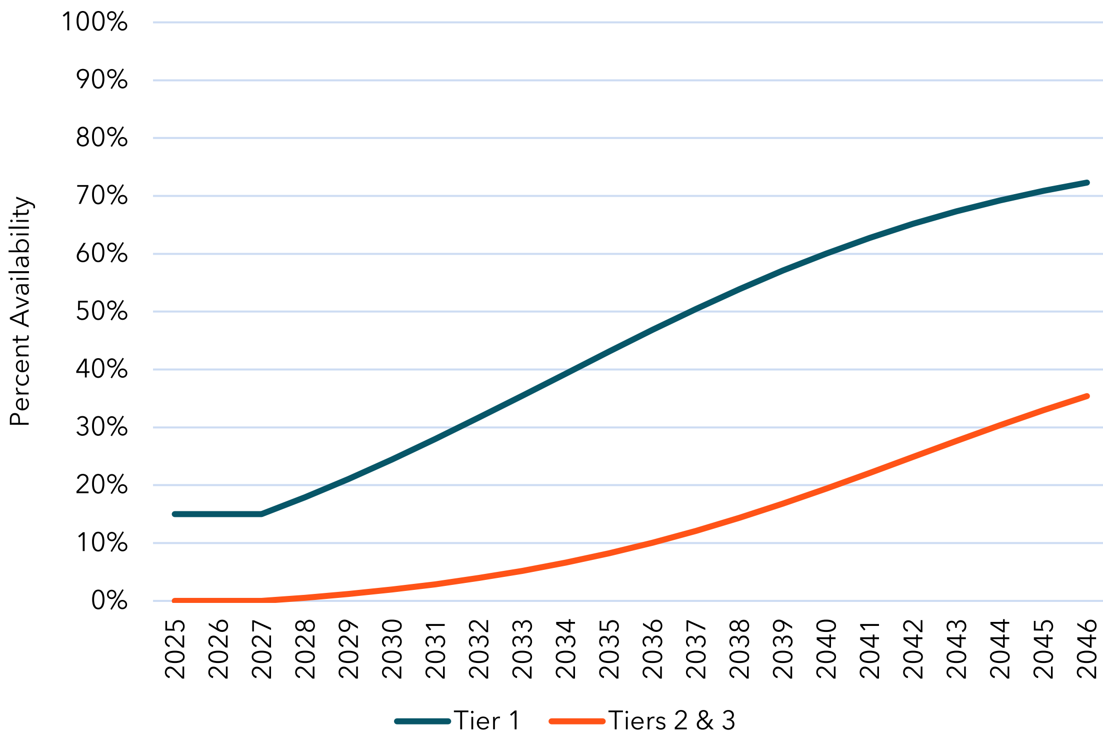
The unplanned market is constrained by availability because these are replacing CRTUs after the existing system fails, opting for products that are readily available. Availability is expected to increase somewhat over time.

Figure 4 shows the BMA Availability curves over the forecast period for each of the three efficient CRTU tiers.

[16] Bonneville Power Administration. (2025). Northwest HVAC Sales Insights 2022–2023. April 2025. 2022-2023-hvac-sales-insights.pdf

[17] BPA's sales insights report included some commercial sales and did not include CRTUs with variable speed compressors. HVAC units with variable refrigerant flow accounted for less than 2% of commercial sales. However, conclusions from the commercial data are significantly limited. As noted in the report, most commercial HVAC sales are through manufacturer representatives and were not included in the data collected for BPA's analysis.

Figure 4. BMA unplanned availability constraint for Tier 1, Tier 2, and Tier 3 products by year



For the unplanned market segment, Availability of Tier 2 and 3 products begins at zero because, as noted in the Market Characterization Report, none of the distributors interviewed stocked inverter-driven CRTUs. However, at least one manufacturer serving the unplanned market noted inverter-driven technologies are in development.

Availability of Tier 1 products is set to 15% at the start of the forecast period based on findings in the Market Characterization Report that found that most entry-level products do not have controls, but the availability is not zero.[18]

Price sensitivity

The logit exponent, γ, determines how large a cost difference is needed to produce a given difference in market share. Absent the AVP and availability constraints, the difference in market share depends on the relative difference in cost between Tier 1, 2, or 3 CRTUs and code-minimum alternatives. The logit coefficient defines the sensitivity of market share to changes in relative costs.

[18] CalMTA. (2025). CRTUs Market Characterization Report. Market-Characterization-Report-Commercial-Rooftop-Units1.pdf

The value of the logit exponent was set at -6, in the range of common values in energy research when modeling energy technology choices (typically between -4 and -6), where the cost of energy is inclusive of costs of technologies being utilized.[19] CalMTA chose the highest absolute value within the range, assuming that decision makers were more price sensitive, rather than less. The Market Characterization Report did ask building owners and facility managers qualitatively their willingness to consider purchasing higher efficiency equipment at higher prices. Less than half of respondents responded that they would consider higher efficiency equipment, and those that did suggested they would consider a price premium of 2.4% to 7.3%, which suggests decisions are highly price sensitive.

Technology costs

CalMTA developed cost estimates for technologies associated with each of the three tiers of efficient CRTUs. Detailed descriptions of the methodology and assumptions applied to develop cost estimates by technology type are provided in Attachment 1: Technology costs of this document. CalMTA estimates these cost components:

Technology/Equipment. CalMTA costs for 10-ton CRTUs using DOE Technical Support Document[20] for commercial unitary air conditioners and heat pumps. The team also developed cost estimates for CCC based on research conducted for the Market Characterization Report.

Installation. Installation costs include labor and material costs associated with CRTU installation. These were applied to align DOE's national cost framework with California labor and material conditions. As seen in Table 5, the installation costs for the Tiers 1, 2, and 3 are estimated to be $185 higher than the cost of installation of the counterfactual code-minimum HP and gas equipment.

Permitting. Permitting costs reflect jurisdictional practices and were developed using permit fee schedules from several California jurisdictions to establish representative costs for CRTU replacements.

Electrical Upgrades. CalMTA considered the potential need for electrical service upgrades when replacing a gas CRTU with a HP. To estimate this cost impact, CalMTA reviewed data from the California Commercial End-Use Survey (CEUS), which provides CZ–specific building characteristics and design conditions.

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[19] Clarke, J.F. and Edmonds, J.A. (1993). "Modelling energy technologies in a competitive market". Energy Economics, Volume 15, Issue 2, 1993, Pages 123-129. https://doi.org/10.1016/0140-9883(93)90031-L.

[20] *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Air-Cooled Commercial Unitary Air Conditioners and Commercial Unitary Heat Pumps.* Published in April 2024 as part of DOE rulemaking docket EERE-2022-BT-STD-0015. https://downloads.regulations.gov/EERE-2022-BT-STD-0015-0096/content.pdf

Table 5 summarizes the cost components for each CRTU tier, including the baseline gas and HP configurations as well as the efficient Tier 1, 2, and 3 products. The table consolidates all cost elements (equipment, installation, permitting, electrical upgrades) into a single comparative framework that underpins the total first-cost estimates used in the analysis.

Table 5. CRTU cost components by tier

CRTU Tier	Technology/ Equipment Cost Per 10-ton CRTU*	Installation Costs	Permitting	Other first costs (electrical /panel, aux heat)
	Dollars ($)	Dollars ($)	Dollars ($)	Dollars ($)
Tier 1	$18,106	$6,870	$1,590	$255
Tier 2	$22,301	$6,870	$1,590	$255
Tier 3	$27,590	$6,870	$1,590	$255
Code-minimum HP CRTU	$17,406	$6,685	$1,590	$255
Code Minimum Gas CRTU	$15,861	$6,685	$374	$0

* Costs for Tier 1 and Tier 3 equipment include $700 for cost associated with advanced controllers and present value of assumed incremental repairs resulting from the CCC features.

These cost estimates serve as the foundation for the incremental cost and cost-effectiveness analysis presented in the TSB and Cost-Effectiveness Analysis section. They represent CalMTA's best available estimates based on DOE and market characterization data, adjusted for California-specific labor, permitting, and technology cost factors.

CRTU price forecast

First-year technology and equipment costs of HP CRTUs were assumed to decline over time, realizing efficiencies of scale as production increases. CalMTA followed DOE's price projection approach using historical producers' price indexes to forecast price trends.[21] In its study, DOE used a constant price assumption as the default forecast to project prices for ACUACs and ACUHPs in its National Impact Analysis (NIA), and used relevant historical producer price indexes to derive price trends for equipment that did not have sufficient data to forecast cumulative

[21] US Department of Energy. (2024). Technical support document: Energy efficiency program for consumer products and commercial and industrial equipment: Air-cooled commercial unitary air conditioners and commercial unitary heat pumps, April 2024 (https://downloads.regulations.gov/EERE-2022-BT-STD-0015-0096/content.pdf accessed on August 15 2025).

production to apply the learning curve method. The learning effect that improves efficiency, resulting in cost reduction over time, is implicit in DOE's approach.

Following DOE's method, CalMTA used an inflation-adjusted "unitary air conditioners, except heat pumps" Producer Price Index (PPI)[22] for the period 1978-2024 available from the Bureau of Labor Statistics (BLS) and estimated the price trend using the best fit of the deflated PPI data into an exponential model with year as the explanatory variable. To do this, CalMTA deflated the PPI by dividing it with the Gross Domestic Product Chained Price Index series[23] in the same period from the Federal Reserve Bank of St. Louis (FRED) and normalized it to the 2024 prices.

After normalizing the PPI to 2024 prices using the exponential model, the PPI was projected for the period 2025-2046. Prices were forecasted by multiplying the 2024 product prices with the projected PPI.

Price projections do not explicitly account for tariff effects on prices because of uncertainty in magnitude and duration of impact and because they are likely to have similar impacts across all CRTU tiers. Because the model uses the relative cost of efficient versus code-minimum CRTUs as an input, as opposed the actual cost, CalMTA decided not to attempt to forecast the effect of tariffs and rather assumed the relative prices would remain the same regardless of future tariffs.

The result is a price projection curve that is multiplied by the 2025 cost to forecast changes in price over time relative to the 2025 cost that is applied to all HP RTUs in the BMA. Section 3.1.3 includes figures comparing the BMA and TMA relative to total costs between each CRTU tier and code-minimum HP RTUs. Equipment costs for gas pack RTUs are assumed to be constant over the forecast period as these are already a mainstream technology and there are no remaining efficiencies of scale to be realized.

Annual operating costs

Annual operating costs were calculated for each CRTU tier based on the expected HVAC energy consumption per 1,000 square feet of conditioned building space. Electric and gas HVAC consumption relied on estimates from Appendix C: Product Assessment Report Energy Consumption and Bill Impacts in Section 9.

Electric and gas rates, held constant over the forecast period, were included in the energy consumption analysis to estimate total building energy bills and bill savings. However, as noted in the product assessment report, the bill savings were calculated at the whole-building level and

[22] PPI series for Air-conditioning, refrigeration, and forced air heating equipment mfg-Unitary air-conditioners, except air source heat pumps, not seasonally adjusted (https://www.bls.gov/pPI accessed on August 15, 2025)

[23] Federal Reserve Bank of St. Louis (FRED), Gross Domestic Product (Chain-Type Price Index) (https://fred.stlouisfed.org/series/A191RG3A086NBEA accessed on August 15, 2025)

the energy bills included both energy and demand charges. Distinct energy and demand charges were not isolated for the HVAC load. Therefore, effective statewide rates were calculated as the averaged bill impacts divided by the averaged whole building energy consumption, which included demand charges on a per-kWh basis for electric bills.

The EUL of CRTUs is 20 years.[24] For use in forecasting consumer decision-making, CalMTA discounted CRTU operating costs at a consumer discount rate of 19% per year for 19 years after installation. The consumer discount rate reflects factors influencing decision making, such as "preferences of consumers facing liquidity constraints, opportunity costs, transaction costs, and multiple uncertainties when making a purchasing decision."[25] Greater discount rates drive longer payback periods because the value of energy bill savings in the future is significantly less than the additional up-front expense, that is: money in the future is worth less than money now. The relatively high consumer discount rate also reflects uncertainty and risk in new, unproven technologies and what degree of energy bill savings are reasonable to expect. A lower discount rate is used for cost-effectiveness analysis, consistent with standard practice, as detailed in Section 7.

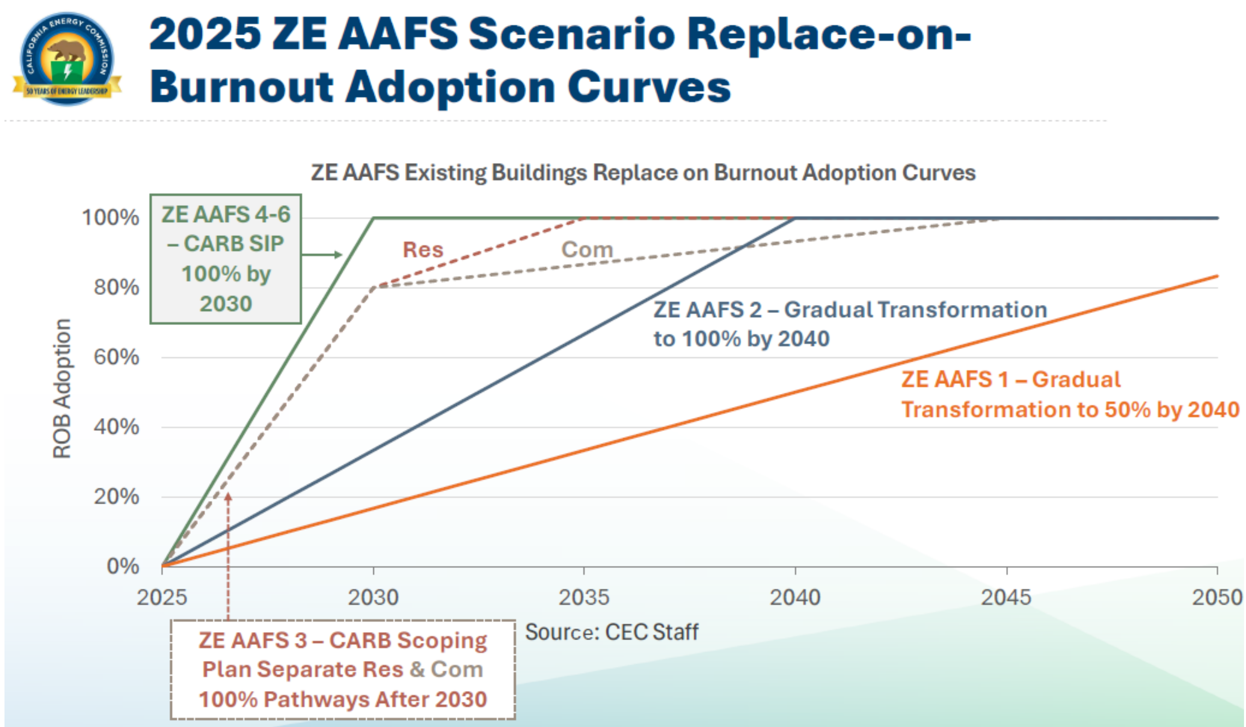
Fuel substitution scenarios

The forecasts for both BMA and TMA assume three policy-driven scenarios of phase out of natural gas commercial space heating. The policy scenarios reflect CEC's proposed 2025 AAFS Scenario Replace-On-Burnout Adoption Curves, which include three scenarios for the rate at which commercial sector gas equipment is phased out (Figure 5).

[24] Multiple Capacity Unitary Air-Cooled Commercial Air Conditioners Between 65 and 240 kBtu/hr. SWHC043-06. https://www.caetrm.com/measure/SWHC043/06/.

[25] Haq, G. and Weiss, M. (2018). Time preference and consumer discount rates - Insights for accelerating the adoption of efficient energy and transport technologies. Technological Forecasting and Social Change. Volume 137, 2018. https://www.sciencedirect.com/science/article/pii/S0040162517311988.

Figure 5. 2025 AAFS Replace-on-Burnout Adoption Curves scenario



The three modeled scenarios are:

- Slow Phase Out Case – AAFS1 Gradual Transformation to 50% by 2040
- Primary Case – AAFS2 Gradual Transformation to 100% by 2040
- Fast Phase Out Case – AAFS3 CARB Scoping Plan Transformation to 80% Commercial by 2030

CalMTA chose AAFS2 as the default, primary case scenario for incremental adoption summarized in the CRTU MTI Plan, because it represents the middle case for assumed timeline and rate of gas phaseout. Results using the slow and fast phaseout scenarios are included in Section 9.1.7, Scenario Analysis.

The model input parameter values do not change between the AAFS scenarios - only the rate at which gas pack RTUs phase out of the market are different between scenarios. The market size and segmentation do not change because the policy scenarios only affect replace-on-burnout CRTU installations, so existing gas CRTUs will be replaced at the same rate regardless of policies around gas phase out.

Price effects are assumed to remain the same across AAFS scenarios as the policy scenarios only affect California rather than the national market and the scenarios change the rate at which gas pack CRTUs are phased out, not whether gas packs are phased out.

The Availability and AVP constraints also remain the same across AAFS scenarios. Because the gas phase-out scenarios affect the actual availability of gas packs, CalMTA manually applied the gas pack market shares corresponding with the AAFS phase-out percentages. The rate of gas phase out does not affect availability and AVP for the CRTUs because the additional demand for electric end uses could be met with code-minimum HP RTUs, for which the constraints are already set to 100%.

3.1.3 Outputs

Annual market shares

The logit model equation, described previously in Section 3.1.1, predicts annual market shares for each CRTU tier by market segment, including baseline, minimally compliant tiers (gas and/or electric, depending on segment). To calculate annual unit adoption and cumulative total adoption, we first translate market shares to annual CRTU additions, then account for retirements from the existing CRTU stock.

The estimated market shares are applied to the annual CRTU replacements for each market segment shown above in Table 4.

CRTU alterations for CRTU type *i* for market segment *j* in year *t* are calculated as:

$$\boldsymbol{RTU\ Additions_{ijt} = \ Predicted\ Market\ Share_{ijt} * \sum RTU\ Retirements_{ijt}}$$

Each alteration replaces an existing CRTU that is retired at the end of its useful life. Annual retirements and changes in the composition of CRTU tiers requires a stock turnover model to allocate retirements across each CRTU type and apply savings correctly for CRTUs with the appropriate gas or electric baseline.

CalMTA assumed the market size is constant over the forecast period within each segment and across segments at the statewide level, meaning the total number of CRTUs in service does not change over time.

The equation for calculating CRTU stock for CRTU type *i* for market segment *j* in year *t* is:

$$\boldsymbol{RTU\ Stock_{ijt} = \ RTU\ Stock_{ijt-1} + \ RTU\ Additions_{ijt-1} - \ RTU\ Retirements_{ijt-1}}$$

Given an EUL of 20 years and a 20-year forecast period, stock turnover assumes five percent of each existing CRTU type are retired each year within each market segment. This also implies there are no differences in the average age of existing stock between CRTU types such that one CRTU type would have a higher rate of retirements in a given year than any other.

The CRTU stock changes over time as gas pack CRTUs and electric resistance CRTUs are retired and replaced with HP CRTUs, and code-minimum HP CRTUs are upgraded to more efficient Tier 1, 2, or 3 CRTUs.

Forecast market adoption

Figure 8 presents the total number of cumulative efficient CRTUs forecast to be installed in the target market between 2025 and 2046, assuming no MTI (BMA cumulative installed units). These installations are shown by market segment in Figure 9.

Table 6. BMA cumulative CRTU installations, 2025 - 2046

CRTU Tier	Cumulative Installed Units
Tier 1 - Code-Minimum HP+CCC	147,782
Tier 2 - Code+20%	38,594
Tier 3 - Code+20%+VS+CCC	50,212
Total – All MTI Tiers	**236,587**

Note: Unit adoption may not sum to total due to rounding.

Table 7. BMA cumulative CRTU installations by market segment, 2025 - 2046

Market Segment	RTU Tier	Cumulative Installed Units
Electric Planned	Tier 1 - Code-Minimum HP+CCC	14,681
	Tier 2 - Code+20%	7,949
	Tier 3 - Code+20%+VS+CCC	10,286
Electric Unplanned	Tier 1 - Code-Minimum HP+CCC	45,670
	Tier 2 - Code+20%	7,495
	Tier 3 - Code+20%+VS+CCC	9,771
Gas Planned	Tier 1 - Code-Minimum HP+CCC	18,730
	Tier 2 - Code+20%	10,293
	Tier 3 - Code+20%+VS+CCC	13,379
Gas Unplanned	Tier 1 - Code-Minimum HP+CCC	68,702
	Tier 2 - Code+20%	12,857
	Tier 3 - Code+20%+VS+CCC	16,776
Total – All MTI Tiers		**236,587**

Note: Totals may not sum to totals in previous table due to rounding.

3.2 Total market adoption (TMA)

The TMA forecast represents adoption predicted to result from the strategic interventions described in the MTI plan and consistent with the MTI market progress milestones.

3.2.1 Methodology

The TMA forecast used the same overall modeling approach and equation used for the BMA forecast (Section 3.1.1, Methodology). The model uses the same input parameters but the values differ between BMA and TMA based on specific MTI outcomes and market progress milestones. The planned MTI market interventions are designed to alleviate the AVP and Availability constraints and reduce the price premium for efficient CRTUs. In addition, CalMTA expects the MTI to modestly increase the rate of fuel substitution from gas to electric beyond the values anticipated by the AAFS policy scenarios. Combined, these market effects will drive adoption of Tier 1, Tier 2, and Tier 3 CRTUs beyond the naturally occurring rate of adoption represented by the BMA forecast.

The market size remains unchanged between BMA and TMA, both within and between market segments. The policy-driven AAFS scenarios also remain unchanged between BMA and TMA.

CalMTA forecasts market adoption beginning in 2025. However, while CalMTA began investing in preliminary market engagement in 2025, significant market changes are not expected until after the start of Phase III in 2027. As such, the input parameters shown in the following figures do not diverge from BMA until 2028, following the start of Phase III, and market adoption does not increase above BMA until 2028.

3.2.2 Inputs and assumptions

This section describes the key assumptions, data sources, and methodologies used to develop the inputs for TMA analysis. These inputs form the basis for modeling CRTU market adoption constraints, technology costs, and fuel substitution decisions under different policy scenarios, assuming the MTI is implemented. Each subsection summarizes the data sources, rationale, and adjustments applied, drawing primarily from CalMTA's CRTUs Market Characterization Report and related market research, to ensure consistent and transparent assumptions across all modeled scenarios.

Market constraints

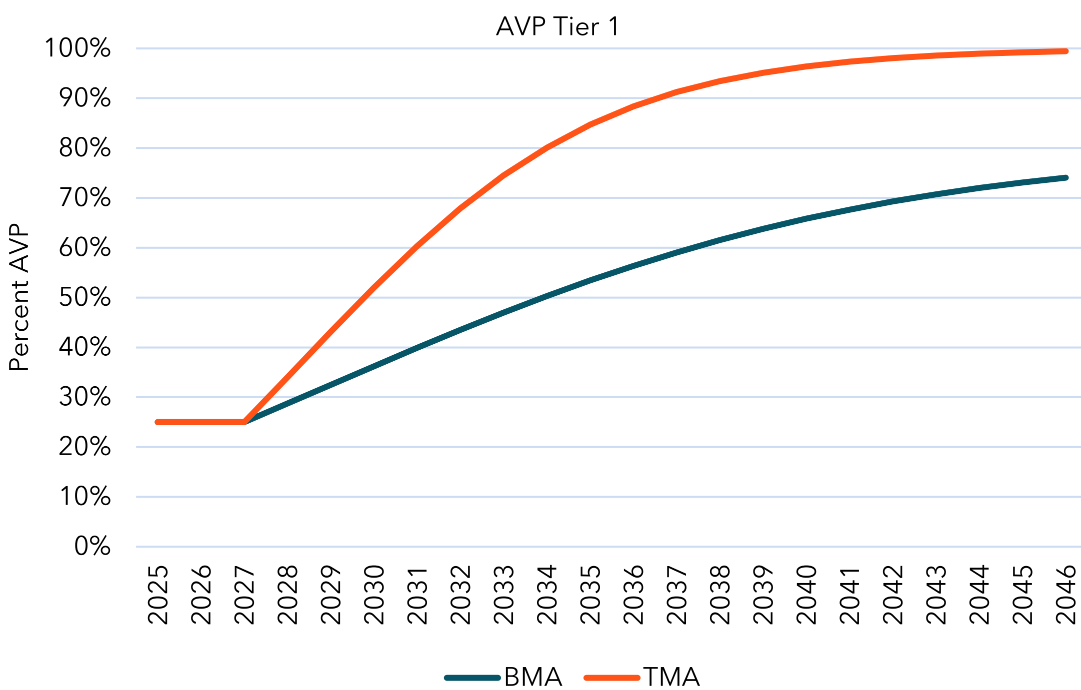
Awareness of value proposition

As described in this MTI Plan, the MTI strategy includes substantial investment in building availability and market actor capability and awareness of the benefits of efficient CRTUs. The MTI program theory and logic model anticipate that one of the key transformative outcomes of these efforts will be an increase in commercial HVAC contractor awareness of the value proposition for, and their frequency of promoting, efficient CRTU technologies.

The market adoption forecasting model therefore assumes that the AVP parameter increases in response to these MTI market interventions. As shown in Figure 6, AVP for Tier 1 CRTUs increases sharply from 2027 through 2034, corresponding with the period of greatest MTI investment and with these market progress milestones:

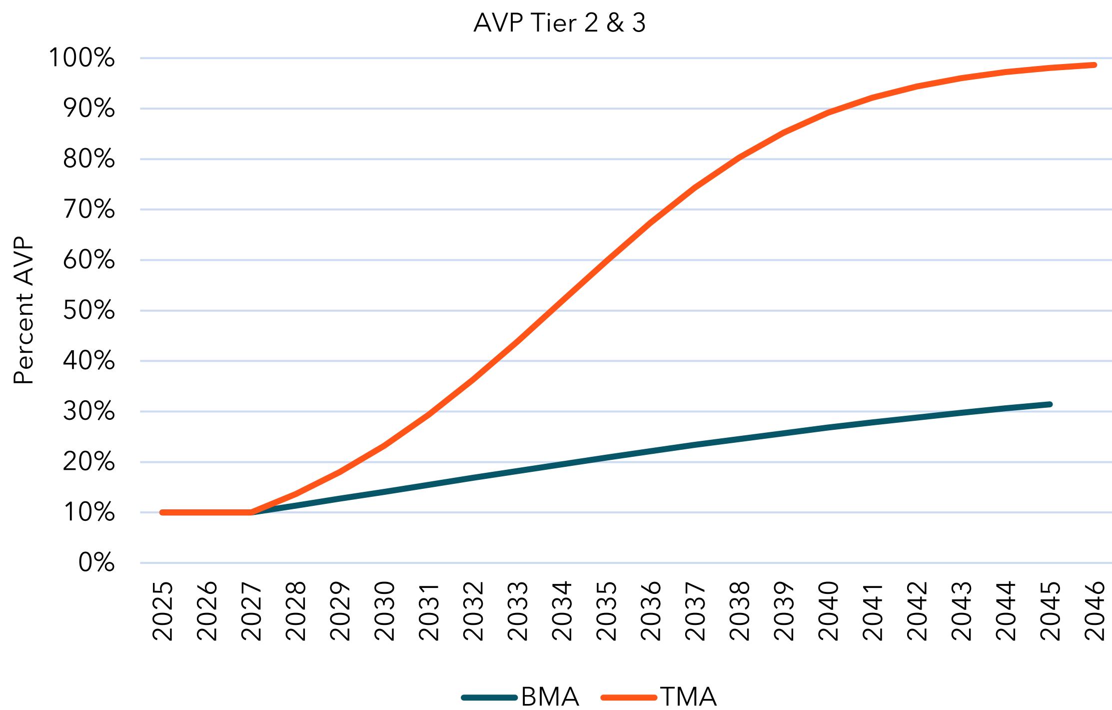
- 60% of distributors stock efficient CRTUs by 2032
- 90% of contractors include CCC in 50% or more bids by 2032
- Installed price of HP RTUs with and without CCC are within 5% by 2035

Figure 6. Tier 1 AVP constraint BMA vs TMA by year



CalMTA assumes that AVP for Tier 2 and Tier 3 CRTUs increases more gradually than for Tier 1 CRTUs, reflecting the fact that these are premium products that contractors currently perceive as less suitable for many decision makers in the unplanned, "2-minute" replacement market. Figure 7 compares the BMA and TMA AVP curves for Tier 2 and Tier 3 CRTUs.

Figure 7. Tier 2 and Tier 3 AVP constraint BMA vs TMA by year



Availability

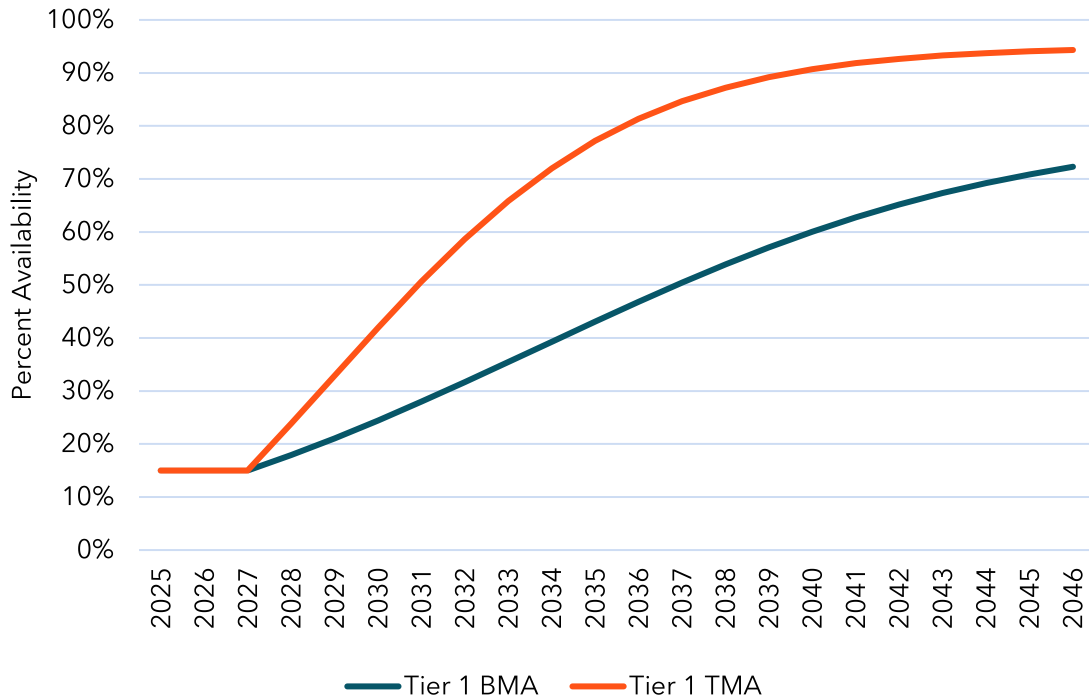
Similar to BMA, the TMA also sets the availability constraint to 100% across all years in the forecast period for baseline CRTUs, both code-minimum HPs and gas packs, because they are both stocked by distributors and readily available in the market.

As described in this MTI Plan, the MTI includes significant investment in engagement with manufacturers and distributors to increase the availability of CRTU technologies. Specifically, the increased number of manufacturers offering CRTUs with efficient features defined by this MTI drive increased availability above the BMA trends, as reflected in these market progress milestones:

- Three minimum-efficiency product lines include CCC as a standard feature by 2031. At least two product lines are from these major equipment manufacturers: Trane, Carrier, Lennox, Johnson Controls, Daikin.
- 60% of distributors stock CRTUs by 2032

As shown in Figure 8, availability of Tier 1 products begins to increase above BMA as a result of manufacturer engagement as early as 2031. By 2037, Tier 1 product availability is anticipated to exceed 90%.

Figure 8. Tier 1 availability constraint BMA vs TMA by year



Availability of Tier 2 and Tier 3 CRTUs (Figure 9 and Figure 10) increases slowly in the early years of implementation because research shows that these products currently have limited production, carry a significant price premium, and are typically custom orders. However, the MTI strategy includes regional and national coordination, along with ongoing manufacturer engagement, to increase the production and distribution of Tier 2 and Tier 3 units, which will eventually result in reducing the price differential between code-minimum and high-efficiency products. While the availability of Tier 2 and Tier 3 products have a similar BMA forecast, the TMA forecast assumes that availability of Tier 3 products grows faster and to a slightly higher level as a result of the MTI market interventions, due to market preference for Tier 3 products. As those changes occur, production, distribution, and availability are expected to increase, as reflected by these market progress milestones:

- Two energy efficiency programs outside of California adopt shared industry tiers/specifications for CRTUs by 2029
- Installed price premium of CRTUs (all tiers) is no more than 30% by 2040

Figure 9. Tier 2 availability constraint BMA vs TMA by year

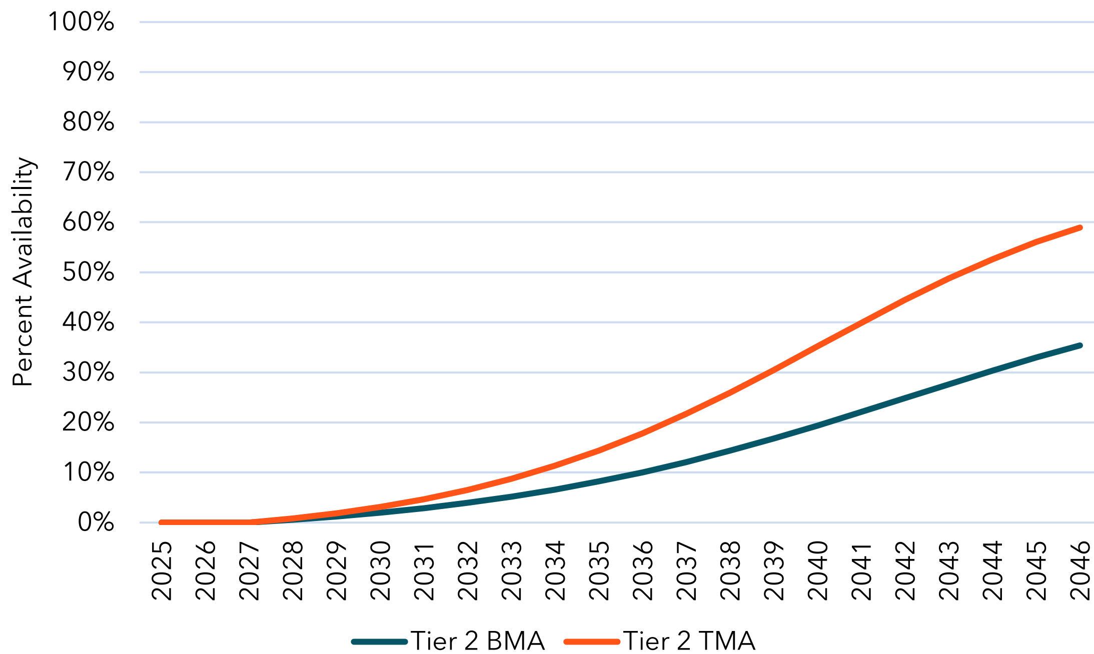
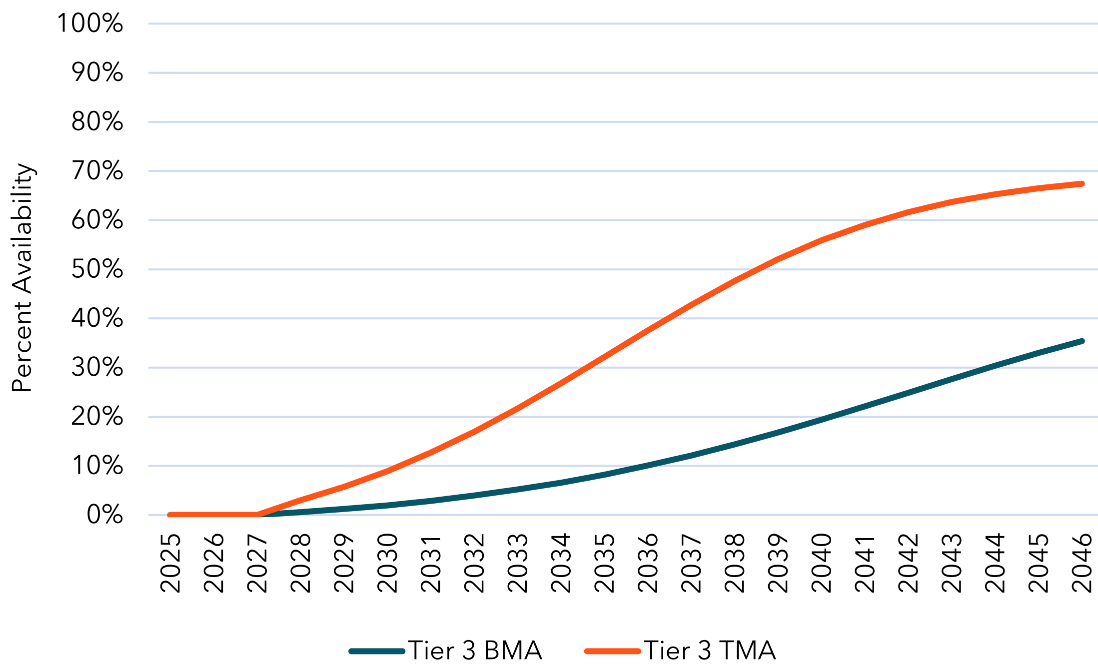


Figure 10. Tier 3 availability constraint BMA vs TMA by year



Price sensitivity

The price sensitivity logit coefficient does not change between the BMA and TMA. The MTI is designed to reduce first-year costs because it is a barrier to adoption, but the model assumes that consumer price sensitivity remains unchanged by the MTI.

Technology costs

The price trends for CRTU TMA represent additional reductions in price for target technologies beyond the projected PPI trend described in the CRTU price (3.1.2, CRTU price forecast) resulting from the MTI market interventions, including manufacturer engagement and upstream incentives, and increased market availability and demand. The prices for gas pack CRTUs are assumed to remain constant in real terms over the forecast period because the market is mature and not in a growth phase. Gas pack RTU prices may change with inflation or via tariffs. However, as noted in the CRTU price discussion in Section 3.1.2, tariffs and inflation are expected to affect all RTU products and do not impact adoption because the model applies relative costs as inputs. So, while tariffs or inflation may affect the starting prices, relative prices would remain the same, and the heat pump RTU prices would decline due to economies of scale at the same rate from a higher nominal value.

CRTU price inputs in the TMA forecast are aligned with these market progress milestones:

- Installed price of code-minimum HP RTUs with and without CCC are within 5% by 2035
- Installed price premium of CRTUs (all tiers) is no more than 30% by 2040

The MTI strategy is designed to achieve price parity between code-minimum products and Tier 1 CRTU products by 2035 as the result of manufacturer engagement and increased demand.

Tier 2 and Tier 3 prices are also expected to decrease, as the result of alignment of upstream incentives, product specifications, and production scale, as manufacturers ship more products. Per the market progress milestone above, this model assumes that the price premium for Tier 3 CRTUs versus code-minimum HP CRTUs will be halved, from the current 60% price premium down to a 30% premium by 2040.

Operating costs

The forecasting model assumes no difference between BMA and TMA in product operating costs or the discount rate applied to determine the net present value of energy bills. All changes in the relative economics of each CRTU tier compared with the baseline CRTUs are driven by changes in prices and installed costs resulting from MTI market interventions.

Relative costs

The model calculates the relative total cost of ownership by adding first-year costs to discounted operating costs as described in Annual operating , with each CRTU tier product total cost divided by the code-minimum HP RTU total cost. The MTI strategic outcomes reduce the up-front equipment costs for each of the three tiers, which improve the relative total costs.

Figure 11 compares the relative cost for Tier 1 CRTUs compared with code-minimum HP RTUs in both the BMA and TMA. The relative total cost for Tier 1 CRTUs is approximately 97% of the total cost of code-minimum HP RTUs at the start of the forecast period, due to modest savings associated with the integrated controls. The relative cost improves slightly through 2035 in the TMA forecast, as the MTI market interventions result in a reduced first-year equipment cost premium.

Figure 11. Tier 1 BMA and TMA total cost relative to code-minimum HP RTU by year

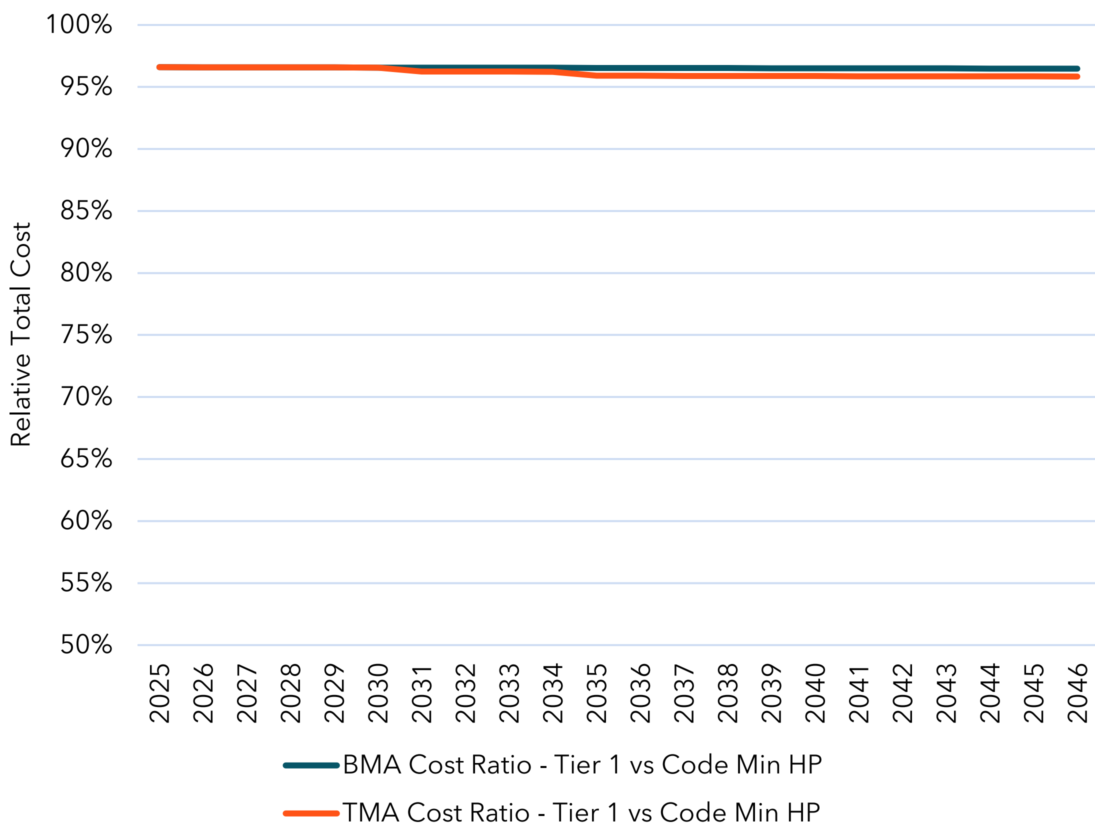


Figure 12 compares the relative cost for Tier 2 CRTUs compared with code-minimum HP RTUs in both the BMA and TMA. The relative total cost for Tier 2 CRTUs is approximately 92% of the total cost of a code-minimum HP RTU at the start of the forecast period given savings from the improved cooling efficiency and declines slightly through the forecast period in the BMA. The relative cost improves through 2035 and 2040 in the TMA as the first-year equipment cost premiums are reduced.

Figure 12. Tier 2 BMA and TMA total cost relative to code-minimum HP RTU by year

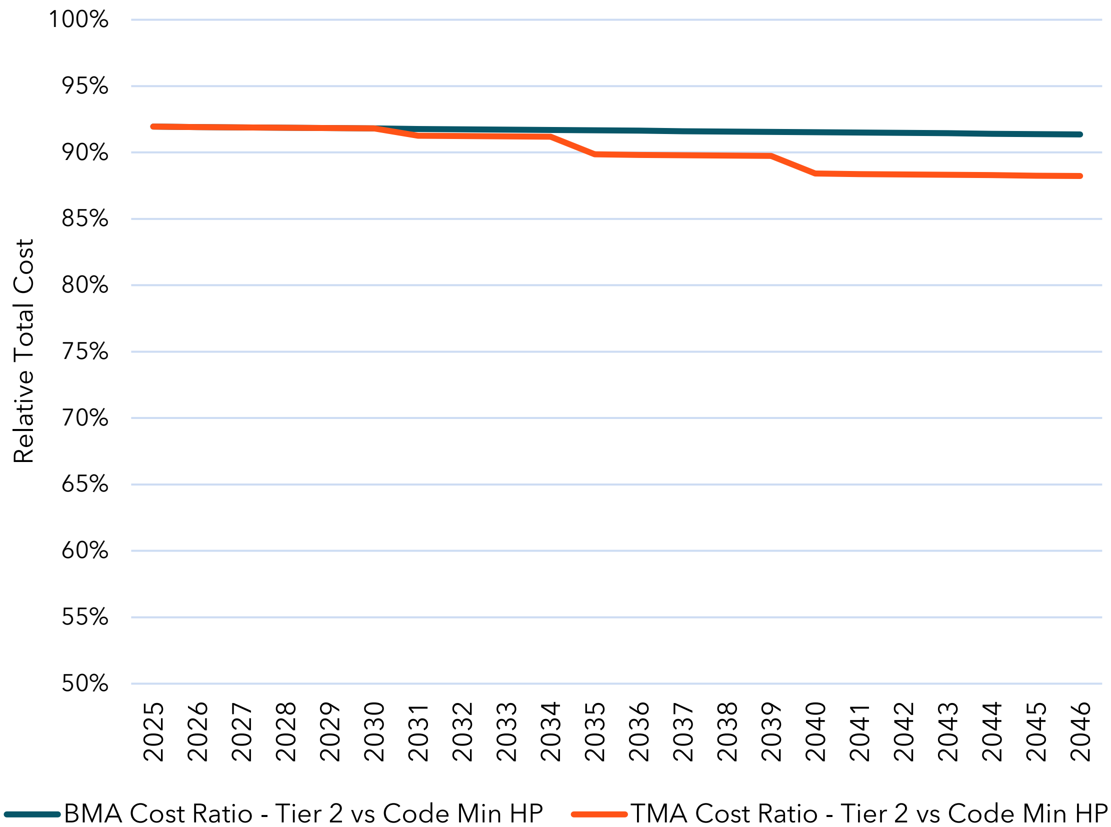
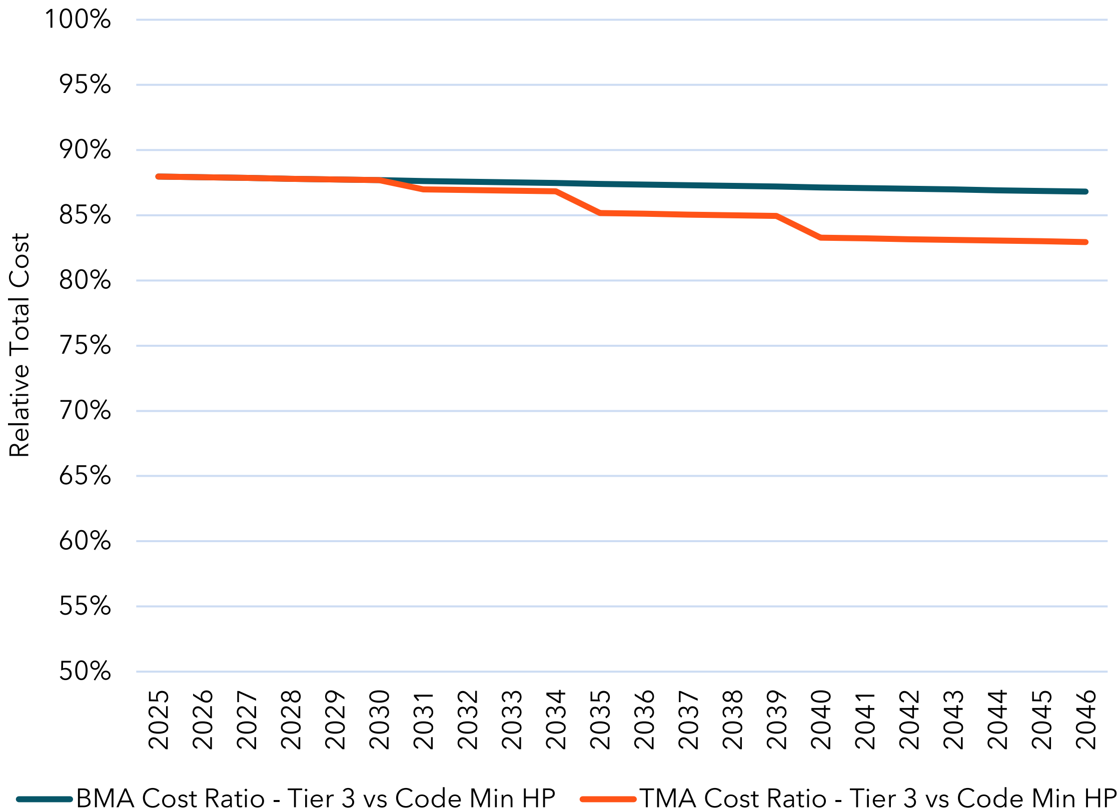


Figure 13 compares the relative cost for Tier 3 CRTUs compared with code-minimum HP RTUs in both the BMA and TMA. The relative total cost for Tier 3 CRTUs is approximately 88% of the total cost of a code minimum HP RTU at the start of the forecast period, given savings from the improved cooling efficiency and the inverter driven variable speed fans and continues to decline slightly in the BMA. The relative cost improves through 2035 and 2040 in the TMA as the first-year equipment cost premiums are reduced.

Figure 13. Tier 3 BMA and TMA total cost relative to code-minimum HP RTU by year



Additional TMA fuel substitution

TMA assumes the same three scenarios of policy-driven phase out of natural gas commercial space heating described in Fuel Substitution Scenarios. The forecasting model assumes that the MTI strategies designed to increase AVP and availability and lower incremental costs for HP CRTUs also result in a modest increase in the rate of fuel substitution beyond the AAFS scenarios, which increases the size of the market considering any HP CRTUs. The increased rate was estimated based on expert judgment of the CalMTA team and was applied as a direct exogenous adjustment to TMA gas market shares rather than the result of changes to the constraints or cost parameter inputs in the model. Recognizing the uncertainty and limitations of this approach, CalMTA considers scenarios in our sensitivity analyses with no additional fuel substitution attributable to the MTI (presented in Section 9.2.8).

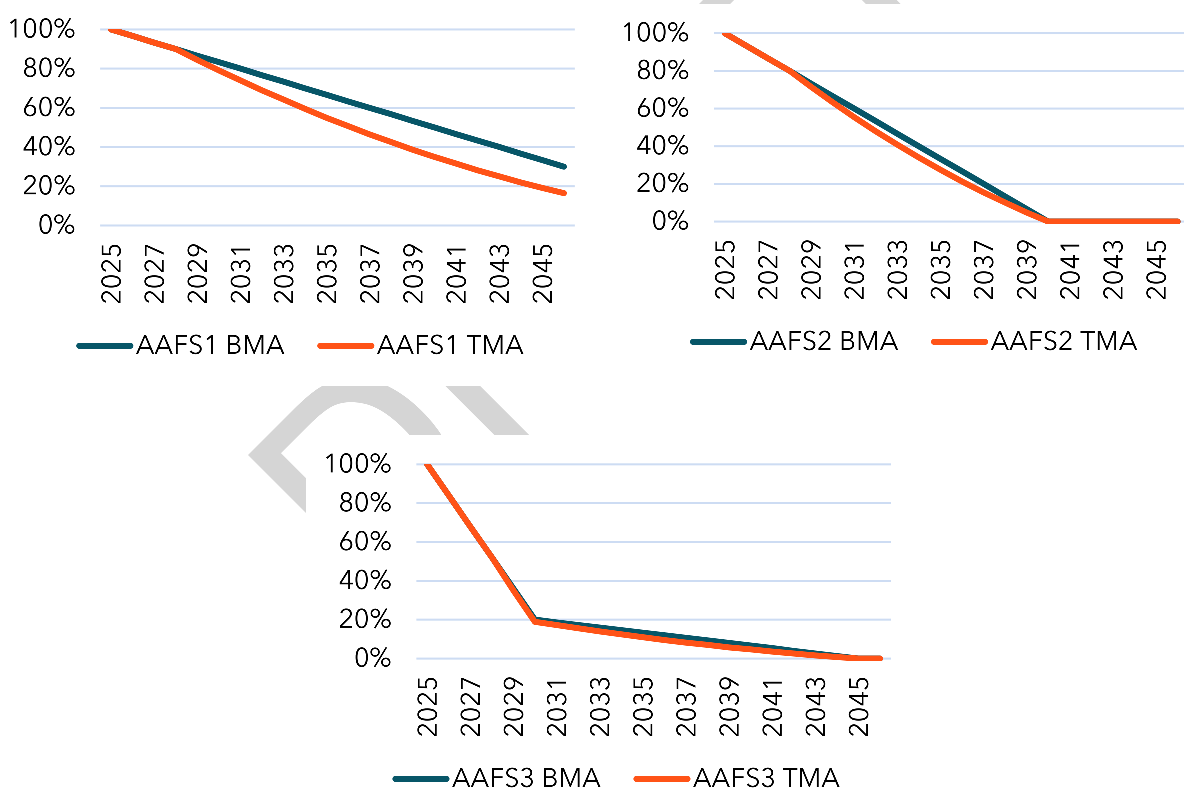
The rate and timeline of fuel substitution varies between each of the three AAFS scenarios. Potential incremental fuel substitution in the TMA forecast is greater for AAFS1, the slowest fuel substitution scenario, than it is for AAFS3 that forecasts 80% fuel substitution by 2030 and therefore leaves very little potential for the MTI to drive incremental fuel substitution.

Figure 14 compares the rate of fuel substitution between BMA and TMA for each of the three AAFS scenarios:

- For AAFS 1, the TMA forecast assumes that by 2039 the MTI increases fuel substitution by 15% above the rate of policy-driven substitution driving BMA.
- For AAFS2, the TMA forecast assumes that by 2033 the MTI increases fuel substitution by 6% above the rate of policy-driven substitution assumed for BMA, but that incremental impact tapers off until policy-driven gas phase out reaches 100% in 2040.
- AAFS3 fuel-substitution occurs more quickly than AAFS1 and AAFS2, with 80% of gas CRTUs phased out by 2030 and provides the least opportunity for the MTI to drive additional fuel substitution.

In all three scenarios, TMA gas market shares are lower than BMA, reflecting the incremental fuel substitution beyond the policy-driven market shares.

Figure 14. TMA gas market shares, by AAFS scenario



3.2.3 Outputs

California TMA statewide market adoption by tier and market segment

Table 8 presents the total number of cumulative efficient CRTUs forecast to be installed in the target market between 2025 and 2046, assuming the MTI is implemented (TMA cumulative installed units). These installations are shown by market segment in Table 9.

Table 8. TMA cumulative CRTU installations, 2025 - 2046

RTU Tier	Cumulative Installed Units
Tier 1 - Code Min HP+CCC	158,056
Tier 2 - Code+20%	87,095
Tier 3 - Code+20%+VS+CCC	153,739
Total	**398,890**

Note: Totals may not sum due to rounding.

Table 9. TMA cumulative CRTU installations by market segment, 2025 - 2046

Market Segment	RTU Tier	Cumulative Installed Units
Electric Planned	Tier 1 - Code-Minimum HP+CCC	12,297
	Tier 2 - Code+20%	12,377
	Tier 3 - Code+20%+VS+CCC	16,478
Electric Unplanned	Tier 1 - Code-Minimum HP+CCC	54,241
	Tier 2 - Code+20%	20,856
	Tier 3 - Code+20%+VS+CCC	42,174
Gas Planned	Tier 1 - Code-Minimum HP+CCC	14,753
	Tier 2 - Code+20%	17,650
	Tier 3 - Code+20%+VS+CCC	23,715
Gas Unplanned	Tier 1 - Code-Minimum HP+CCC	76,764
	Tier 2 - Code+20%	36,212
	Tier 3 - Code+20%+VS+CCC	71,372
Total MTI Tiers		**398,890**

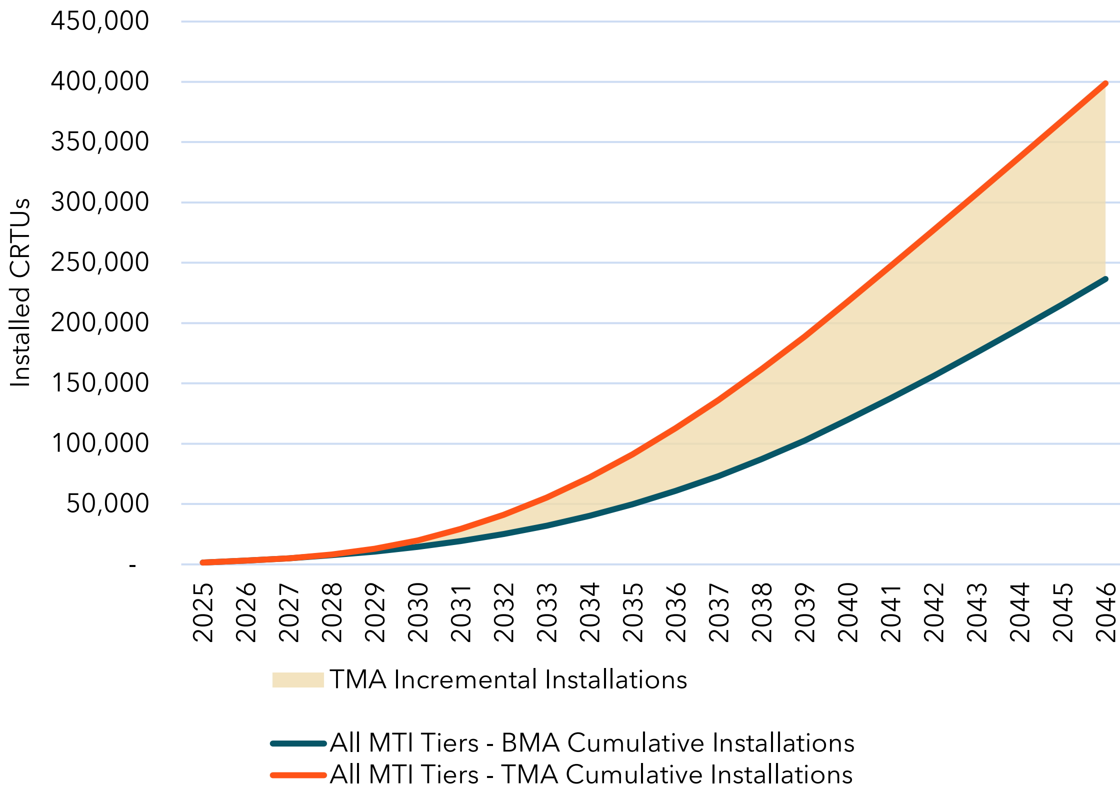
Note: Totals may not sum due to rounding.

Statewide BMA and TMA cumulative CRTU adoption by tier

The following figures compare the forecast cumulative adoption in both the BMA and TMA and show incremental adoption – the area between the BMA and MTA curves. These graphs do not show PA-verified units. PA-verified units and net incremental adoption are presented in Sections 3.3 and 3.4.

Figure 15 shows BMA, TMA, and incremental adoption for all MTI CRTUs over the forecast period.

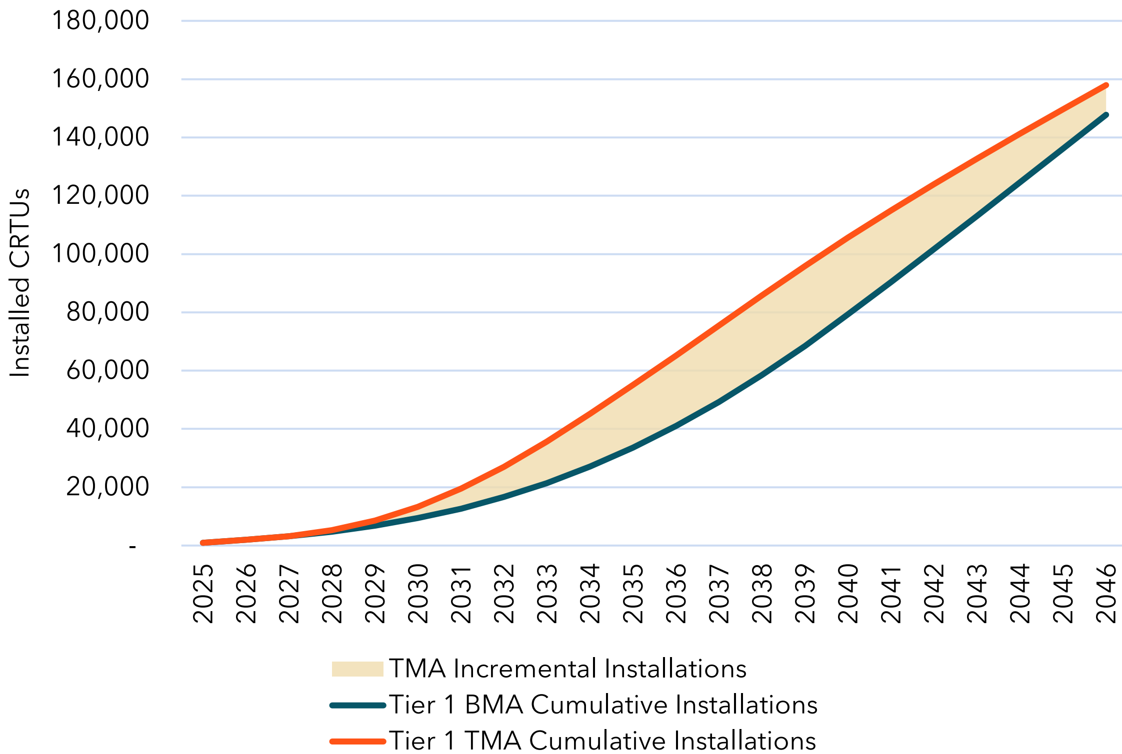
Figure 15. BMA vs TMA cumulative installed CRTUs – all tiers



3.2.4 Tier 1 CRTUs

Figure 16 shows the cumulative BMA and TMA installations for Tier 1 CRTUs. TMA adoption diverges from BMA starting in 2028 with the MTI accelerating the rate of adoption of Tier 1 CRTUs as the price premium reductions are realized and AVP and Availability increase via expanded product lines. The difference between TMA and BMA adoption begins to slow around 2040.

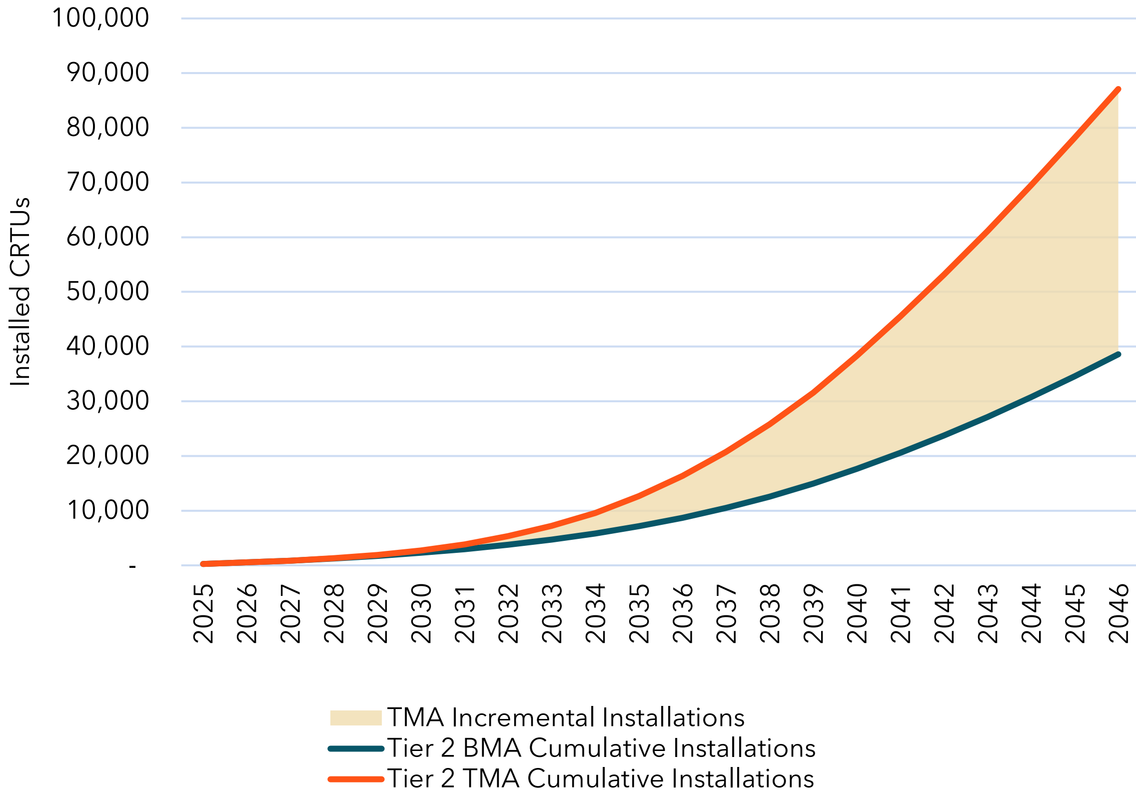
Figure 16. Tier 1 CRTU cumulative and incremental installations – BMA vs TMA



3.2.5 Tier 2 CRTUs

Figure 17 shows the cumulative BMA and TMA installations for Tier 2 CRTUs. Adoption ramps up slowly for Tier 2 CRTUs through 2034 as AVP and Availability begin to increase and the market is less constrained for Tier 2 products. Adoption begins to diverge from BMA adoption more quickly through the remainder of the forecast period as price premiums are reduced in 2035 and 2040.

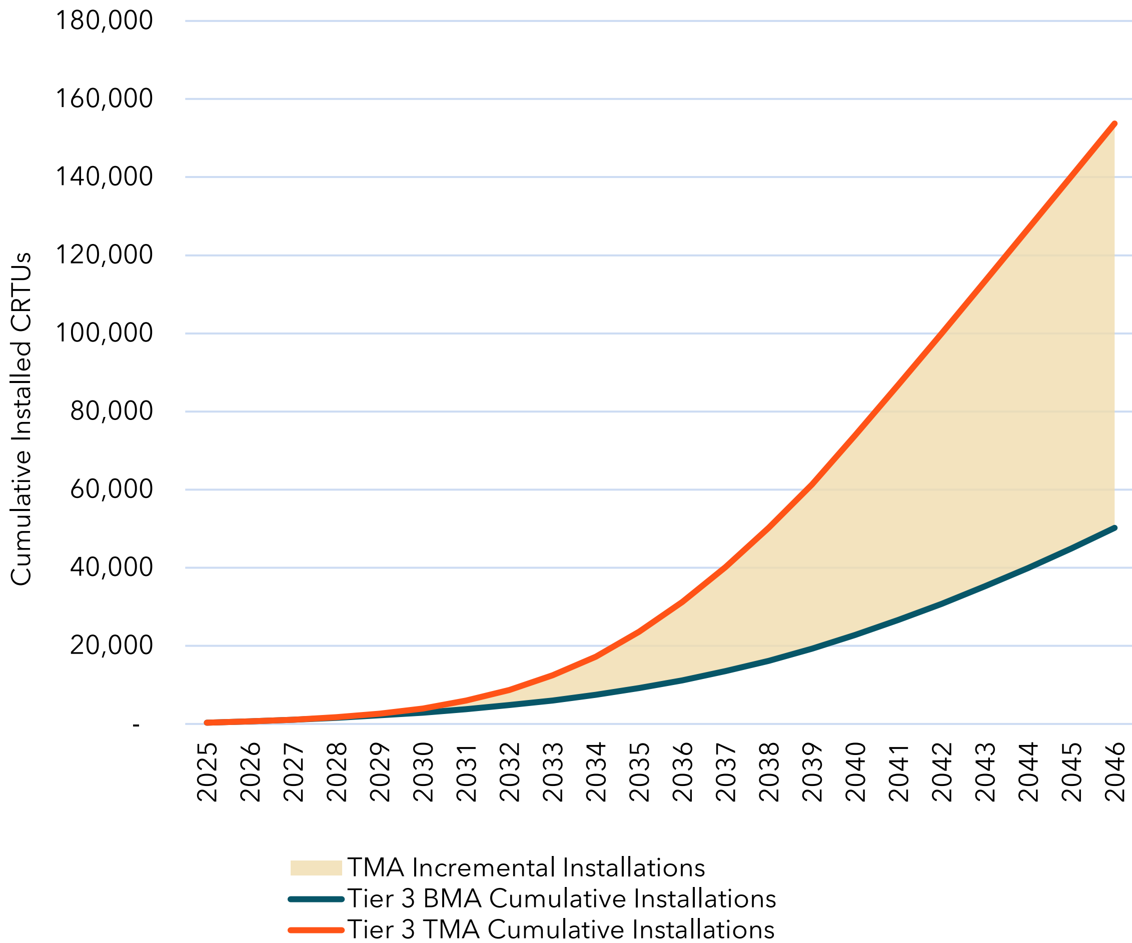
Figure 17. Tier 2 CRTU cumulative and incremental installations – BMA vs TMA



3.2.6 Tier 3 RTUs

Figure 18 shows the incremental adoption of Tier 3 CRTUs. Adoption ramps up slowly for Tier 3 CRTUs through 2033 as AVP and Availability increase and the market is less constrained for Tier 3 products. AVP and Availability increase more rapidly from 2035 and beyond and product lines expand to offer more Tier 3 CRTUs. The MTI expects to achieve key milestones regarding reduction in price premiums by 2035 and 2040, which correspond with improved relative economics of Tier 3 CRTUs versus CRTU alternatives, accelerating adoption through the remainder of the forecast period.

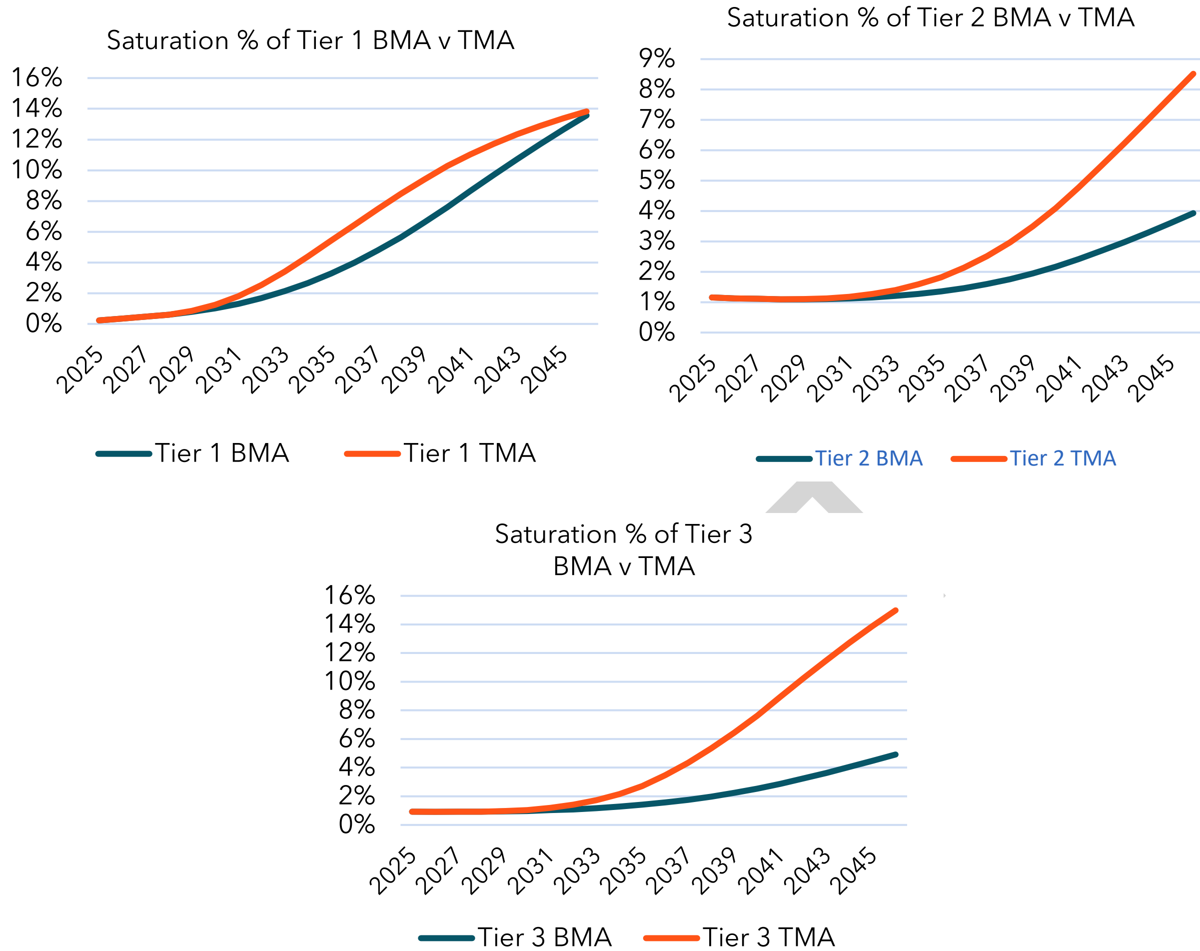
Figure 18. Tier 3 CRTU cumulative and incremental installations – BMA vs TMA



Statewide BMA and TMA saturation by tier

Figure 19 shows the resulting forecast saturations over the MTI lifetime for each Efficient CRTU Tier.

Figure 19. Statewide efficient CRTU saturations, by tier



3.3 Program administrator verified units

Per the MTI Evaluation Framework, CalMTA calculates net incremental adoption attributable to the MTI by subtracting units associated with PA-verified savings from measured TMA baseline market adoption.

To forecast adoption associated with PA-verified savings, CalMTA reviewed existing programs, program claims in CEDARs, IOU business plans, and similar MT initiatives in other jurisdictions. There is no reliable source for an estimate of PA savings claims in the future, since the technology tiers as defined by the MTI are not currently incentivized. The forecast assumes that PA-verified program savings begin in 2031, resulting from alignment with the CRTU tiers and associated program incentives. The forecast makes the following assumptions regarding the percentage of PA-verified CRTUs:

- By 2031 some additional program offerings will include MTI technologies and will contribute to 4% of total adoption of efficient CRTUs.
- By 2035, program offerings that include MTI technologies will be more widely available in part due to collaboration with the MTI. CalMTA assumes a steady ramp up in program units with 20% of total efficient RTU units adopted being PA-verified by 2035 and will continue at 20% through the remainder of the forecast period.

CalMTA will true up the PA-verified units estimated in the MTI forecast annually based on units reported in CEDARS.

3.4 Net incremental market adoption

Per the attribution approach agreed upon in the MTI Evaluation Framework, CalMTA calculates the net incremental impacts of MTIs and uses this value to calculate MTI cost effectiveness. Net incremental adoption of CRTUs attributed to the market transformation efforts by CalMTA may be written as:

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

Where Y represents cumulative adoption of CRTUs over the forecast period of 2025 to 2046. The superscripts $N.incremental$, TMA, BMA, and PA represent net incremental adoption attributed to the MTI, TMA, BMA, and PA-verified savings respectively.

Table 10 presents the BMA, TMA, PA-verified, and incremental market adoption in CRTU units by tier and at the statewide level over the entire forecast period.

Table 10. Net incremental adoption – CRTU units

RTU Tier	BMA	TMA	RA	Net Incremental
Tier 1 - Code Min HP+CCC	147,782	158,056	0	10,274
Tier 2 - Code+20%	38,594	87,095	9,333	39,168
Tier 3 - Code+20%+VS+CCC	50,212	153,739	19,773	83,754
Total	**236,587**	**398,890**	**29,106**	**133,196**

Note: Unit adoption may not sum to total due to rounding.

4 Load shape

The team completed a total of 1,600 full building energy model simulations to represent a range of HVAC equipment, faults, building types, and CZs. These were blended together using weighting factors based on proportion of building type and CZ population to represent ten different installation scenarios, each with two load shapes - one for the baseline equipment and one for the proposed equipment – the difference between which was calculated to get unique 8,760 kWh and therm savings shapes for each installation scenario, which were used as inputs for avoided cost calculations. More details can be found in Attachment 2.

5 Unit energy impacts

To determine the unit energy savings, estimates were developed through a set of energy models comparing different base and efficient cases for each CZ. CalMTA analyzed UEI inputs for each of the three IOUs: PG&E, SCE, SDG&E. Consequently, each installation condition (a set of six baseline and efficient equipment mixes based on equipment tiers and fuel substitution) had three sets of utility-specific UEIs. CalMTA applied an 8,760 hourly load shape that estimates how likely an end user would be to use the equipment in any given hour of the year, to determine average annual unit energy savings.

Table 11 provides electric savings (in kWh) and gas savings (in therms) by the six installation conditions, decision types, and IOU per 1,000 ft^2 of conditioned space. Each savings value in this table represents a composite of multiple building types and CZs as detailed further in Attachment 2: Documentation of unit energy savings and avoided cost calculations for commercial rooftop units. Under certain installation conditions, average annual kWh savings are negative, as gas heating equipment is replaced with electric equipment, resulting in additional electric consumption. Installation conditions 1 to 3 are electric to electric HP baseline replacements, while installation conditions 4 to 6 are electric equipment replacing gas pack RTUs that use gas for heating and air conditioners for cooling.

Table 11. Unit energy savings by installation condition

Counterfactual equipment	Number	Proposed Equipment Specification	IOU	Average annual electric savings (kWh)	Average annual gas savings (therms)
Code-Minimum All Electric HP CRTU	1	Tier 1: Code-Minimum Heat Pump CRTU + Integrated monitoring with remote access and control, App-based Startup Commissioning, AFDD	PGE	323.63	-
			SCE	205.68	-
			SDGE	184.71	-
Code-Minimum All Electric HP CRTU	2	Tier 2: Heat Pump CRTU w/ cooling efficiency >20% of federal minimum	PGE	633.20	-
			SCE	535.60	-
			SDGE	472.91	-
Code-Minimum All Electric HP CRTU	3	Tier 3: Heat Pump CRTU w/ cooling efficiency >20%, with VSD* + Tier 1 features	PGE	1,409.05	-
			SCE	1,114.44	-
			SDGE	973.18	-

Counterfactual equipment	Number	Proposed Equipment Specification	IOU	Average annual electric savings (kWh)	Average annual gas savings (therms)
Code-Minimum AC + Furnace	4	Tier 1: Code-Minimum Heat Pump CRTU + Integrated monitoring with remote access and control, App-based Startup Commissioning, AFDD	PGE	(1,395.36)	205.26
			SCE	(571.14)	104.26
			SDGE	(509.23)	94.00
Code-Minimum AC + Furnace	5	Tier 2: Heat Pump CRTU w/ cooling efficiency >20% of federal minimum	PGE	(948.12)	200.00
			SCE	(183.25)	101.26
			SDGE	(169.92)	91.26
Code-Minimum AC + Furnace	6	Tier 3: Heat Pump CRTU w/ cooling efficiency >20%, with VSD + Tier 1 features	PGE	(309.94)	205.58
			SCE	337.62	104.32
			SDGE	279.25	93.93

*VSD – Variable Speed Drive

A detailed description of these models and additional details regarding the conditions and assumptions used to determine per-unit savings can be found in Attachment 2 of this document.

6 Effective useful life

The EUL for commercial air conditioning (AC) and HPs was updated in DEER 2025/26 to 20 years, from 15.[26] Given the normal replacement decision type in this analysis, CRTUs contribute energy impacts for 20 years after installation. For example, a unit installed in 2030 continues to operate until the final year of the EUL in 2049.

7 Avoided costs

Avoided costs are defined as the marginal costs of energy that the utility 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.

CalMTA developed measure-specific avoided cost values using the latest E3 2024 ACC for PG&E, SCE, and SDG&E.[27] CalMTA included avoided costs from 2024 to 2054 in each utility's territory and

[26] Multiple Capacity Unitary Air-Cooled Commercial Air Conditioners Between 65 and 240 kBtu/hr. SWHC043-06. https://www.caetrm.com/measure/SWHC043/06/ .

[27] Avoided Cost Calculator for Distributed Energy Resources (DER) - E3 Version 2024 V1b

used these to determine the TSB, as well as TRC and PAC ratios. For CRTUs in operation from 2055-2065, beyond the range of estimated avoided costs in the ACC, the analysis used the 2054 avoided cost value as a proxy. CalMTA applied avoided costs to the incremental adoption for PG&E, SCE, and SDG&E for each installation condition in each year. Next, CalMTA aggregated and discounted these benefits using the average nominal discount rate of 7.30%[28] (Table 12) to determine the MTI TSB in 2025 dollars.

Table 12. Discount rate by IOU

IOU	Discount Rate
PG&E	7.27%
SCE	7.44%
SDGE	7.18%
Average discount rate	7.30%

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

- Social cost of carbon (SCC) [29]
- Base SCC (50th percentile of possible climate impacts) by IOU and year[30]
- High SCC (95th percentile of possible climate impacts) by IOU and year[31]
- Base value of methane leakage: 2.3% of gas consumption
- Statewide air quality adder: $14/MWh
- Societal test-specific discount rate: 3% in real dollars (5.06% nominal)

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 2025 dollars.

8 Cost inputs

8.1 Initiative costs

Initiative costs are realized through the implementation of the MTI. These include costs to managing the MTI, research and evaluation, marketing, product development, manufacturer

[28] 2024 Avoided Cost Calculator Guidance. 2024-acc-documentation-v1b_clean_posted_nowm.pdf
[29] Avoided Cost Calculator for Distributed Energy Resources (DER) - E3 Version 2024 V1b
[30] Avoided Cost Calculator for Distributed Energy Resources (DER) - E3 Version 2024 V1b
[31] Avoided Cost Calculator for Distributed Energy Resources (DER) - E3 Version 2024 V1b

engagement, policy development, and data collection. Including Phase II and Phase III costs, total initiative costs were $42.8M (see 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 flow-down incentive (FDI) costs, which are the cost of incentives that flow down to the consumer and reduce consumer costs. All test parameters are in line with California Cost Effectiveness standard practices.[32]

8.2 Incremental measure cost

CalMTA conducted secondary research to develop estimates of incremental costs (IMCs) associated with MTI technologies. The methodology used to derive the costs and estimated costs per 10-ton unit is described in Attachment 1: Technology costs. The IMC values presented in this section are based on those cost estimates and then are expressed on a per-1,000 ft² basis, in line with the values developed for incremental adoption and energy savings models. Incremental cost components include baseline and efficient technology costs, add-on technology costs, electric system upgrade costs, labor costs, and permitting costs.

Table 13 lists the first-year incremental costs in the first year of incremental adoption (2028) used in this analysis:

Table 13. First year IMCs by installation condition ($/1,000 ft² Conditioned)

Counterfactual Equipment	Proposed Equipment Specification	Technology IMC	Labor IMC	Permitting IMC	Other First Costs IMC	First-year Total IMC
Code-Minimum All Electric HP CRTU	Tier 1: Code-Minimum Heat Pump CRTU + Integrated monitoring with remote access and control, App-based Startup Commissioning, AFDD	$81.12	$21.65	$-	$-	$102.77
Code-Minimum All Electric HP RTU	Tier 2: Heat Pump CRTU w/ cooling efficiency >20% of federal minimum	$567.30	$21.65	$-	$-	$588.95

[32] CPUC. (2001). California Standard Practice Manual. cpuc-standard-practice-manual.pdf

Counterfactual Equipment	Proposed Equipment Specification	Technology IMC	Labor IMC	Permitting IMC	Other First Costs IMC	First-year Total IMC
Code-Minimum All Electric HP RTU	Tier 3: Heat Pump CRTU w/ cooling efficiency >20%, with VSD + Tier 1 features	$1,180.25	$21.65	$-	$-	$1,201.90
Code-Minimum AC + Furnace	Tier 1: Code-Minimum Heat Pump CRTU + Integrated monitoring with remote access and control, App-based Startup Commissioning, AFDD	$238.06	$21.65	$142.61	$29.91	$432.23
Code-Minimum AC + Furnace	Tier 2: Heat Pump CRTU w/ cooling efficiency >20% of federal minimum	$724.24	$21.65	$142.61	$29.91	$918.41
Code-Minimum AC + Furnace	Tier 3: Heat Pump CRTU w/ cooling efficiency >20%, with VSD + Tier 1 features	$1,337.19	$21.65	$142.61	$29.91	$1,531.36

CalMTA 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.

8.2.1 Trends in incremental measure costs

Changes in incremental measure costs over the forecast period are driven by the price projection curves and the difference between the BMA and TMA curves presented in Table 14 and Table 15. The BMA price projection curves apply equally to all HP CRTUs, including code-minimum.

Table 14. IMC trend

Counterfactual Equipment	Proposed Equipment Specification	2028	2030	2035	2046
Code-Minimum All Electric HP CRTU	Tier 1: Code-Minimum Heat Pump CRTU + Integrated monitoring with remote access and control, App-based Startup Commissioning, AFDD	$102.77	$108.14	$45.00	$55.97
Code-Minimum All Electric HP RTU	Tier 2: Heat Pump CRTU w/ cooling efficiency >20% of federal minimum	$588.95	$618.83	$476.72	$394.53
Code-Minimum All Electric HP RTU	Tier 3: Heat Pump CRTU w/ cooling efficiency >20%, with VSD + Tier 1 features	$1,201.90	$1,262.70	$1,151.83	$1,224.47
Code-Minimum AC + Furnace	Tier 1: Code-Minimum Heat Pump CRTU + Integrated monitoring with remote access and control, App-based Startup Commissioning, AFDD	$432.23	$440.03	$379.68	$373.65
Code-Minimum AC + Furnace	Tier 2: Heat Pump CRTU w/ cooling efficiency >20% of federal minimum	$918.41	$950.73	$811.41	$712.21
Code-Minimum AC + Furnace	Tier 3: Heat Pump CRTU w/ cooling efficiency >20%, with VSD + Tier 1 features	$1,531.36	$1,594.60	$1,486.51	$1,542.16

9 TSB and cost-effectiveness analysis

CalMTA took a systematic approach to developing the cost-effectiveness model, beginning with determining all the necessary model inputs and outputs for the MTI. As depicted previously (Figure 1), there are seven primary inputs required to estimate TSB and cost effectiveness: net incremental market adoption, UEIs, load shape, EUL, initiative costs, avoided costs, and IMCs. Each of these inputs must have consistent units of analysis, which for this MTI is 1,000 square feet of conditioned space.

TSB and cost-effectiveness analyses consider the installation conditions (the combination of counterfactual and efficient technologies), fuel types, target sector, and costs incurred in MTI implementation.

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 CZs, using approved 8,760 load shapes and defined avoided costs. However, since the analysis for this MTI required custom 8,760 load shapes not currently supported by CET-16, the CalMTA team used an in-house Excel-based cost-effectiveness model which allowed for full insight into how the model generated outputs based on dynamic and varying inputs.

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 CRTU MTI:

1) Phase II: 3 years (2024 to 2026)
2) Phase III: 20 years (2027 to 2046)
3) EUL: 20 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, base SCT, and high SCT. To account for the time value of money, the team applied a nominal discount rate of 7.30% (3% real discount rate for base and high SCT, 5.06% nominal discount rate) to discount benefits and incremental measure cost to the first year of the MTI, in line with current guidance from the CPUC.[33]

9.1 Total system benefit

TSB is a function of the inputs described in earlier sections. The team used the following CET-based formula to determine TSB:[34]

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

[33] Avoided Cost Calculator for Distributed Energy Resources (DER) - E3

[34] The CET formula *((ElectricBen+GasBen+NumUnits * (NTGRkWh+ MarketEffectsBenefits) * RefrigBens) - (ElecsupplyCost + GasSupplyCost) + NumUnits * (NTGRkWh + MarketEffectsCosts) * UnitRefrigCosts)* was simplified to represent refrigerant benefits and costs as total values, consistent with the electric and gas benefits. NTG Ratio is assumed to be 1 for this analysis and MarketEffectsBenefits are assumed to be 0.

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

After calculating TSB, the team disaggregated the total TSB into three components: energy, grid, and GHG benefits (categorized as refrigerant and non-refrigerant) to identify the broad avoided cost categories where the MTI provides value. The team categorized the avoided cost factors into three categories: energy benefits, grid benefits, and GHG benefits. Table 15lists the ACC workbook factors from the electric and gas models by the three categories for reporting.

Table 15. TSB avoided cost factors by category

Category	Electric Model	Gas Model
Energy	Energy	Market (commodity)
Grid	Generation capacity	Transmission and distribution
	Transmission capacity	
	Distribution capacity	
	Ancillary Services	
	Losses	
GHG	Cap and trade	Environment (CO_2 and NO_X emission)
	GHG adder	Upstream methane leakage
	GHG rebalancing	Behind-the-meter methane leakage
	Methane leakage	Gas air quality adder
	Air quality adder	N/A

Table 16 shows the TSB estimates disaggregated for energy, grid, and GHG impacts.

Table 16. TRC, PAC, base SCT, and high SCT TSB estimates, 2025-2046

MTI Approach	TSB ($M) *	Energy ($M)	Grid ($M)	GHG non-refrigerant ($M)
TRC (standard)	595	148	147	300
SCT base	951	234	232	486
SCT high	1,024	234	232	559

Source: CalMTA estimates.
*TSB refers to Total System Benefits for the TRC test and Total Societal benefits for the SCT.

The CRTU MTI will generate approximately $595 million in TSB using TRC assumptions. The largest share of the benefit can be attributed to mitigated non-refrigerant GHG emissions, with an estimated $300 million in TSB. The second largest share of TSB is energy benefits driven by savings related to electricity and natural gas, with $148 million in TSB. Finally, reductions generate nearly $147 million in TSB driven by grid benefits.

SCT based TSB (Total Societal Benefit) shows substantially higher benefits, largely driven by smaller overall discount rates and greater benefits attributed to GHG emissions reductions. The

SCT discount rate of 5.06% nominal (3.0% real) affords greater value to benefits accrued in the latter years of the MTI. In both SCT TSB approaches, the contribution of GHG benefits to overall TSB is significantly higher than it is under the standard TRC based approach.

9.2 Cost effectiveness

9.2.1 Total resource cost test

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 formula used by the Excel tool to determine TRC:

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

9.2.2 Program administrator cost test

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 formula used by the Excel tool to determine PAC:

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

9.2.3 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 Excel 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:

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

9.2.4 Cost-effectiveness results

Table 17 provides the cost-effectiveness estimates for the MTI over the period 2025-2046.

Table 17. MTI cost-effectiveness estimates, 2025-2046

TRC	PAC	Base SCT	High SCT
2.65	20.52	3.23	3.47

9.2.5 Cost-effectiveness schedule

Table 18 shows the cumulative TSB and cost-effectiveness estimates and incremental investment required every five years for the CRTU MTI. Although cost effectiveness for MTIs is properly calculated only over the entire MTI lifetime (2025-2046),[35] [36] Table 18 illustrates the fact that cost effectiveness is fully realized only after the MTI effects the structural market changes described in the MTI logic model and program theory. It also shows the expected incremental investment required after each 5 years of Phase III, Market Deployment, which decreases markedly after 2035.

Table 18. Cost-effectiveness and Incremental Investment, at 5-Year Timepoints

Forecast metric	2031	2036	2041	2046
TSB	$ 41M	$ 218M	$ 434M	$ 595M
TRC ratio	1.51	2.48	2.62	2.65
PAC ratio	2.00	7.92	15.02	20.52
Estimated incremental investment	$ 26.7M	$ 12.2M	$ 3.4M	$ 0.4M

9.2.6 Co-created and statewide TSB

Co-created TSB: Co-created impacts refer to the total impacts (including utility-reported savings) influenced by the MTI. As described earlier, CalMTA estimated market adoption associated with PA-verified 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 program verified adoption influenced by the MTI, for the three IOUs and on a statewide basis as shown in Table 17.

[35] Prahl, Ralph, and Keating, Ken. December 9, 2014. Building a Policy Framework to Support Energy Efficiency Market Transformation in California. MT_Policy_White_Paper_final_Dec 9 2014.doc (live.com).

[36] CPUC D.19-12-021 https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M321/K507/321507615.PDF

Statewide TSB: The CRTU 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. CalMTA developed adoption estimates for "non-IOU" territories (described in Program Verified Units) and developed avoided costs for non-program adoption by applying population-weighted average avoided costs for the three utilities. The resulting Statewide TSB estimates are shown in Table 19.

Table 19. Co-created and statewide TSB

TSB Basis	TSB
TSB "attributed" to CalMTA (IOU service territory only, and excludes program verified units)	595
Co-created TSB (IOU service territory only, and includes program verified units)	724
Statewide TSB (statewide and excludes PA-verified savings)	807
Co-created Statewide TSB (statewide and includes program verified units)	983

9.2.7 Scenario analysis

As described in the Fuel substitution scenarios and Additional TMA fuel , CalMTA used the AAFS2 scenario to inform the BMA forecast. CalMTA also forecasted market adoption, TSB, and cost effectiveness using the AAFS1 and AAFS3 scenarios. The TSB and cost-effectiveness analysis results of these alternative scenarios, compared to the primary case, are shown in Table 20 below.

Table 20. MTI cost-effectiveness estimates, 2025-2046

AAFS Scenario	Scenario Description	TSB ($M)	TRC	PAC	Base SCT	High SCT
AAFS1	Slower fuel substitution: 50% by 2040	793	3.82	27.36	5.57	5.72
AAFS 2 **Primary Case**	Moderate fuel substitution: 100% by 2040	595	2.65	20.52	3.23	3.47
AAFS3	Faster fuel substitution: 80% by 2030; 100% by 2040	593	2.55	20.47	3.07	3.32

As shown in Table 20, the MTI is forecast to be cost effective under all three AAFS scenarios. The MTI forecast indicates that the CRTU MTI is substantially more valuable and cost effective under the slower fuel substitution scenario, and very similar to the primary case in the faster fuel substitution scenario. These findings underscore the fact that market transformation value is particularly valuable when policy solutions lag. In this case, the slower policy-driven fuel substitution increases the MTI's potential impact on adoption of efficient CRTUs.

9.2.8 Sensitivity analysis

To assess the impacts of risks identified in Appendix G. Risk Management Plan, CalMTA ran six sensitivity analyses. These sensitivity analyses evaluated the impact on MTI incremental adoption and cost effectiveness of changing these MTI performance-related inputs:

1) Lower MTI impact on AVP and availability
2) Lower incremental fuel substitution
3) Combination of (1) and (2), and lower assumed reduction in price premium
4) Lower Tier 1 CRTU energy impacts
5) Slower Tier 1 CRTU market adoption in the TMA forecast
6) Additional Incremental Software Costs

CalMTA ran these six sensitivity analyses for the primary AAFS2 scenario forecast, as described in Table 21.

Table 21. Sensitivity Analyses

Sensitivity Analysis	Variables Adjusted	Description/Rationale for Adjustment
1)	AVP and Availability	Assumes half the rate of increase from BMA to TMA Reflects the risk that the MTI may be less successful at addressing the key barriers of awareness of value proposition (AVP) and availability
2)	Incremental Fuel Substitution	Assumes no incremental fuel substitution above the AAFS scenarios Reflects the fact that FS is not the primary focus of the MTI and that there may be resistance to FS
3)	Combination of: AVP and Availability (1) and Incremental fuel substitution (2), and lower assumed reduction in price premium	Assumes (1) and (2) above, and half the reduction in price premium for Tier 2 and Tier 3 CRTUs relative to code-minimum products. Reflects the risk that price premiums for Tier 2 and 3 units vs. code minimum units may not fall from 60% to 30% over the MTI lifetime, as assumed – and may only fall from 60% to 45%.
4)	Tier 1 CRTU energy impacts	Assumes energy impacts for Tier 1 CRTU are only 62% of the value assumed in the primary analysis Reflects the risk that not all faults detected by CCC will be fixed
5)	Tier 1 CRTU market adoption timing in the TMA forecast	Assumes Tier 1 CRTU market adoption takes an additional three years to: reach 20% (2035 vs. 2032); and to reach its peak (2039 vs. 2036) Reflects the risk that market acceptance of CCC offered as part of standard code minimum equipment will be slower than anticipated
6)	Additional Software Costs	Assumes additional costs for monthly subscription software for fault detection and monitoring for Tier 1 and Tier 3 equipment

The results from the five sensitivity analyses are shown below in Table 22.

Table 22. MTI cost-effectiveness estimates, 2025-2046 – sensitivity analysis

Sensitivity Analysis	TSB	TRC	PAC	Base SCT	High SCT
1) AAFS 2 Primary Case	595	2.65	20.52	3.23	3.47
2) Decreased AVP and Availability	403	2.70	13.89	3.35	3.59
3) No Incremental Fuel Substitution	521	2.35	17.98	2.75	3.02
4) Combination (1) and (2), and lower Price Premium Reduction	308	2.00	10.62	2.30	2.53
5) Lower Tier 1 CRTU energy impacts	596	2.54	20.56	3.06	3.31
6) Slower Tier 1 Market Adoption	613	2.51	21.14	3.05	3.29
7) Additional Software Costs	595	1.94	20.52	2.26	2.43

Additional context and summary findings for each of the five sensitivity analyses follows, below.

1) Decreased AVP and availability

The Availability and AVP constraints are expected to relax in the TMA as the MTI increases awareness of the value proposition for efficient CRTUs and availability of Tier 1, Tier 2, and Tier 3 CRTUs in the market. The sensitivity analysis modeled adoption assuming AVP increased only half as much above BMA as shown in Figure 6 and Figure 7, which compare AVP constraints between TMA and BMA. Additionally, the sensitivity analysis assumed Availability increased half as much as shown in Figure 8 through Figure 10, which compare the TMA and BMA Availability constraints for each of the CRTU Tiers.

Compared to the primary case, the added constraints in Availability and AVP led to a decrease in total TSB from $595 million (Table 23) to $403 million and a slight improvement to the TRC ratio (Table). While *total* adoption decreases, there is a stronger preference for less expensive Tier 1 products compared to Tier 2 and Tier 3 products, leading to lower average incremental measure cost relative to savings. This produces a lower overall TSB, while generating a slightly higher TRC ratio.

Table 23. MTI cost-effectiveness estimates, 2025-2046: sensitivity analysis 2: decreased AVP and availability scenario

Sensitivity Analysis	TSB	TRC	PAC	Base SCT	High SCT
Primary Case	595	2.65	20.52	3.23	3.47
1) Decreased AVP and Availability	403	2.70	13.89	3.35	3.59

2) No incremental fuel substitution

The MTI expects to drive a small amount of incremental fuel substitution, as shown in Figure 13. The sensitivity analysis with respect to fuel substitution assumed that the MTI drives no incremental fuel substitution beyond the rate of gas phase out in the AAFS2 scenario.

Compared to the primary case, the removal of any incremental fuel substitution reduces TSB from $595 million to $521 million, and the TRC ratio decreases from 2.65 to 2.38. The main drivers of these differences are a reduction in incremental market adoption and higher incremental measure costs relative to energy savings based on greater proportional adoption of Tier 2 and Tier 3 products.

Table 24. MTI cost-effectiveness estimates, 2025-2046: sensitivity analysis 2 - no incremental fuel substitution

Sensitivity Analysis	TSB	TRC	PAC	Base SCT	High SCT
Primary Case	595	2.65	20.52	3.23	3.47
2) No Incremental Fuel Substitution	521	2.38	17.98	2.75	3.02

3) Combination (1) and (2), and lower price premium reduction

This sensitivity analysis combines the two previous sensitivity analyses with a lower reduction in price premium for all CRTUs relative to code-minimum products.

As described in 3.2.2, Technology costs, the MTI milestones indicate price parity by 2035 between code-minimum HP CRTUs and Tier 1 CRTUs. Additionally, the milestones indicate the price premium for Tier 2 and Tier 3 CRTUs relative to code-minimum HP CRTUs will decrease from 60% to 30% by 2040 via economies of scale as production increases.

The sensitivity analysis with respect to first-year costs modeled increased adoption if the MTI achieves only half the expected price reductions – the price differential between Tier 1 and code-minimum HP CRTUs is reduced by half but does not achieve price parity. The sensitivity analysis also assumes the price premium for Tier 2 and 3 CRTUs is reduced from the initial premium of 60% down to 45%, rather than the target of 30%, by 2040.

Compared to the primary case, this scenario results in a decrease in total TSB from $595 million to $308 million (Table 27) and a decrease in the TRC ratio (Table). The main driver of these changes came from the decrease in overall incremental adoption.

Table 25. MTI cost-effectiveness estimates, 2025-2046: sensitivity analysis 3 - Primary (AAFS 2) Scenario

Sensitivity Analysis	TSB	TRC	PAC	Base SCT	High SCT
Primary Case	595	2.65	20.52	3.23	3.47
3) Combination (1) and (2), and lower Price Premium Reduction	308	2.00	10.62	2.30	2.53

4) Lower Tier 1 CRTU energy impacts

One of the risks identified in the MTI Risk Management Plan is that end-users do not respond to faults as frequently as would be ideal. Although the MTI Plan includes activities to mitigate this risk, CalMTA ran this sensitivity analysis to quantify the impact of faults being repaired less frequently than assumed in the primary case. This sensitivity analysis assumes a reduction in estimated unit energy impacts associated with Tier 1 CRTUs by 38% compared to the primary case.

The lower assumed savings from Tier 1 products results in Tier 2 and Tier 3 products becoming more attractive from an economic standpoint. In this scenario, adoption of higher-tier products increases while adoption in Tier 1 decreases. The net result is a small increase in TSB compared to the primary case ($596 million versus $595 million), but with a lower TRC ratio (2.54 versus 2.65), because Tier 1 products have lower incremental measure costs per unit of energy saved than Tier 2 and Tier 3 products.

Table 26. MTI cost-effectiveness estimates, 2025-2046: sensitivity analysis 4 - Primary (AAFS 2) Scenario

Sensitivity Analysis	TSB	TRC	PAC	Base SCT	High SCT
Primary Case	595	2.65	20.52	3.23	3.47
4) Lower Tier 1 CRTU Energy Impacts	596	2.54	20.56	3.06	3.31

5) Slower Tier 1 market adoption

One MTI risk is that it will take longer to overcome barriers to market adoption for Tier 1 efficient CRTUs. The impact of lower AVP, availability, and price premium reduction is quantified in analysis (3) above. In addition to scenario 3, CalMTA considered the impact of Tier 1 adoption increasing more slowly than planned in sensitivity analysis (5). In this analysis, Tier 1 market adoption is assumed to increase more slowly and peak in 2039, three years later compared to the primary case.

Similar to the previous analysis, slowing Tier 1 adoption leads to greater relative adoption of Tier 2 and Tier 3 products. In this scenario, TSB increases relative to the primary scenario by roughly $18M while the TRC ratio falls. This is driven by the proportionally higher savings from Tier 2 and Tier 3 units generating higher TSB while increasing the relative incremental measure costs for each unit of energy saved. As adoption slows among Tier 1 products, TSB for those cases drop by approximately $40 million. However, TSB driven by Tier 2 and Tier 3 products increases by approximately $58 million, reflecting a modest increase in the number of consumers that choose Tier 2 and Tier 3 equipment.

Compared to the primary case, this scenario results in an increase in total TSB from $595 million to $613 million and a weaker TRC ratio, shifting from 2.65 to 2.51.

Table 27. MTI cost-effectiveness estimates, 2025-2046: sensitivity analysis 5 - Primary (AAFS 2) Scenario

Sensitivity Analysis	TSB	TRC	PAC	Base SCT	High SCT
Primary Case	595	2.65	20.52	3.23	3.47
5) Slower Tier 1 Market Adoption	613	2.51	21.14	3.05	3.29

6) Additional software costs

CalMTA estimated CRTU technology costs for each CRTU Tier, as summarized in Table 7. Based on available research, CalMTA assumed that the present value of costs associated with CCC software are included in the $700 incremental cost above code-minimum CRTUs. There is some uncertainty, however, regarding HVAC installers future business model regarding fault detection software and related services. To quantify the impact of potentially higher than assumed CCC software licensing costs, CalMTA ran a sixth sensitivity analysis including *additional* costs that might be associated with a subscription to remote fault detection and management package. These costs were assumed at $240 per year for Tier 1 and Tier 3 product packages.

In this sensitivity analysis, Tier 1 market adoption decreases by 4% and Tier 3 market adoption decreases by 5% because of the additional subscription costs making the economics slightly less favorable compared with code-minimum RTUs and Tier 2 CRTUs, which show an increased market adoption of 6%.

This scenario results in the same TSB as the primary case ($595 million) but a lower TRC ratio (1.94, down from 2.65) reflecting the higher assumed incremental costs.

Table 28. MTI cost-effectiveness estimates, 2025-2046: sensitivity analysis 6 - primary (AAFS 2) scenario

Sensitivity Analysis	TSB	TRC	PAC	Base SCT	High SCT
Primary Case	595	2.65	20.52	3.23	3.47
6) Additional Software IMCs	595	1.94	20.52	2.26	2.43

Attachment 1: Technology costs

CalMTA developed cost estimates for three tiers of efficient CRTUs and for baseline technologies of single-zone code-minimum HP RTUs and gas pack RTUs. The team developed estimates for individual cost components including equipment, installation and other costs to develop total estimates by technology tier. These cost estimates serve as the foundation for the incremental cost and cost-effectiveness analysis presented in the TSB and Cost-Effectiveness Analysis section. They represent CalMTA's best available estimates based on DOE and market characterization data, adjusted for California-specific labor, permitting, and technology cost factors.

Equipment

Commercial packaged rooftop units (CRTUs)

CalMTA estimated incremental first costs for 10-ton CRTUs using the DOE TSD[37] for commercial unitary air conditioners and heat pumps. CalMTA used the TSD, which provides nationally representative equipment and installation costs, as the basis upon which to estimate costs rather than relying solely on the cost estimates included in the CalMTA CRTUs Market Characterization Report, which relied on a single vendor quote for a variable-speed DOAS system[38] as a proxy for a Tier 3 efficient CRTU. As a result, the reported incremental cost estimate of $3,800 per ton likely overstates actual costs and does not reflect the wide variability in market pricing by application and distribution channel.

The DOE TSD defines Efficiency Levels (ELs) – EL1, EL2, EL3, and higher tiers – as its own framework for modeling cost and performance improvements; EL4 aligns most closely with the program's Tier 3 measure definition of roughly 20% higher efficiency, including the cost of the variable speed drive (inverter). These DOE EL designations are separate from the program's previously described tier structure.

Because DOE's TSD reflects mature-market pricing and does not provide a method for estimating early-market premiums, CalMTA applied a 35% equipment cost adder to the estimated cost of a 10-ton CRTU that is 20% higher efficiency than code-minimum CRTUs, based on a 2022

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[37] *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Air-Cooled Commercial Unitary Air Conditioners and Commercial Unitary Heat Pumps.* Published in April 2024 as part of DOE rulemaking docket EERE-2022-BT-STD-0015. https://downloads.regulations.gov/EERE-2022-BT-STD-0015-0096/content.pdf.

[38] A Dedicated Outdoor Air System (DOAS) is designed primarily to provide 100% outdoor ventilation air, with integrated energy recovery and advanced control sequences to manage temperature, humidity, and ventilation independently from the main HVAC system. The unit and price quote referenced in the CalMTA market characterization included advanced controls features and internet connectivity for remote monitoring and configuration, which contribute to higher equipment costs relative to standard variable speed HP RTUs intended for packaged rooftop applications.

Slipstream study[39] indicating that emerging HP CRTUs can carry 20% to 50% higher first costs than mature-market expectations.

DOE's TSD develops cost estimates for air-cooled unitary air conditioners (ACUAC) paired with gas furnaces and air-cooled unitary heat pumps (ACUHP) with electric heat. The TSD estimates costs for 7.5-, 15-, and 30-ton CRTUs representing small, large, and very large equipment classes. Each higher DOE efficiency level represents incremental performance gains; for example, EL4 represents about a 25% IEER improvement enabled by design options such as variable speed compressors and inverter technologies. Installation costs are assumed independent of efficiency level and are based on the total installed cost (TIC) framework,[40] which combines manufacturer production cost (MPC), market markups (including sales tax), and labor/material installation pricing updated from DOE's 2016 methodology using BLS indices.[41]

Table 1 shows the baseline and incremental markup multipliers applied to convert manufacturer production cost (MPC) estimates into consumer purchase prices. DOE's methodology distinguishes between two components:

- **Baseline markup** – This is the multiplier that converts the MPC of baseline-efficiency equipment (after applying the manufacturer markup) into the end-user purchase price under existing market distribution practices.
- **Incremental markup** – This is the multiplier applied only to the incremental cost (i.e. MPC increase) required to reach higher-efficiency performance levels. That increment is converted via this separate markup into the additional consumer cost.

The total consumer price for a high-efficiency unit is constructed as:

$$Consumer\ Price_{high} = \underbrace{\boxed{MPC_{base} \times Baseline\ Markup}}_{\text{Baseline Consumer Price}} + \underbrace{\boxed{(MPC_{high} - MPC_{base}) \times Incremental\ Markup}}_{\text{Incremental Cost to Consumer}}$$

The rationale for separating the markups is that fixed business overheads, sales and administrative costs, and non-scalable channel costs do not increase proportionally with

[39] Hackel, S., Marsicek, G., Schuetter, S., Bridgeland, B., and Tilak, A. (2022). *The Present and Future of Decarbonizing through Electrification in Commercial Buildings in the Midwest. Slipstream & Rocky Mountain Institute. Sustainable Energy Action.* https://sustainableenergyaction.org/wp-content/uploads/2023/03/Commercial-Biulding-Electrification-in-the-Midwest-Slipstream-and-RMI.pdf

[40] DOE defines the Total Installed Cost (TIC) framework in its Technical Support Document for Commercial Packaged Air Conditioners and Heat Pumps (Chapter 5: Engineering Analysis, U.S. Department of Energy, 2023), which outlines how manufacturer costs and market markups are combined to estimate end-user equipment costs.

[41] DOE updates installation labor and material costs using Bureau of Labor Statistics (BLS) Producer Price Indices for relevant mechanical equipment and construction labor categories, consistent with its methodology documented in the Commercial Packaged Air Conditioners and Heat Pumps Technical Support Document (Chapters 8 and 10, U.S. Department of Energy, 2023).

incremental equipment cost; thus, DOE treats the markup applied to the increment more conservatively. The markup multipliers (baseline and incremental) are themselves derived as weighted averages across distribution channels (e.g., national account, wholesaler, contractor) and include the effect of sales tax.

To align with the CRTU size class that represents the MTI's target market (10-ton CRTU), CalMTA converted the available TSD 7.5-, 15-, and 30-ton estimates to cost per ton, and then used a weighted average to derive costs for a typical 10-ton CRTU[42] represented in bold text in Table 1. These estimates for 10-ton units form the basis of the installation and equipment first-cost estimates presented. CalMTA's approach to estimating installation costs is discussed in the next section, Installation. Table 1 presents equipment-only costs for baseline gas CRTUs, baseline HP CRTUs, and the +20% efficient HP CRTU; it excludes add-on components (e.g., VSDs, CCC) that are incorporated later in the technology-tier cost estimates. The total equipment costs for each technology tier, including costs for VSD and CCC, are addressed in the following section, Equipment cost by technology tiers.

Table 1. Baseline equipment and +20% efficient variable speed HP CRTU equipment and installation cost estimates

Component	Description	Tons	Gas Baseline: ACUAC (IEER 14.8/IVEC 10.6)	Code-Minimum HP: ACUHP (IEER 14.1/IVEC 10.1/IVHE 6.0)	Tier 3 Basis: ACUHP EL4 (IEER 18.1/IVEC 12.9/IVHE 7.3)
Manufacturer Production Cost (MPC)*	The cost to manufacture the unit, based on teardowns and modeling.	7.5	$4,708	$5,162	$5,993
		15	$6,233	$6,847	$7,808
		30	$12,435	$13,663	$18,704
Total Equipment Price (MPC × AvgMarkup)	The consumer purchase price for the equipment, before installation. Uses average overall markup weighted across replacement distribution	7.5	3.00**	3.00**	2.90**
			$14,118	$15,486	$17,395
		15	2.80**	2.80**	2.73**
			$17,452	$19,172	$21,333
		30	2.64**	2.64**	2.47**
			$32,828	$36,070	$46,136

[42] Weighted average assuming 80% 7.5 ton, 13% 15-ton, and 7% 30-ton

Component	Description	Tons	Gas Baseline: ACUAC (IEER 14.8/IVEC 10.6)	Code-Minimum HP: ACUHP (IEER 14.1/IVEC 10.1/IVHE 6.0)	Tier 3 Basis: ACUHP EL4 (IEER 18.1/IVEC 12.9/IVHE 7.3)
	channels. For higher efficiency: Baseline MPC × Baseline Markup + Incremental MPC	**10**	**$15,861**	**$17,406**	**$26,890**[43]
Installation Cost	Total cost for installation, including labor, materials (e.g., ductwork, piping, curb), overhead, profit, commissioning, and engineering design. Derived as the difference between TIC and equipment price. Assumes similar for ACUHP, but slightly higher due to potential differences in configuration.	7.5	$4,554	$4,619	$4,619
		15	$6,986	$7,367	$7,367
		30	$13,911	$14,640	$14,640
		10	**$6,685*** **	**$6,870*** **	**$6,870*** **

*DOE TSD Packaged Air Conditioners and Heat Pumps (2023) Tables 5.8.1-5.8.6
** Total average Manufacturer Production Cost (MPC) multiplier
***Adjusted by installation index factor (INST) of 1.21 (see discussion below).

While Table 1 presents the equipment and installation cost estimates, the derivation underlying the costs warrants further explanation:

- The DOE TSD specifies a set of replacement-specific markups that reflect how packaged CRTUs move through the supply chain, from manufacturer to wholesaler to mechanical contractor, before reaching the customer. These markups vary by equipment size and efficiency level, with incremental markups generally lower than baseline markups due to economies of scale and established distributor pricing practices.
- For the program analysis, CalMTA applied DOE's replacement-specific markups using a 50/50 weighting of large and small contractors. This approach recognizes that both large mechanical firms and smaller local contractors play a role in the replacement market.

[43] Estimate derived was $19,919, then marked up by a factor of 1.35.

- The incremental markups are critical because they directly influence the consumer purchase price of above-code HPs relative to baseline systems and therefore drive the total installed cost differential that underpins the incremental cost analysis.

Table 2 shows both baseline and incremental multipliers used to compute the consumer purchase price of higher-efficiency equipment for each size class (and efficiency level). Differences between the baseline and incremental multipliers reflect DOE's assumption that not all cost increases should bear full proportional markup. Sales tax is applied consistently across baseline and higher-efficiency equipment. The combined effect of these assumptions produces overall markup multipliers that decrease with equipment size, reflecting the lower relative transaction costs and economies of scale for larger units.

Table 2. Markup table for baseline and higher efficiency CRTUs (replacement scenario)

Distribution Channel Segment	7.5-ton		15-ton		30-ton	
	Baseline Markup	Incremental Markup	Baseline Markup	Incremental Markup	Baseline Markup	Incremental Markup
Manufacturer	1.30	1.18	1.31	1.18	1.32	1.18
Wholesaler	1.403	1.177	1.403	1.177	1.403	1.177
Mechanical Contractor (large/small)	1.416 / 1.53	1.227 / 1.23	1.35 / 1.47	1.20 / 1.21	1.29 / 1.41	1.16 / 1.17
Sales Tax	1.07	1.07	1.07	1.07	1.07	1.07
Overall Markup (large/small contractor)	3.19 / 2.78	2.32 / 2.02	2.99 / 2.61	2.23 / 1.95	2.82 / 2.46	2.12 / 1.85

Source: DOE TSD Packaged Air Conditioners and Heat Pumps (2023) Sections 5.7, 6.5, 6.7.

Equipment cost by technology tiers

Tier 1 equipment costs

As seen in Table 1, the cost of a 10-ton code-minimum unit is $17,406. The Tier 1 technology definition includes the incremental costs associated with CCC capabilities. The incremental cost of advanced controllers was assumed to be $700 per unit, resulting in a total estimated cost for Tier 1 equipment of $18,106. The $700 estimate was based on the information provided in the CalMTA CRTUs Market Characterization Report (p. 100, Table 11).[44] CalMTA assumed this cost

[44] CalMTA. (2025). CRTUs Market Characterization Report. Market-Characterization-Report-Commercial-Rooftop-Units1.pdf

includes equipment costs as well as the present value of incremental costs associated with maintenance and ongoing repairs resulting from the CCC capabilities.

Tier 2 equipment costs

The Tier 2 configuration achieves the same +20% efficiency improvement as Tier 3 but does not include a VSD or CCC. To isolate the incremental cost effect of the VSD and CCC, while maintaining identical efficiency performance, CalMTA derived the Tier 2 cost of $22,301 by subtracting the cost of the VSD and CCC from the Tier 3 cost of $27,590. The team used the per-ton cost of $457 reported in the CalMTA CRTUs Market Characterization Report as the basis for deriving VSD costs and then used a weighted average to derive costs for a typical 10-ton CRTU.[45] This adjustment ensures that Tier 2 and Tier 3 are modeled with equivalent efficiency assumptions, differing only by the cost associated with the VSD and CCC.

Tier 3 equipment costs

The Tier 3 equipment cost was developed starting from the DOE's TSD-derived EL 4 equipment cost ($19,919) and multiplied by 1.35, arriving at $26,890 (see Table 1) to reflect the higher first costs of emerging HP CRTUs relative to DOE's TSD mature-market estimates, consistent with the 2022 Slipstream study indicating a 20% to 50% early-market cost premium. This results in a Tier 3 equipment cost of $27,590 after applying the CCC cost of $700.

Tier 3 represents the highest efficiency level evaluated—defined as approximately 20% above the baseline heat pump efficiency—and incorporates VSD technology and CCC. DOE's TSD EL4, which aligns closely with Tier 3, does not explicitly specify inclusion of a VSD; however, given the design options needed to achieve EL4-level performance, it is very likely that a VSD is integrated. Accordingly, CalMTA assumed the Tier 3 cost estimate reflects a system that includes a VSD.

Installation

Installation cost adjustments were applied selectively to align DOE's national cost framework with California labor and material conditions. DOE's TSD develops regional cost indices using RSMeans city factors for labor (INST) and materials (MAT), which CalMTA used to tailor installation costs to California market conditions while maintaining consistent installation hours across efficiency tiers. Note that theTSD's methodology includes slightly higher labor requirements for tiers above code minimum, which in practice equates to roughly one additional hour of labor for the efficient tiers. This results in an incremental labor cost difference of $185 relative to the code-minimum CRTU.

- **Labor costs:** Installation requirements (i.e., number of labor hours) were assumed to be the same for baseline and higher-efficiency CRTUs; however, California labor rates are higher than

[45] A weighted average of 10.05 tons was used in CalMTA's equipment cost estimation (assumed 80% 7.5 ton, 13% 15-ton, and 7% 30-ton). The resulting cost estimate for the VSD was $4,589 for a 10-ton RTU.

the national average. To reflect this, CalMTA applied the San Diego labor installation index (INST = 1.21)[46] to the labor portion of DOE's national installation cost.

- **Materials costs:** RSMeans data for San Diego[47] show a materials index (MAT) of 100.3, effectively equal to the national average. Because this deviation is negligible, no material cost adjustment was applied.

As a result, installation costs in this analysis incorporate a 1.21 multiplier on labor but no adjustment to materials, maintaining parity in labor effort while accounting for California's higher labor rates. This approach ensures incremental first-cost differences reflect realistic California market conditions without overstating regional variation.

Permitting

Unlike installation costs, permitting costs could not be drawn directly from DOE's TSD because the TSD does not provide a way to estimate the labor hours associated with plan review and permitting. Instead, CalMTA reviewed permit fee schedules from several California jurisdictions to establish representative costs for CRTU replacements. The following sources and values were used to inform the analysis:

- City of Los Angeles – Mechanical/HVAC permit costs ranged from $2,600–$3,000 for single RTU replacements and $1,600–$1,800 for multiple-unit projects.[48]
- City and County of San Francisco – Approximately $400 for a single RTU and $200 for each additional unit.[49]
- City of Sacramento – $350–$400 for single RTU replacements and $200–$300 for additional units.[50]

[46] "INST" refers to the RSMeans City Cost Index installation location factor for San Diego (installation labor/equipment relative to the U.S. average (1.00). CalMTA applied this city-specific installation factor to scale DOE's national installation cost; DOE's TSD does not publish a San Diego-specific factor. See "City Cost Indexes – V2, RJ1030-010 Building Systems" Available at: https://www.rsmeans.com/media/wysiwyg/quarterly_updates/2021-CCI-LocationFactors-V2.pdf

[47] RSMeans City Cost Index (CCI). (2021). Q2 Update. Gordian (RSMeans Data Online), Table "MAT.INST.TOTAL Index – San Diego, CA." Available at: https://www.rsmeans.com/media/wysiwyg/quarterly_updates/2021-CCI-LocationFactors-V2.pdf

[48] City of Los Angeles Department of Building and Safety, Mechanical/HVAC Permits. Available at: https://dbs.lacity.gov/services/plan-review-permitting/mechanical-hvac-permits

[49] City and County of San Francisco Department of Building Inspection, Table 1A-C – Plumbing/Mechanical Issuance & Inspection Fees (2025). Available at: https://media.api.sf.gov/documents/Table_1A-C_-_PlumbingMechanical_2025.pdf

[50] City of Sacramento Community Development Department, Building Fees. Available at: https://www.cityofsacramento.gov/community-development/building/building-fees

- County of San Diego – $356 base permit fee, with a 65 % plan-review surcharge applicable for heat-pump conversions, based on a project valuation under $50,000.[51]

Los Angeles exhibited the highest commercial HVAC permitting costs, while San Francisco, Sacramento, and San Diego were significantly lower. To balance these extremes, San Diego's schedule was selected as the representative basis for the analysis. Specifically, the analysis assumed:

- A $374 base permit fee (projects <$50k valuation);
- A 1.65 multiplier to account for the plan review surcharge required for all heat pump conversions;
- A permit-related subtotal of approximately $620; and
- An additional five hours of labor at $195/hr to reflect additional design and permitting effort for heat pump conversions.[52]

Together, these assumptions result in a total permitting cost of about $1,590 per project for HP CRTU replacements. One exception is the baseline CRTU with AC and gas heat. A code-minimum replacement would not typically require additional plan review or design work, so the analysis assumed only the base $374 permit fee with no 65% plan review markup specifically for HP CRTU upgrades and no additional labor for permit application process. This approach ensures permitting costs reflect realistic jurisdictional practices while keeping incremental cost differences tied to the added complexity of heat pump conversions.

Electrical upgrades

In addition to equipment, installation, and permitting, CalMTA considered the potential need for electrical service upgrades when replacing a gas CRTU with a heat pump. To estimate this cost impact, CalMTA reviewed data from the California Commercial End-Use Survey (CEUS),[53] which provides CZ–specific building characteristics and design conditions. The CEUS indicates that approximately 22.5% of commercial buildings in California are in CZs with winter design temperatures below 35 °F. These colder zones are more likely to require higher electric service capacity when switching from gas to electric heating. Based on engineering judgment and review of typical service conditions, we assumed that about 25% of these buildings would require some level of electric panel or service upgrade to support a heat pump retrofit. This equates to roughly 5% of all commercial buildings statewide (22.5% × 25% ≈ 5%).

[51] County of San Diego Planning & Development Services, Form PDS 613 – Fee Schedule for Building Permits. Available at: https://www.sandiegocounty.gov/pds/docs/pds613.pdf

[52] Engineering estimate for labor in TSD of $160/hr adjusted by 1.21 for California labor prices
2025 California Energy Code Technical Measure Report for Nonresidential HVAC Heat Pump Baseline Measures (p. 34). https://efiling.energy.ca.gov/GetDocument.aspx?tn=255318-3&DocumentContentId=91006

[53] https://www.energy.ca.gov/data-reports/surveys/2006-california-commercial-end-use-survey-ceus

For buildings that do require upgrades, cost estimates were taken from the 2025 California Energy Code Technical Measure Report: Nonresidential HVAC Heat Pump Baseline Measures,[54] which reports a $4,200–$6,000 range for typical electric service upgrades associated with HVAC heat pump conversions. We used the midpoint of this range (~$5,100) as a representative upgrade cost. Because only ~5% of projects are expected to incur this cost, we applied a 5% probability factor to the $5,100. This approach yields a $255 average cost estimate per CRTU to account for the small share of installations that would require electrical upgrades while avoiding overinflating the typical project cost for the broader market.

[54] https://efiling.energy.ca.gov/GetDocument.aspx?tn=255318-3&DocumentContentId=91006, p. 21.

Attachment 2: Documentation of unit energy savings and avoided cost calculations for commercial rooftop units

This document is a reference of the scenarios 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 CRTU MTI.

Product information

The MTI-proposed products considered are defined as single-zone rooftop heat pump units with between 3 and 20 tons of cooling capacity that exceed the federal minimum cooling efficiency by at least 20%. The product leverages sensors, analytics, cloud-connectivity, and simple, app-based tools to:

- Increase installed efficiency through improved startup, commissioning, and compliance with Title 24 Acceptance Testing requirements;
- Optimize long-term operational efficiency through predictive analytics and machine learning;
- Increase load flexibility and occupant comfort through integration of weather data, utility DR signals, and thermal load data; and
- Remotely monitor RTU performance to detect, diagnose, and resolve faults by providing alerts to owners and actionable information to HVAC technicians.

The two main baseline equipment technologies are mixed fuel RTUs and HP RTUs without enhanced connectivity and controls.

Baseline equipment

For normal replacement,[55] we consider mixed fuel RTUs and all-electric RTUs each without enhanced connectivity and controls. For both systems, baseline RTU properties and efficiencies were derived to match the code-minimum efficiency requirements of California Title 24 Part 6, 2022. For the all-electric system, we assumed electric resistance for back-up supplemental heat. A set-point based on outdoor air temperature is included to prevent back-up heat from excessively operating. A compressor lockout based on outdoor air temperature was also implemented for all-electric systems disabling the compressor and only using back-up heat below that temperature.

[55] The MTI only considers opportunities in existing buildings and, thus, does not consider new construction.

Table 1. Baseline RTU efficiency levels and design characteristics

Characteristic	Mixed Fuel (GF_Baseline)	All Electric (AE_Baseline)
Heating efficiency (AFUE, COP)	81%	3.64
Cooling efficiency (COP)	3.9	3.9
HVAC Heating Sizing Factor	1.25	1.25
HVAC Cooling Sizing Factor	1.15	1.15
HRV/ ERV Included	No	No
Fan Efficiency (%)	60%	60%
Fan Speed	2-Speed	2-Speed
Compressor Speed	2	2
Backup Heat Availability Setpoint	N/A	35°F
Compressor Lockout Setpoint	N/A	25°F
Backup Heat Element	N/A	Electric Resistance
Enclosure Insulation R-Value	2	2

Proposed equipment

The proposed equipment matches the MTI product definition of a high efficiency HP RTU with enhanced controls and capabilities. As stated above, mechanical heating and cooling efficiencies exceed the federal minimum by 20%. The HP is equipped with a variable capacity compressor and a variable speed fan.

Connected commissioning ensures equipment is operating as designed and intended. Enhanced control strategies can require in-depth commissioning; because the level of sophistication of installation personnel will vary, connected commissioning ensures equipment is operating as designed and intended.

Remote monitoring and automated fault detection diagnostics identify performance deficiencies that will occur over time. CRTUs are likely to encounter numerous faults throughout the equipment lifetime. Table 2 categorizes many common faults for commercial RTUs and qualitatively summarizes whether common faults in each category have a direct or indirect impact on equipment performance. Faults that are included in the modeled cases are also noted in Table 2.

Table 2. Summary of common RTU faults

Fault Category	Common Faults	Impact on Equipment Performance	CalMTA Modeled Savings
Economizer Faults	Damper stuck, incorrect OA/RA mixing, damper leakage, damper limit, excess outside air	Direct	Yes (damper stuck and temperature limit)
Condenser and Coil Fouling	High condenser temperatures/pressure, increased recovery time	Direct	Yes
Refrigerant Faults	Over or under charged, non-condensables	Direct	No
Cooling/Heating Faults	Set point faults, combustion air switch, high heating limit, freeze state, compressor lockout, etc.	Direct	No
Airflow Faults	Dirty or blocked filters, fan motor faults, duct leakage, low airflow	Direct	No
Sensor Faults	Temperature, humidity, pressure, CO_2, airflow sensor failures	Direct and indirect	No
Compressor Faults	Pressure/temperature limits, abnormal current signatures, short cycling	Direct	No
Communication Faults	BACNET, MODBUS, office, etc.	Indirect	No
Power/Phase Fauls	Power loss, phase loss, etc.	Direct and indirect	No
Other	Control and set point errors, sequencing errors, schedule problems, mode mismatch, software issues, smoke alarms, control boards, and more	Direct and indirect	Yes (schedule problems)

The prevalence, incident frequency, and persistence of all the common individual faults is not comprehensively understood or easily quantified. Empirical evidence indicates faults are prevalent and frequently observed across substantial portions of monitored equipment (20% to

50%).[56,57,58,59,60,61] The frequency of fault incidents varies, but studies have shown daily faults occurring on 40% of monitored air handling unit equipment. The impact on energy consumption from faults is directly related to how long faults persist before intervention. Select empirical evidence and simulation studies indicate faults that persist impose a wide range of energy penalties that can be substantial (from single to two-digit percentage energy penalties), especially when unaddressed or undiagnosed for extended periods of time.

The persistence of faults that remain unaddressed or undiagnosed can produce substantial degradation in system performance, increase operational costs, and in severe cases, contribute to premature equipment failure. Without comprehensive existing studies or data, estimating the prevalence, frequency, and persistence of various individual faults for CRTUs across California is difficult to quantify and would be overburdened by assumptions including a range of operational, organizational, and maintenance-related considerations.

As summarized in Table 2, a subset of specific faults have been evaluated, but not all. The modeling approach is not intended to be comprehensive, nor designed to reflect a distribution of individual faults. Rather, those faults selected and modeled are meant to be representative in aggregate of the potential cumulative impact across with the myriad of faults that CRTUs are likely to encounter, without resolving the contribution of each fault. There are potential savings not captured by the specific modeled cases so that the aggregated estimates are not overly optimistic. For example, refrigerant charge faults are not directly modeled for savings but can cause a cascade effect that reduces RTU capacity, lowers efficiency, and in extreme situations, can lead to unstable equipment cycling. Laboratory and field-survey studies report that

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56 Kim, J., Trenbath, K., Granderson, J., Chen, Y., Crowe, E., Reeve, H., Newman, S., and Ehrlich, P. (2021). "Research Challenges and Directions in HVAC Fault Prevalence." Science and Technology for the Built Environment 27 (5): 624–40. doi:10.1080/23744731.2021.1898243.

57 Shoukas, G., Bianchi, M., and Deru, M. (2020). Analysis of Fault Data Collected from Automated Fault Detection and Diagnostic Products for Packaged Rooftop Units. Tech. rep. National Renewable Energy Laboratory, Sept. 2020. https://doi.org/10.2172/1665808. https://www.osti.gov/biblio/1665808.

58 Crowe, E., Chen, Y., Granderson, J., Reeve, H., Troup, L., Yuill, D., and Chen, Y. (2022). "What We Learned From Analyzing 18 Million Rows of Commercial Buildings' HVAC Fault Data." In 2022 Summer Study on Energy Efficiency in Buildings. Aug. 2022. https://www.osti.gov/biblio/1889192.

59 Katipamula, S., Underhill, R.M., Fernandez, N.E., Kim, W., Lutes, R.G., and Taasevigen, D.J. (2021). "Prevalence of typical operational problems and energy savings opportunities in U.S. commercial buildings." Energy and Buildings 253. December. https://doi.org/10.1016/j.enbuild.2021.111544. https://www.osti.gov/biblio/1829706.

60 Crowe, Eliot & Chen, Yimin & Reeve, Hayden & Yuill, David & Ebrahimifakhar, Amir & Chen, Yuxuan & Troup, Lucas & Smith, Amanda & Granderson, Jessica. (2023). Empirical Analysis of the Prevalence of HVAC Faults in Commercial Buildings. Science and Technology for the Built Environment. 29. 1-15. 10.1080/23744731.2023.2263324.

61 Katipamula, S., Kim, W., Lutes, R., Underhill, R.M. (2015). "Rooftop unit embedded diagnostics: automated fault detection and diagnostics (AFDD) development, field testing and validation. Pacific Northwest National Laboratory. Richland, WA. PNNL-23790. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23790.pdf.

undercharging a system by even 25% can lead to an average reduction in 20% cooling capacity and a 15% reduction in energy efficiency.[62]

The faults evaluated for energy savings include two common economizer faults, condenser coil fouling, and scheduling alterations. The models quantify the impact of these selected faults on an annual basis to bound annual energy impacts. Fault occurrence probabilities and assumptions that adjust the modeled outputs for each fault are discussed in a later section and are summarized in Table 9.

The HP RTU is controlled with a demand response thermostat capable of responding to signals to adjust the temperature set point during event periods when the grid is impacted.

Energy modeling software

The open-source DOE building energy modeling software, EnergyPlus (version 22.1), was used in this work. A custom template was created to allow Modelkit to control the input parameters needed to implement the baseline single-zone RTU systems and efficiency measure included in the analysis. 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. In this case, the simulations are set to run with six timesteps per hour. Each savings shape is an 8,760 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[62] with ASHRAE 90.1-2004 DOE reference building models to represent typical commercial buildings[63] with single-zone RTUs that would be replaced rather than new construction. These models were selected as reasonable for defining an existing building construction set while also leveraging models available in EnergyPlus.

To simplify the analysis and comparability of results, the building envelope remains fixed to CZ6A, including exterior walls, roof, and fenestration. The prototypes selected for the analysis and provided visually in Figure 1 include:

- Quick service restaurant consisting of dining and kitchen spaces
- Warehouse with bulk and fine storage zones and one office space
- Primary school includes a diverse space type mix compared to other prototypes with classrooms, gym, kitchen, cafeteria, and corridors

[62] https://energyplus.net

- *Medium office consisting of a typical four perimeter zones and one core zone*
- Retail strip mall encompassing eight small stores and two larger stores each with individual thermal zones.

The medium office prototype was adapted to a single-story building to simulate a smaller office building. The system configuration for the warehouse prototype was modified to a single-zone RTU with thermostat control serving the bulk storage area, which matched the fine storage area. This modification allows a whole building assessment of a conditioned warehouse rather than a small fraction of the floor space.

Additional details on the prototype building area and the number of RTUs are provided in Table 3.

Figure 1. Buildings used for energy modeling

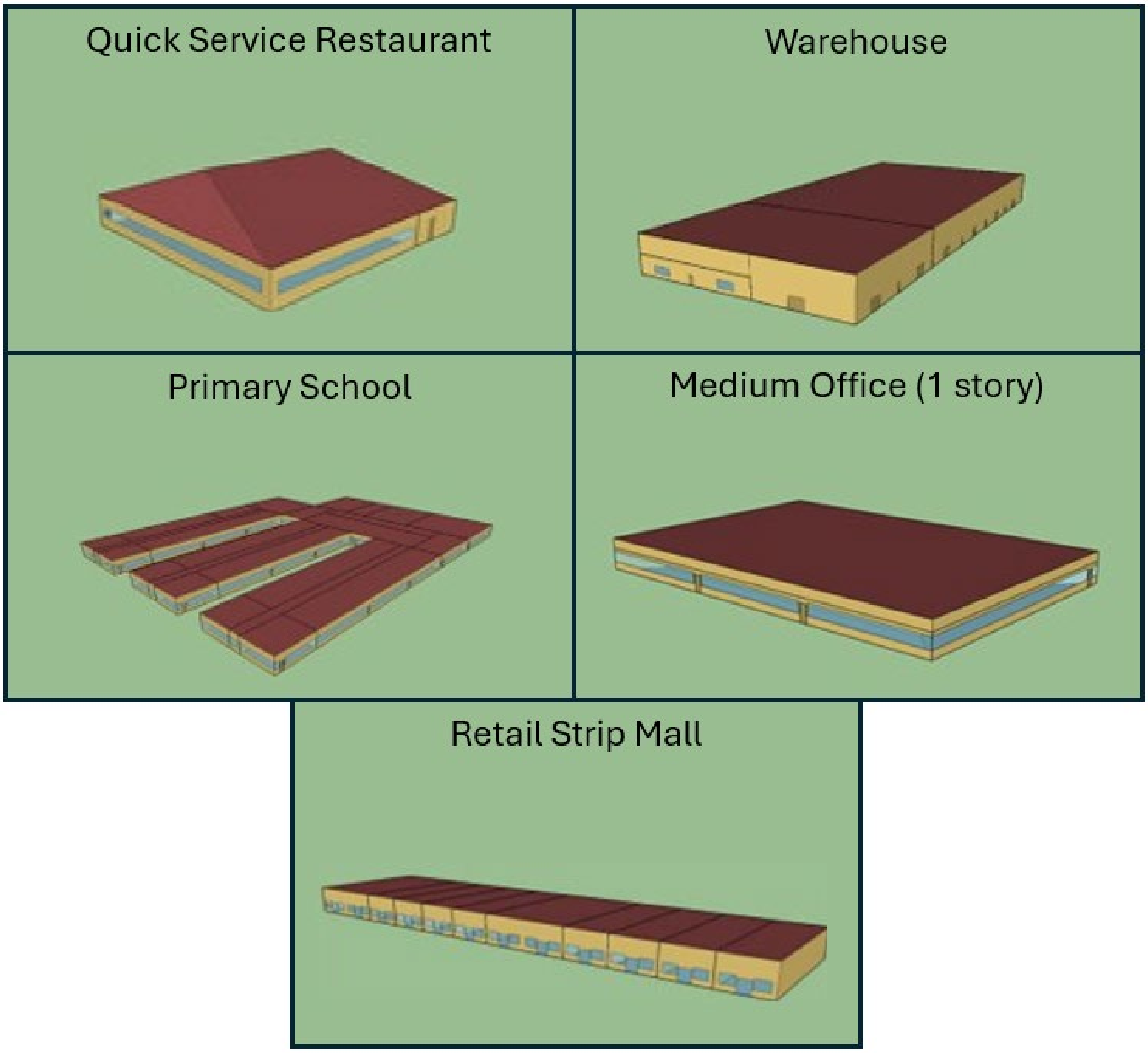

Table 3. Description of buildings used for energy modeling

Source	Code Vintage[64]	Type	Stories	Building Area [ft²]	Number of RTUs
DOE	2004	Quick Service Restaurant	1	2,500	2
DOE	2004	Warehouse	1	52,000	3
DOE	2004	Primary School	1	74,000	25
DOE	2004	Medium Office	1	17,000	5
DOE	2004	Retail Strip Mall	1	22,500	10

Case descriptions

The measures analyzed consisted of 20 different cases as shown in Table 4. Each case represents a specific equipment package, efficiency improvement, or fault behavior intended to represent some behavior of either a baseline or proposed installation case. Cases 1-12 represent all-electric (HP) RTUs, while cases 13-20 represent mixed fuel RTUs with a gas furnace.

Table 4. Summary of case characteristics

#	Case name	Case description	Case details
1	AE_Baseline	All electric baseline as described in Table 1	Cooling speed 1/2 COP: 3.9 / 4.13 Heating COP: 3.64 / 3.86[65]
2	AE_Baseline_RAS	All electric baseline without remote access scheduling	All Sundays are conditioned like Weekday (+1 conditioned day per week). *Restaurant switched to 24/7 conditioning.
3	AE_COP20	20% increase of the baseline heating and cooling COP	Cooling speed 1/2 COP: 4.68 / 4.96 Heating speed 1/2 COP: 4.32 / 4.58
4	AE_COP20_VS	Adding a variable speed compressor and fan to case #3	4-speed compressor for cooling and heating,[66] Cooling COP (all speeds): 4.21 Heating COP (all speeds): 3.89 Continuously variable fan

[64] Refers to the version of ASHRAE 90.1 DOE prototype buildings used. Some modifications were made to standard prototypes as discussed within the text.
[65] The COP values in this table are the gross-rated coil coefficient of performance values being input to EnergyPlus that do not include fan energy and are higher than the true system COP
[66] Four speeds is the limit for the EnergyPlus multi-speed DX coil object for both heating and cooling.

#	Case name	Case description	Case details
5	AE_ConnComCont	Controls fault where economizer malfunctions	No economizing and increased outdoor air for base heat pump RTU
6	AE_DamperLimit	Damper fault results in excess outside air (OA)	15% increase in OA for base heat pump RTU
7	AE_CoilFouling	Condenser coil fouling decreases heat transfer efficiency of heat pump	8.8% penalty on heating and cooling efficiency [20% condenser fouling]. [67]
8	AE_ConnComCont_RAS	Controls fault where economizer malfunctions with incorrect thermostat schedule	Combining the fault from case #5 with the increased conditioning schedule of case #2
9	AE_DamperLimit_RAS	Damper fault results in excess outside air (OA) with incorrect thermostat schedule	Combining the fault from case #6 with the increased conditioning schedule of case #2
10	AE_CoilFouling_RAS	Condenser coil fouling decreases heat transfer efficiency of heat pump with incorrect thermostat schedule	Combining the fault from case #7 with the increased conditioning schedule of case #2
11	AE_ERHeat45	Resistance heating used instead of heat pump below 45°F	Resistance heat at 45°F and compressor lockout at 45°F instead of compressor lockout at 25°F
12	AE_ERHeat45_RAS	Resistance heating used instead of heat pump below 45°F with incorrect thermostat schedule	Same as case #11 with the increased conditioning schedule of case #2
13	GF_Baseline	Mixed fuel RTU baseline as described in Table 1, with gas furnace	Cooling speed 1/2 COP: 3.9 / 4.13 Heating AFUE: 81%
14	GF_Baseline_RAS	Gas furnace baseline without remote access scheduling	All Sundays are conditioned like Weekday (+1 conditioned day per week). *Restaurant switched to 24/7 conditioning.
15	GF_ConnComCont	Controls fault where economizer malfunctions	No economizing and increased outdoor air for base heat pump RTU
16	GF_DamperLimit	Damper fault results in excess outside air (OA)	15% increase in OA for base heat pump RTU
17	GF_CoilFouling	Condenser coil fouling decreases heat transfer efficiency of heat pump	8.8% penalty on heating and cooling efficiency [20% condenser fouling].[67]

[67] https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23790.pdf

#	Case name	Case description	Case details
18	GF_ConnComCont_RAS	Connected commissioning and controls fault where economizer malfunctions combined with incorrect thermostat schedule	Combining the fault from case #5 with the increased conditioning schedule of case #2
19	GF_DamperLimit_RAS	Damper fault results in excess outside air (OA) combined with incorrect thermostat schedule	Combining the fault from case #6 with the increased conditioning schedule of case #2
20	GF_CoilFouling_RAS		Combining the fault from case #7 with the increased conditioning schedule of case #2

[1] References for baseline is 2022 Title 24 and measure case is product availability research

[2] Engineering judgment was used for the baseline and measure case characteristics

[3] Pacific Northwest National Lab Rooftop Unit Embedded Diagnostics: Automated Fault Detection and Diagnostics (AFDD) Development, Field Testing and Validation

HVAC properties

Within the five types of building models considered, we vary the heating and cooling systems and operational parameters to mimic the various cases listed in Table 2. Additional details on modeling techniques, where warranted, are provided in this section.

Baseline and proposed systems: cooling and heating efficiency levels

For cases #1 and #2, IEER cooling and heating efficiency improvement and baseline cooling efficiencies are from Title 24 2022 Table 110.2-A for both air conditioners and heat pumps. The EER of 11.2 was used and converted to a COP without fan energy of 3.9 COP (Gross Rated Cooling COP in EnergyPlus). For heating, the base heat pump heating efficiency of 3.4 COP was used and converted to a compressor only efficiency of 3.64 COP (Gross Rated Heating COP in Energy Plus). The baseline models used two-speed compressors, to account for increased efficiencies in the model for multi-speed compressors and additional speed options used a 6% increase in the rated COP efficiency. A two-speed fan was also used with a fan total efficiency of 60%.

Proposed system: variable capacity compressor and variable speed fan

Variable capacity compressor is modeled by using a four-speed compressor and continuously variable fans. The choice to use a four-speed compressor object in EnergyPlus was due to the additional complexity and assumptions needed to accurately model the fully variable speed compressor, specific part load curve performance data and other inputs would be required. The limit of modeling up to four speeds came from the EnergyPlus MultiSpeed DX coil object. The EnergyPlus four-speed object was used with a constant gross COP of 4.21 for cooling and 3.89 for heating. The fan was modeled as continuously variable natively in EnergyPlus with a fan total efficiency of 60%.

EnergyPlus objects:

- Coil:Cooling:DX:MultiSpeed

- Coil:Heating:DX:MultiSpeed
- Fan:SystemModel
    - Continuous, Speed Control Method

Baseline system: economizer fault

Inefficient economizing behavior was modeled with incorrect setpoints and increased outside air. This resulted in the inability for the outdoor air damper to fully close and operate effectively at all hours. The maximum limit outdoor air dry-bulb temperature was set to 60°F, effectively providing no economizing, and outdoor air was increased 20% above baseline outdoor air ventilation levels

Baseline system: condenser coil fouling

Research indicated that efficiencies of heating and cooling could be reduced by 8.8% when the coils on the condenser heat exchanger are fouled (Table 4). The model for low refrigerant charge simply implemented a reduced COP by 15% for both heating and cooling efficiency. This method allows the maximum impact to be assessed and appropriately weighted into further analysis.

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 Multiple Capacity Unitary Air-Cooled Commercial Air Conditioners Between 65 and 240 kBtu/hr from the eTRM and adopt the EUL for commercial heat pump RTU from the DEER database, which is 20.0 years.[68]

Climate zones

We analyze energy consumption and bill impacts across all 16 CZs in California. The CZ2022 weather files are used, which represent 20 years of weather from 1998 to 2017 and were adopted for Title 24 Version 2022.[69] The weather files used are shown in Table 5.

Table 5. Weather files for energy modeling in each climate zone

Climate Zone	Weather Location	Included in TSB Calculations
CZ01	Redwood, CA	Yes
CZ02	Sonoma County, CA	Yes
CZ03	Oakland, CA	Yes
CZ04	Paso-Robles, CA	Yes
CZ05	Santa Maria, CA	Yes
CZ06	Los Angeles, CA	Yes

[68] Multiple Capacity Unitary Air-Cooled Commercial Air Conditioners Between 65 and 240 kBtu/hr. SWHC043-06. https://www.caetrm.com/measure/SWHC043/06/ .
[69] https://www.calmac.org/weather.asp

Climate Zone	Weather Location	Included in TSB Calculations
CZ07	San Diego, CA	Yes
CZ08	Fullerton, CA	Yes
CZ09	Hollywood-Burbank, CA	Yes
CZ10	Riverside, CA	Yes
CZ11	Red Bluff, CA	Yes
CZ12	Sacramento, CA	Yes
CZ13	Fresno, CA	Yes
CZ14	Palmdale, CA	Yes
CZ15	Palm Springs, CA	Yes
CZ16	Blue Canyon, CA	Yes

Avoided cost calculations

The CPUC's ACC[70] 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.[71] 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 TSB. The previous TSB calculations for CRTUs 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.

[70] 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."

[71] 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.

There are significant changes in the factors between the 2022 and 2024 ACC workbooks, including the following, per E3:[72]

- 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

CalMTA uses both the electric and gas workbooks. CalMTA does 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 CRTU products and baseline commercial AC products will have similar refrigerant characteristics. The ACC workbook settings used to produce hourly factors are shown in Table 6.[73] One CZ was used for each IOU to develop avoided cost factors as a simplification due to the large amount of data required from the avoided cost workbooks for each new set of factors (the factor data file for a single CZ contains approximately 9 million entries). Using all 16 CZs for unit energy savings applied to a single set of hourly avoided cost factors is an improvement in data resolution from the previous CalMTA work on room heat pumps, where a single representative CZ was used to develop unit energy savings for each IOU.[74]

Table 6. Avoided cost workbook settings

Cost test	**Total Resource Cost (TRC)**	**Societal Cost Test (SCT)**
ACC workbook version	2024 v1b	2024 v1b
Discount rate	7.30%	5.06%
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

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

[73] 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.

[74] https://calmta.org/wp-content/uploads/2025/04/Appendix-B_MF-CE-Modeling_RHP.pdf

Cost test	Total Resource Cost (TRC)	Societal Cost Test (SCT)
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	Commercial	Commercial
End use	Small boiler	Small boiler
Emission control	Low NOx	Low NOx
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[75]	FALSE	TRUE

Weighting factors

The final 10 avoided cost calculations scenarios included energy modeling results from 16 CZs, five building types, and 20 different modeling cases for 1,600 unique load shapes. These were combined into the final unit energy savings (UES) hourly profiles using weighting representing the relative contribution of each building type, CZ, and modeling case. The unit for energy savings is kWh per 1,000 square feet of conditioned floor space for electric energy and therms per 1,000 square feet of conditioned floor space for natural gas energy. A single UES is derived as follows:

$$UES_n = 1{,}000 \sum_{i=1}^{5} \sum_{j=1}^{16} \frac{w_{bldg,i} \cdot w_{cz,j}}{A_{bldg,i}} \left[\sum_{k=1}^{20} w_{base,k} \cdot BLS_{base,k} - \sum_{m=1}^{20} w_{prop,m} \cdot BLS_{prop,m} \right]$$

Where UES_n represents the savings shape for the n^{th} scenario (in either kWh or therms), w_{bldg} is the weighting of building type, w_{cz} is the weighting of the CZ, $A_{bldg,i}$ is the conditioned floorspace of building i (in square feet) $w_{base,k}$ is the weighting of the case k for the baseline equipment, $BLS_{base,k}$ is the hourly building load for the base equipment in case k (in either kWh or therms), $w_{prop,m}$ is the

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

weighting of case m for the proposed equipment, and $BLS_{prop,m}$ is the hourly building load for the proposed equipment in case m (in either kWh or therms).

The weighting factors for buildings are based on base year HVAC energy consumption by the buildings. The data is taken from the ComStock and CBECS databases. The school category is intended to include primary, secondary, and higher education. The warehouse category includes fully conditioned floor space only. The building weighting factors are shown in Table 7.

Table 7. Building weight factors

Building Type	Factor
School	0.1846
Office	0.1217
Retail	0.3426
Restaurant	0.2578
Warehouse	0.0933
Total	1.0000

Separate avoided cost factors are developed for each IOU since the avoided cost calculator contains different avoided cost values for each IOU. The CZ weighting factors vary for each utility based upon the energy consumption by IOU and CZ (Table 8).

Table 8. Climate zone weighting factors for investor-owned utilities

Climate Zone	PG&E	SCE[76]	SDG&E
1	0.010	-	-
2	0.060	-	-
3	0.272	-	-
4	0.136	-	-
5	0.027	0.000	-
6	0.003	0.142	0.065
7	-	-	0.502
8	-	0.221	0.037
9	-	0.380	-
10	-	0.166	0.334
11	0.060	-	-
12	0.313	-	-
13	0.102	0.011	-
14	0.001	0.045	0.041
15	-	0.029	0.020

[76] SCE weighting factors are used for SoCalGas natural gas avoided costs as well.

Climate Zone	PG&E	SCE[76]	SDG&E
16	0.016	0.005	0.000
Total	1.000	1.000	1.000

The 20 cases are used to create 10 unique scenarios for avoided costs and market adoption. In certain scenarios, the conversion from modeling case to installation scenarios are straightforward (for example, where a high efficiency variable speed heat pump is compared to a code-minimum heat pump in scenario 2).

In other cases, where the proposed equipment includes advanced fault detection and remote monitoring (e.g., scenario 3), multiple modeling cases with different faults are combined to estimate an aggregated savings shape representing the cumulative impact, considering specific occurrence probabilities of the modeled faults. The probabilities of fault occurrences were derived from existing literature where possible as noted in Table 9. The reviewed studies report probabilities of fault occurrences and detections observed during the period of study. Our method of calculating savings and avoided costs relies on average savings levels that are continuous throughout the life of the RTU rather than discrete events. This is also consistent with population level savings where savings will be characterized in the aggregate by probabilities.

To estimate the reported prevalence of faults across the RTU population, CalMTA converts lifetime occurrence probabilities into an average fraction of units affected at any instant in time. If one assumes a fault has a probability of occurring over the equipment lifetime and assumes it persists for the remaining lifetime after it occurs, then one can estimate a snapshot prevalence across the population to be the multiplied results of those two factors. CalMTA assumes each fault has an equal probability to occur in any year of the RTU lifetime, and thus multiply the lifetime probability of a fault by 0.5 to estimate the average prevalence rate. More advanced probability factors were not applied due to insufficient field data available. Table 9 summarizes the snapshot prevalence for each fault included in the modeled cases.

Table 9. Probability factors for fault occurrences

Type	Factor	Source
Condenser coil fouling - FDD	0.24	UCDavis WCEC Study[77]
Damper stuck (+15% OA) - CCC	0.12	UCDavis WCEC Study[77]
High compressor lock out temperature - CCC	0.04	NYSERDA Study[78]
Economizer operational faults - FDD	0.12	UCDavis WCEC Study[77]

[77] https://wcec.ucdavis.edu/wp-content/uploads/2013/01/Case-Study_FaultDetectionDiagnostics_PRINT.pdf
[78] https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/PPSER/Program-Evaluation/2024-DPS-EMV-Technical-Study.pdf

Type	Factor	Source
Total fault factor (HP)	0.52	-
Total fault factor (GF)	0.48	-

The faults, equipment, and efficiency packages are combined for each baseline scenario as shown in Table 10 and for each proposed scenario as shown in Table 10. It should be noted that the blending of the correct thermostat schedule and increased occupancy thermostat schedule (cases noted with "RAS") are blended with 50/50 splits based on the market data showing only 43% of the market uses smart thermostats.[79]

[79] https://calmta.org/resourcereport/commercial-rooftop-units-market-characterization-report/

Table 10. Weights for modeling cases for each avoided cost scenario – baseline cases

Case name	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10
01_AE_Baseline	0.5	0.5	0.24	0.42	0.24	0	0	0	0	0
02_AE_Baseline_RAS	0.5	0.5	0.24	0.42	0.24	0	0	0	0	0
03_AE_COP20	0	0	0	0	0	0	0	0	0	0
04_AE_COP20_VS	0	0	0	0	0	0	0	0	0	0
05_AE_ConnectedComCont	0	0	0.06	0.06	0.06	0	0	0	0	0
06_AE_DamperControlLimit	0	0	0.06	0	0.06	0	0	0	0	0
07_AE_CoilFouling	0	0	0.12	0	0.12	0	0	0	0	0
08_AE_ConnectedComCont_RAS	0	0	0.06	0.06	0.06	0	0	0	0	0
09_AE_DamperControlLimit_RAS	0	0	0.06	0	0.06	0	0	0	0	0
10_AE_CoilFouling_RAS	0	0	0.12	0	0.12	0	0	0	0	0
11_AE_ERHeat45	0	0	0.02	0.02	0.02	0	0	0	0	0
12_AE_ERHeat45_RAS	0	0	0.02	0.02	0.02	0	0	0	0	0
13_GF_Baseline	0	0	0	0	0	0.5	0.5	0.26	0.44	0.26
14_GF_Baseline_RAS	0	0	0	0	0	0.5	0.5	0.26	0.44	0.26
15_GF_ConnectedComCont	0	0	0	0	0	0	0	0.06	0.06	0.06
16_GF_DamperControlLimit	0	0	0	0	0	0	0	0.06	0	0.06
17_GF_CoilFouling	0	0	0	0	0	0	0	0.12	0	0.12
18_GF_ConnectedComCont_RAS	0	0	0	0	0	0	0	0.06	0.06	0.06
19_GF_DamperControlLimit_RAS	0	0	0	0	0	0	0	0.06	0	0.06
20_GF_CoilFouling_RAS	0	0	0	0	0	0	0	0.12	0	0.12

Table 11. Weights for modeling cases for each avoided cost scenario – proposed cases

Proposed load shape	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10
01_AE_Baseline	0	0	1	1	0	0	0	1	1	0
03_AE_COP20	1	0	0	0	0	1	0	0	0	0
04_AE_COP20_VS	0	1	0	0	1	0	1	0	0	1