Commercial Rooftop Unit Market Transformation Initiative

Appendix C: Product Assessment Report

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List of abbreviations

Abbreviation	Definition
AC	Air-Conditioning
ACC	Avoided Cost Calculator
ACEEE	American Council for an Energy-Efficient Economy
AFDD	Automated fault detection and diagnostics
AFDD+	Enhanced Automated Fault Detection and Diagnostics
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ATT	Acceptance Test Technician
BAS	Building automation system
BMS	Building management system
Btu/h	British Thermal Unit per hour
CA	California
CAHPP	California Heat Pump Partnership
CalMTA	California Market Transformation Administrator
CalNEXT	California Statewide Emerging Technology Program (electric)
CARB	California Air Resources Board
CCC	Connected Commissioning and Controls
CCX	Connected Commissioning
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CEER	Combined Energy Efficiency Ratio
cfm	cubic feet per minute
CO_2	Carbon Dioxide
COP	Coefficient of Performance
CPUC	California Public Utilities Commission
CRTU	Commercial Rooftop Unit
CUAC	Commercial unitary air conditioner
CZ	Climate Zone
DFHP	Dual Fuel Heat Pump
DOAS	Dedicated Outside Air Systems
DOE	Department of Energy
DR	Demand Response
DSC	Digital Scroll Compressor

Abbreviation	Definition
EIS	energy information system
EPA	Environmental Protection Agency
EPCA	Energy Policy and Conservation Act
ER	Electric resistance
ERTU	Efficient Rooftop Unit
ERV	Energy recovery ventilator
EUL	Effective useful life
FDAS	Flexible Demand Appliance Standards
FDD	Fault detection and diagnostics
ft	feet
GHG	Greenhouse Gas
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HP	Heat Pump
HRV	Heat recovery ventilator
HVAC	Heating, Ventilation, and Air Conditioning
IEER	Integrated Energy Efficiency Ratio
IOU	Investor-Owned Utility
IPCC	Intergovernmental Panel on Climate Change
IVEC	Integrated Ventilation, Economizing, and Cooling
IVHE	Integrated Ventilation and Heating Efficiency
kWh	kilowatt-hour
MBC_X	Monitoring based commissioning
MN CEE	Minesota Center for Energy and Environment
MT	Market transformation
MTI	Market Transformation Initiative
NEEA	Northwest Energy Efficiency Alliance
NREL	National Renewable Energy Laboratory
OEM	Original equipment manufacturer
PG&E	Pacific Gas and Electric
QPL	Qualified products list
RM	Remote Monitoring
RTU	Rooftop Unit
SCE	Southern California Edison
SCG	Southern California Gas Company

Abbreviation	Definition
SCORE	Seasonal cooling and off-mode rating efficiency
SDG&E	San Diego Gas and Electric
SEER2	Seasonal Energy Efficiency Ratio 2
SHORE	Seasonal heating and off-mode rating efficiency
TOU	Time of Use
TSB	Total System Benefit
UES	Unit Energy Savings
VRF	Variable Refrigerant Flow
VSC	Variable Speed Compressor
WCEC	Western Cooling Efficiency Center

Glossary of key terms and acronyms

Term	Definition
Remote Monitoring	Remote monitoring capability supporting control, scheduling, automated fault detection and diagnostics (AFDD) with alerts, and load flexibility for cooling and electric heating, including (but not limited to) mobile app-based alerts and control.
Enhanced Automated Fault Detection and Diagnostics (AFDD+)	Provides AFDD capability beyond Title 24 minimum (economizer) FDD requirements. Includes alerts notifying the user to at least two of these: • Low airflow/clogged filter • Heating stage failure/cannot reach setpoint • Cooling stage failure/cannot reach setpoint • Disconnected/failed sensors • Low refrigerant charge • Coil fouling • Component failure • Energy consumption/performance • Backup resistance heating activated
App-Based Startup Commissioning	Mobile app that supports streamlined on-site startup and commissioning process by enabling simplified controls and sequence programing. Provides real-time system performance data such as amperage, damper position, fan speeds, and refrigerant pressures.
Controls	Controls are a combination of hardware and software that when used in combination allow the user to control the product.
Connected Commissioning & Controls (CCC)	Includes all three features: Remote Monitoring, AFDD+, and App-Based Start-Up Commissioning.
Dual Fuel Heat Pump RTU	Can provide heating using heat pump (compressor) and/or gas furnace in one packaged RTU. The furnace is typically used to provide backup heating during periods of high heating load and/or low outdoor temperatures.
Mixed Fuel RTU	Uses compressor to provide cooling (A/C) and gas furnace to provide heating.
Fixed Capacity Compressor	Fixed capacity compressors run at constant speed and capacity, maintaining temperature by cycling on and off between 100% and 0% of rated capacity. This results in relatively short, frequent heating and cooling cycles, relatively poor temperature and humidity control, and lower part-load and overall efficiency than staged or variable capacity systems. However, some fixed capacity systems operate efficiently under full-load conditions.
Staged Compressor Systems	Staged compressors operate at constant speed, providing two or more discrete capacities by using a valve to relieve pressure. Two-stage compressors typically operate at either 100% or 70% of rated capacity. Staging can also be accomplished by using multiple fixed-capacity compressors. When used as a heat pump, two-stage operation is typically limited to the cooling cycle. Compared to fixed capacity compressors, staged compressors can better match

	cooling loads, resulting in longer cycles, more precise temperature control, and improved overall efficiency.
Variable Capacity and Variable Capacity Compressors	Variable capacity is used as an umbrella term encompassing systems that can modulate capacity to match building heating and cooling loads. This includes: staged systems with three or more stages, digital scroll compressors (DSC), variable speed compressors, or a combination of fixed, staged, and/or variable capacity compressors. The term variable capacity compressor refers to a DSC, which uses a valve to engage or disengage for part of each compression cycle. Although DSC compressors operate at constant speed (hertz), they can modulate capacity to match load anywhere between 10% and 100% of rated capacity.
Variable Speed Compressor (VSC)	Variable speed compressors (VSC), which are also called inverters, modulate capacity by increasing or decreasing the frequency of oscillations (hertz) from 100% down to as low as 15%, allowing for increased efficiency when the compressor is not running at full capacity. Compressor speed is controlled by a microprocessor that varies electrical frequency and voltage supplied to the motor. Controlling compressor speed and capacity allows VSCs to provide the most precise temperature and humidity control, and the highest overall efficiency in the market. Since VSCs can slowly ramp up to full capacity, they also have lower startup power demand than fixed-speed systems. VSCs can temporarily "overspeed" by temporarily exceed nominal operating capacity, boosting capacity to improve cold-weather performance and reducing the need for supplemental electric resistance (ER) heating.

1 Purpose and context

The purpose of the Product Assessment Report is to provide a detailed explanation of the methods used to refine and evaluate the Target Technology and to share key findings that directly inform the development of a market transformation (MT) strategy and interventions, which are described in the Market Transformation Initiative Plan (MTI Plan).

This report is not intended to provide an exhaustive examination of commercial heating, ventilation, and air conditioning (HVAC) products and technology. Instead, it focuses on the key technical barriers, opportunities, and potential impacts from the broader adoption of advanced rooftop units (RTUs) in California, and the implications for developing effective MT strategies to achieve that objective. This report focuses on technical aspects of the product and generally avoids discussion of the RTU market, which is covered in Appendix D: Market Characterization Report—although some overlap is necessary.

This document briefly characterizes commercial RTU (CRTU) technology, summarizes the CalMTA team's research and analysis, highlights key findings, and concludes with a list of short-, medium-, and long-term objectives for product development activities.

2 Executive summary

This Product Assessment Report discusses the key findings of CalMTA's product and technical research into CRTUs, including product features, limitations, and technical considerations for their use in California. The main product assessment activities informing this report include a literature review, product specification and marketing materials review, manufacturer and stakeholder discussions, field study results, and energy modeling.

The results of the activities show that most commercial RTU replacements are code-minimum mixed-fuel or heat pump (HP) units that do not encompass energy efficiency attributes such as variable speed compressors, remote monitoring and automated fault detection, or connected commissioning. Increasing the efficient operation of RTUs presents a significant opportunity, as almost 60% of commercial floor space in California is conditioned by single-zone packaged rooftop units, most of which provide less than 11 tons of cooling capacity.[1] Manufacturers have reported that anywhere from 40% to 85% of HVAC replacements are like-for-like, and the existing market is focused on designing drop-in replacements.[2] This presents a greater opportunity for MT as many RTUs that are being installed are not obtaining permits, limiting the impact of energy code updates.

2.1 A note on naming conventions

This idea was initially submitted to CalMTA as "Efficient Rooftop Units (ERTUs)." This naming convention was used through the Advancement Plan development process. Through collaboration with other initiatives around the United States and communication with HVAC manufacturers, it became apparent that the term "ERTU" was associated with a specific set of product attributes, which did not encompass the same set of products that are the focus of CalMTA's RTU initiative. As such, CalMTA's initiative development effort was renamed the "Commercial Rooftop Unit (CRTU) MTI".

In other contexts, the term "commercial rooftop unit" can be used to describe a broad class of HVAC equipment. Since most readers may not associate that term with a specific set of performance features, throughout this report "CRTU MTI" is used to describe the overall initiative, while the terms "Target Technology" and "products meeting CalMTA's CRTU product definition" are used to describe RTUs with attributes and specifications described in the CalMTA product definition below.

It should also be noted that the terms "connected commissioning," "continuous commissioning," and "monitoring-based commissioning (MBCx)" are all related, and may be used in different ways

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[1] California Commercial Saturation Survey

[2] 2019 AHR Expo Findings & Commercial HVAC Research

by different organizations. For example, the Northwest Energy Efficiency Alliance (NEEA) uses the term Connected Commissioning (CCX) to refer to a Bluetooth-based tool that leverages either on-board sensors or portable tools used on the job site.

CalMTA coined the term Connected Commissioning and Controls (CCC) to refer to the broad suite of benefits achievable from factory-installed sensors, logic boards, and communications equipment. These include initial startup and commissioning, AFDD, and remote monitoring and control of RTUs.

2.2 Main product assessment findings

Finding 1: The largest opportunities for non-residential RTUs in California are 1) increasing adoption of HP, 2) increasing cooling efficiency, 3) integrating variable capacity, and 4) incorporating factory-installed sensors and connectivity to enable app-based startup, remote monitoring, and enhanced automated fault detection and diagnostics (AFDD+).

Finding 2: Development of variable speed HVAC equipment in the U.S. has focused on the residential sector, with some spillover into the small non-residential RTU market; most commercially available rooftop units with cooling capacities greater than 65,000 Btu/h (5.4 tons) do not currently include an inverter-driven, VSC.

Finding 3: Efficiency designs such as energy or heat recovery and enclosure insulation that are used to boost unit efficiencies in cold climates are generally not cost effective in California due to the moderate climate; there are other performance enhancements that are better suited to California's climate and energy priorities.

Finding 4: RTU performance is regulated at both the federal and state level and market interventions therefore need to consider both sets of regulations. Federal standards apply equally to equipment used in both new construction and existing buildings, while California's codes and standards have significantly different requirements for new construction and replacement.

Finding 5: Although there are many options for non-residential RTUs with CCC, manufacturers have not aligned on consistent standards, strategies, and user interfaces.

Finding 6: Despite Title 24 requirements for AFDD, many existing RTUs do not operate as intended.[3] However, operational performance can be improved with effective FDD, customer notifications, and remote access for technicians.

[3] A 2021 field study found that a combination of factors led to poor installed performance, despite code requirements for AFDD. For more information see: RTU/Economizer Analysis and Field Assessment.

Finding 7: High switchover temperatures[4] for HPs with backup ER heat strips can impact customer bills, but customers may not be aware since it will not impact heating performance.

3 Product overview and definition

This section provides a general overview of RTUs, highlights the specific product attributes identified by CalMTA, and discusses other potential product enhancements that are not included in CalMTA's CRTU MTI product definition.

3.1 General product overview

Non-residential RTUs are self-contained units commonly referred to as a packaged system that include cooling, heating, and air handling in one unitary device that is typically installed on the roof of the building in a weatherproof enclosure and connected directly to the building's ductwork. RTUs can be configured as single-zone systems controlled by a single thermostat, or multi-zone systems where air terminal units modulate the temperature of the air supplied to each zone.

3.2 Product definition

Following the publication of the Advancement Plan, the CalMTA team conducted a preliminary assessment of non-residential RTU technology options through research, energy modeling, and discussions with experts and stakeholders to refine the focus of the initiative. Based on that work, the team developed the following product definition.

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 variable speed HP products that exceed federal minimum cooling efficiency by at least 20%,[5] and use sensors, analytics, cloud-connectivity, and simple, app-based tools to:

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[4] The DOE defines the switchover temperature as the "ambient temperature at which the unit switches from primary (mechanical) heating to resistance heating (all-electric HP RTUs) or gas heating (dual fuel HP RTUs)."

[5] 20% improvement in cooling efficiency is relative to current federal standards in place at the time of sale for the RTU. When federal standards are updated, the performance target will be updated relative to the new minimum efficiency requirements.

- Increase installed efficiency through improved startup including app-based startup routines, commissioning, and compliance with Title 24 Acceptance Testing[6] 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 (DR) signals, and thermal load data
- Remotely monitor RTU performance, allow for remote connectivity for scheduling and other important functions, and automatically detect, diagnose, and resolve faults by providing alerts to owners and actionable information to HVAC technicians

The methods used to arrive at this product definition are described in the Research Objectives and Methodology section.

3.3 Key product features and attributes

Although RTUs are one of the simplest types of equipment used for space conditioning in non-residential buildings, there are many ways to improve their performance, efficiency, and grid impacts. Since each of these product improvements can add cost, CalMTA focused on features and attributes with the greatest benefits to California ratepayers. Table 1 shows an inexhaustive list of products and how they meet this MTI's product definition. While not all units meet the full CalMTA CRTU product definition, this list is helpful to show the prevalence of each CRTU component and the opportunity to encourage manufacturers to continue adopting variable speed technologies and remote monitoring capabilities.

[6] 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.

Table 1. Alignment between currently available HP RTU products and CRTU MTI product definition

Manufacturer	Brand	Fuel	Capacity	Variable Capacity[7]	SEER/SEER2/IEER[8]	Percent Above Federal Min	Remote Monitoring/ AFDD+	App-Based Start-Up Commissioning
Daikin	Rebel DPS	HP	3-20 tons	Yes	Up to 22.7 IEER	61%	Siteline	Quality Install
	Rebel Applied	ER/ NG	20-160 tons	Yes	Up to 20.0 IEER	48%		
Aaon	RN	HP	6-140 tons	Yes	Up to 22.5 IEER	60%	Prism	N/A
	RQ		2-5 tons	Yes	Up to 20.3 SEER	46%		
Lennox	Enlight	HP	3-25 tons	Available	Up 17.5 SEER2 and 17.3 IEER	31% / 23%	Lennox CORE	CORE Service[8]
	Xion		2-20 tons	Available	Up to 14.0 SEER2 and 15.5 IEER	4% / 10%		
	Model L	ER/ NG	3-25 tons	Yes	Up to 21.2 SEER2 and 23.1 IEER	58% / 64%		

[7] For the purposes of this table, variable capacity includes DSCs, products with 3+ stages of mechanical cooling, products that use a combination of fixed and variable capacity compressors, and inverter-driven compressors.

[8] SEER = seasonal energy efficiency ratio; SEER2 = seasonal energy efficiency ratio 2; IEER = integrated energy efficiency ratio

Manufacturer	Brand	Fuel	Capacity	Variable Capacity[7]	SEER/SEER2/IEER[8]	Percent Above Federal Min	Remote Monitoring/ AFDD+	App-Based Start-Up Commissioning
Carrier	Weather Master	HP	3-25 tons	No	Up to 16.8 SEER2 and 17.6 IEER	25% / 25%	SystemVu	BluEdge[9]
	Weather Maker		3-25 tons	No	Up to 13.4 SEER2 and 15 IEER	0% / 6%		
	Weather Expert	ER/ NG	2-5 tons	Yes	Up to 18.9 SEER2	41%		
Trane	Precedent	HP	3-25 tons	Available	Up to 13.4 SEER2 and 14.1 IEER	0% / 0%	Symbio 700	Symbio 700
	Precedent	ER/ NG	3-25 tons	Yes	Up to 25.6 IEER	82%		
	IntelliPak	ER/ NG	20-75 tons	Yes	Up to 19 IEER	52%		

[9] Only available currently to installers and engineers.

Manufacturer	Brand	Fuel	Capacity	Variable Capacity[7]	SEER/SEER2/IEER[8]	Percent Above Federal Min	Remote Monitoring/ AFDD+	App-Based Start-Up Commissioning
Johnson Controls/York	Core	HP	3-12 tons	No	Up to 16.8 SEER2 and 17 IEER	25% / 21%	Verasys	RTU Toolkit
	Pro		6.5-12.5 tons	No	Up to 21.2 IEER	50%		
	Series 20		15-20 tons	No	Up to 18 IEER	28%		
	Premier	ER/ NG	25-150 tons	Yes	Up to 17.9 IEER	43%		
Bosch	IDP Plus	HP	3 or 5 tons	Yes	Up to 15.2 SEER2	13%	N/A	N/A
Midea	MRD Series	HP	3 or 5 tons	Yes	Up to 15.2 SEER2	13%	N/A	N/A
Greenheck	RV/RVE/ RVC*	HP	5-30 tons	Yes	Up to 23.7 IEER	68%	N/A	N/A
CaptiveAire	Paragon (DOAS)*	HP	3-30 tons	Yes	Up to 21.3 IEER	51%	CASLink	Remote Connected Commissioning Services™

*Products are technically DOAS units, but they are also marketed as RTU units.

3.3.1 Increased cooling efficiency

Federal standards for packaged RTUs require that a unit meet a minimum efficiency rating, based on laboratory testing performed using Department of Energy (DOE)-approved test procedures. CalMTA's Target Technology will be 20% more efficient than federal cooling efficiency standards in place at the time when the unit is sold. Once product ratings become available using the new Integrated Ventilation, Economizing, and Cooling (IVEC) metric, CalMTA will reevaluate this target to confirm that 20% improvement above minimum is still achievable, and/or adjust as needed.

California's grid has struggled to meet summer peak electricity loads for several decades, and peak cooling continues to be the primary source of summer peak electricity demand. Focusing on cooling efficiency will therefore have outsized benefit to California's ratepayers and grid operators.

Research has found that in the Northwest, nearly all units were only minimally compliant with the federal standard.[10] 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. See the Codes and Standards section for more details on federal energy standards.

Table 2 shows the current federal minimum standard and the proposed 20% efficiency increase. Using a cooling efficiency target based on federal standards will help program participants and partners understand program requirements even as federal standards are updated.

Table 2. Current federal minimum cooling efficiency metric and proposed cooling efficiency metric by capacity range

Capacity Range (Btu/h)	Capacity Range (tons)	Federal Standard Current Minimum/2029 Minimum	Proposed 20% Efficiency Increase
<65,000	<5.4	13.4 SEER2	16 SEER2
≥65,000 and <135,000	≥5.4 and <11.25	14.1 IEER / 13.4 IVEC	17.3 IEER / 16 IVEC
≥135,000 and <240,000	≥11.25 and <20	13.5 IEER / 13.1 IVEC	16.8 IEER / 15.7 IVEC

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) maintains a Certification Directory, a voluntary program that ensures products perform to the manufacturer's published

[10] HVAC Market Intelligence Report

claims.[11] There are currently a total of 595 unique model numbers that AHRI has classified as a Single Package Heat Pump Air-Source or a Year-Round Single Package Heat Pump Air-Source that meet the current federal energy efficiency standard. Currently, six manufacturers offer 330 models that exceed the current minimum efficiency IEER standard by at least 20% (Table 3).

Table 3. Number of Units in AHRI's Certification Directory that Exceed IEER Standard by 20%[11]

Capacity Range (tons)	Federal Standard Current Minimum		Proposed 20% Efficiency Increase	
	Unique Manufacturers *	Unique Model Numbers	Unique Manufacturers *	Unique Model Numbers
≥5.4 and <11.25	21	299	5	141
≥11.25 and <20	24	296	6	189

*8 of the brands listed offer the same models manufactured by Carrier.

3.3.2 Variable speed compressors

CalMTA's Target Technology includes inverter-driven variable speed HPs, which can significantly improve energy efficiency during both heating and cooling seasons, especially relative to fixed-capacity systems. Although 2-stage cooling (which is required by code for RTUs over 65,000 Btu/h) offers slightly better energy and comfort performance than fixed-capacity systems, it does not improve heating efficiency and does not offer the part-load efficiency of variable speed systems.

In contrast to fixed-capacity and staged systems, inverter-driven systems offer more precise control of the compressor speed to adjust to the needs of the conditioned space at any given time. This results in fewer on/off cycles, lower startup power needs, better temperature and humidity control, and lower energy consumption.

Other methods of achieving variable capacity (such as using multiple/staged compressors) can achieve some of the same benefits and may achieve similar efficiency ratings. However, since manufacturers can design staging to align with the demands of federal test procedures, test procedures may not capture the full benefits of variable speed compressors, which generally offer the best part-load efficiency across California's wide range of climates. Some manufacturers rely on one large variable speed compressor to achieve these benefits, while others combine one or more fixed-capacity compressors with a variable speed compressor to achieve a similar degree of control.

[11] AHRI Directory of Certified Product Performance

Variable speed compressors can significantly improve cooling efficiency when used in a mixed-fuel RTU. However, variable speed is an even more important technology for HPs. In mixed-fuel RTUs, furnace (heating) and compressor (cooling) capacity can be sized separately to match the loads of a particular building. However, since HPs use the same compressor system for both heating and cooling, unless heating and cooling loads are roughly equivalent, HP RTUs need to be sized to meet either peak heating or peak cooling demand. In this case, the compressor will be inherently oversized during the opposite season, creating inefficiencies. Given California's diverse climate and building stock, most existing buildings will have mismatched heating and cooling loads. The part-load efficiency of variable speed compressors reduces the impact of these mismatched heating and cooling loads.

The term "variable speed heat pump" was once synonymous with the term "cold climate heat pump." This is because variable speed heat pumps can overspeed to provide heating in low ambient, high heating load conditions, and because variable speed compressors can be sized to meet heating loads. Cold temperature performance of variable speed heat pumps is also important in California, since it can reduce reliance on inefficient electric strip heating, and therefore reduce the impact of building electrification on winter peak electricity demand. However, the term variable speed heat pump is no longer synonymous with cold climate heat pump. Regions with very cold winters (unlike most of California) are now beginning to focus on technologies such as vapor injection, which can maintain heating capacity well below freezing. Vapor injection is an advancement better suited to very cold climates and is not needed in California. Since vapor injection will add cost to the unit without providing significant benefit to California, CalMTA's long-term target includes adoption of *conventional* variable speed compressors—but not true cold climate heat pumps.

3.3.3 Remote monitoring and enhanced automated fault detection and diagnostics (AFDD+)

CalMTA's Target Technology will incorporate factory-installed sensors and connectivity, allowing building managers and HVAC service providers to better understand RTU performance, schedules, and to detect faulty equipment and operational inefficiencies remotely without having to be on-site. Over the long term, this technology can also enable market participants to diagnose and resolve RTU performance issues using machine learning and automation.

Conventional AFDD algorithms and tools for commercial buildings can be incorporated into various building controls and automation systems, including energy information systems (EIS), building management systems (BMS), and building automation systems (BAS). Although these systems can help building owners and managers identify and resolve faults causing inefficient operation, they are very expensive, require skilled and attentive building operators to ensure that faults are detected and addressed, and do not typically integrate with enhanced factory-installed sensors in packaged rooftop equipment. As a result of the high cost and because they offer the greatest value to buildings with more complex, multi-zone systems, only 13% of buildings less than 50,000 square feet have adopted these systems based on nationwide data.[12]

In the last few years, low-cost alternatives to sophisticated control and automation systems have begun to emerge. Non-residential RTUs have started integrating remote monitoring and automated fault detection via the use of sensors, internal logic, and cloud connectivity. Several manufacturers are now offering cloud-connected controls applications and fault detection systems as part of the purchase of a new unit. Some of these systems are included at little to no extra cost to the consumer, providing some of the benefits of a BAS without the need to purchase additional equipment. Since these new tools also include the integration of additional sensors within the unit, they can provide even more insight than many BAS systems.

Research has found that most commercial HVAC equipment is not operating as intended,[13] even when equipped with Title-24-compliant AFDD systems[14] that provide notifications via the thermostat or wall-mounted control. Although few studies specifically investigate the increased potential for remote monitoring to detect issues, alert building managers, and help service providers resolve faults in single-zone RTUs, many studies have documented the benefits of remote monitoring to detect and resolve faults in larger multi-zone commercial systems.[15,16,17]

3.3.4 Load flexibility

Many of the same connectivity and control functions used to support fault detection and optimize long-term performance of variable speed HP RTUs can also support load flexibility. Instead of responding to DR events on the grid by simply raising the setpoint, variable speed HPs can be controlled to run at part-load, reducing strain on the grid with less impact on occupant comfort. Furthermore, connected controls can integrate building load data and day-ahead weather and grid forecasts to pre-cool or pre-heat buildings in advance of demand events, further enabling load flexibility.

3.3.5 App-based startup commissioning

The same sensors and connectivity that enable long-term remote monitoring and AFDD+ can also support improved startup and commissioning, which is particularly important for advanced HPs to

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[12] Commercial Building Sensors and Controls Systems - Barriers, Drivers, and Costs

[13] 2019 AHR Expo Findings & Commercial HVAC Research

[14] Code Readiness: RTU/Economizer Analysis and Field Assessment

[15] Better Buildings. Case Study: Smart Monitoring and Diagnostic System (SMDS) for RTUs

[16] ACEEE. Going Big on Small Buildings: Spotlight on efforts to improve controls

[17] PNNL. Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction

optimize energy performance. Several manufacturers have begun to offer Bluetooth-based applications that allow HVAC technicians to review settings and performance data, enhancing the commissioning process while on-site during the installation of a new RTU.

However, Bluetooth-based apps cannot connect to the unit once the installer leaves the site, limiting ongoing commissioning. Since there is still value in using these applications to ensure a successful startup, in the short term, CalMTA may support the use of Bluetooth apps during the installation and startup process, while the technician is still on-site. Over the long term, CalMTA envisions that connected commissioning will leverage internet connectivity to enable off-site monitoring, troubleshooting, and streamlined resolution of inefficient operation.

Furthermore, the inclusion of more robust sensors may help to streamline and improve compliance with the Title 24 Acceptance Testing requirements by reducing or eliminating the need for an Acceptance Test Technician (ATT) to visit the site.

As part of Title 24 compliance, installation contractors must complete and submit up to five different Acceptance Test forms, some of which require the ATT to perform tests and collect data while at the job site. On-site Acceptance Testing requirements add cost and administrative complexity to RTU installations and may be one reason that many RTU installations do not submit Title 24 compliance forms.

By providing much of the same data obtained during on-site testing, remote monitoring, enhanced sensors, and app-based startup and commissioning tools may be able to support the ATT process and eventually offer an alternative to on-site verification, potentially streamlining and increasing the rate of Title 24 compliance.

From a customer-operations perspective, app-based startup may also help reduce variation in the quality of startup and commissioning due to differing levels of installer experience and address performance deficiencies that would have gone unnoticed by building management staff for long periods.

3.3.6 Single-zone/3 to 20 tons

CalMTA's CRTU MTI product definition focuses on single-zone packaged RTUs (which are less complex than multi-zone RTU systems), helping to focus the opportunities for market transformation. This MTI also focuses on units under 20 tons because products above 20 tons are less likely to be single-zone and have different efficiency metrics. Finally, the MTI includes products as small as 3 tons, since over half of the CRTUs installed in California commercial buildings have between 3 and 5 tons of cooling capacity.

3.4 Additional product attributes evaluated

Before finalizing a product definition, an initial phase of energy modeling was performed for a list of potential measures. This process was used to help identify the improvements with the largest impact both in energy savings and avoided costs, while screening out other potential improvements. To reduce modeling time and effort for this preliminary assessment, three building prototypes were modeled for three climate zones. Once the product definition was developed, more detailed energy modeling was conducted to reflect all 16 CEC CZs and multiple building prototypes. The CPUC's Avoided Cost Calculator (ACC) was used to determine the 30-year avoided cost in net present value (NPV) for this initial modeling phase.

Per the CPUC[18], "the primary benefits of demand-side resources are the avoided costs related to generation and distribution of energy". The ACC "is used to determine the benefits of Distributed Energy Resources (DER), such as energy efficiency and demand-response, for cost-effectiveness analysis". More details on the ACC can be found in Section 8.6 of this report.

Climate zones 7, 10, and 12 were chosen to be representative of the four IOUs in California: PG&E (12), SCE/SCG (10), and SDG&E (7). These climate zones were also selected because they collectively reflect the climatic variation of California's most populated regions. CZ 12 (Sacramento) has relatively high heating and cooling loads, CZ 10 (Riverside) has high cooling loads, and CZ 7 (San Diego) is a mild year-round climate with relatively low heating and cooling loads.

Figures 1 and 2 show the initial energy modeling savings and avoided cost for a medium office building for the three climate zones modeled. Ultimately, optimized cooling, variable capacity compressor technology, and fault detection were found to provide the largest benefits. Measures that were investigated but not included as part of the product definition generally showed low statewide savings. However, some of these features could still provide meaningful savings for buildings in coldest parts of California, or those with unique attributes such as high ventilation rates. The additional features investigated are described in the subsections below.

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[18] https://www.cpuc.ca.gov/dercosteffectiveness

Figure 1. Initial energy modeling savings and avoided cost results for the Medium Office Building all-electric code baseline

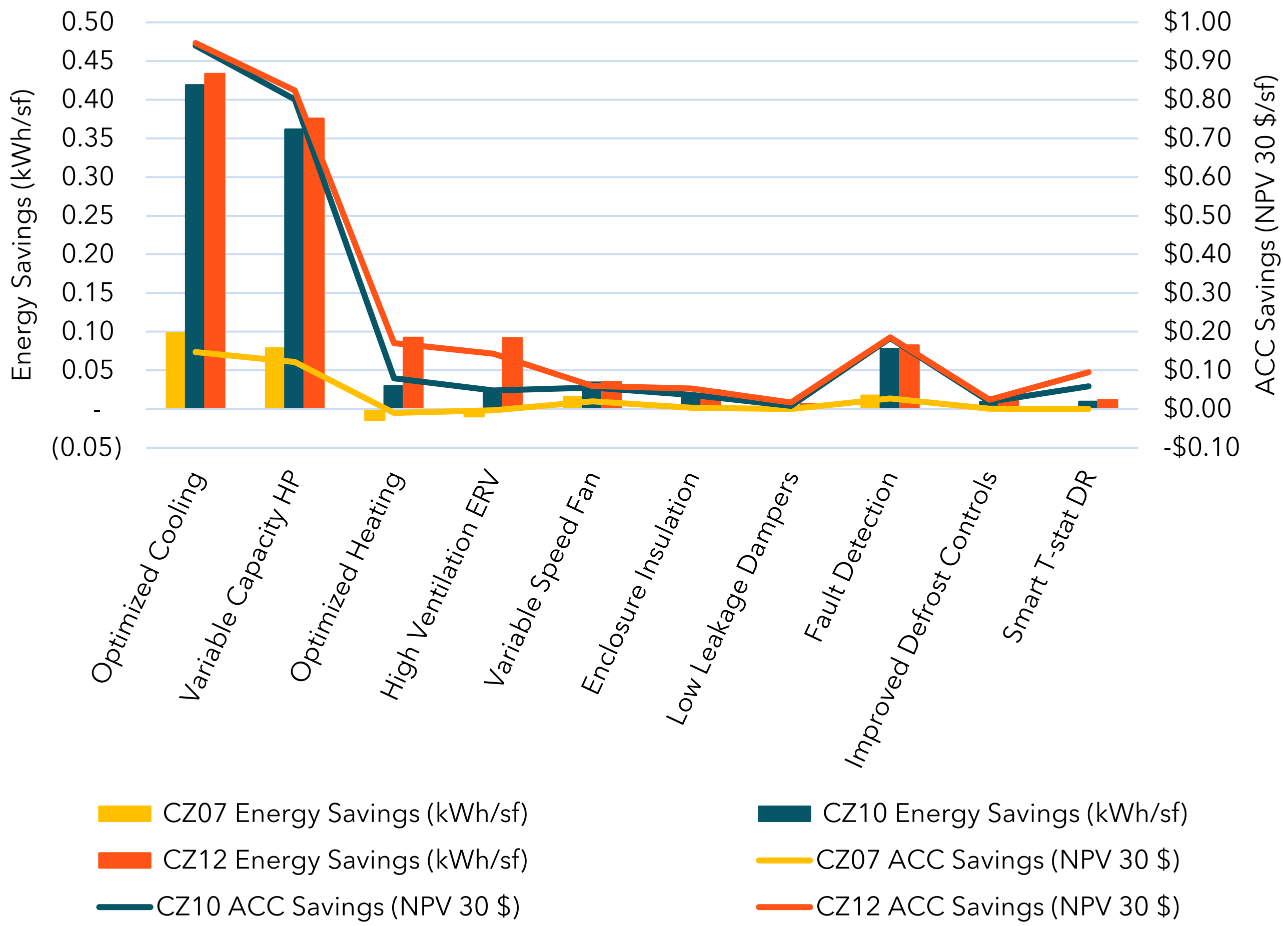
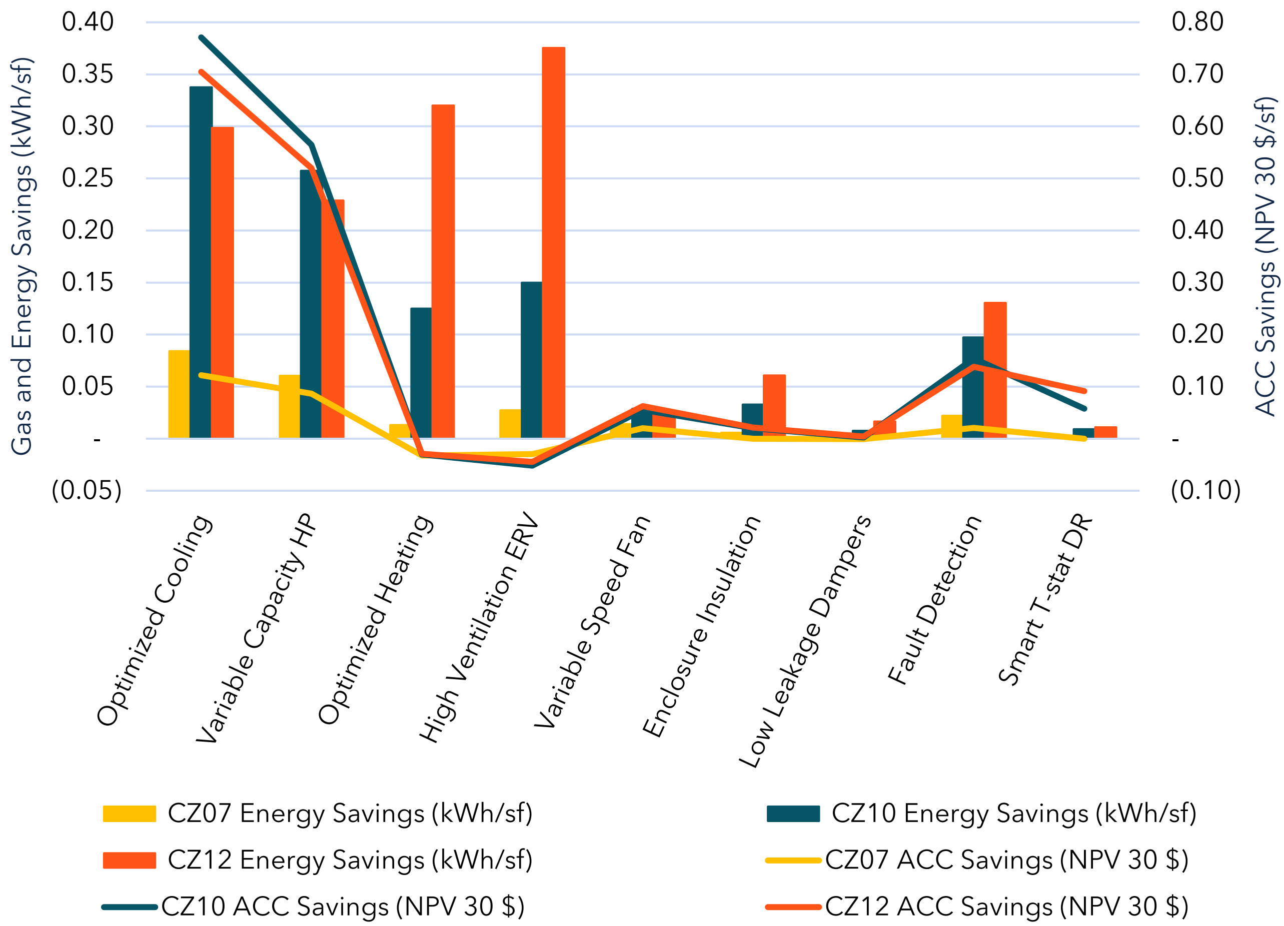


Figure 2. Initial energy modeling savings and avoided cost results for the Medium Office Building gas furnace code baseline



3.4.1 Optimized heating performance

While optimized heating performance is a focus of research and advocacy efforts in colder climates, there is less benefit to California, which generally experiences milder climates. HVAC systems are generally sized based on the cooling load, with the exceptions of climate zones 1, 16, and sometimes 14, which represent 0.5%, 1.5%, and 2.5% of the population, respectively. Furthermore, many advocates in colder climates are focused on dual-fuel HPs (which combine a gas furnace with a HP), thermal insulation for RTU enclosures, and/or furnace efficiency, none of which have significant statewide benefits in California.

Dual-fuel HPs offer an alternative to all-electric HPs, helping to bridge the gap in the conversion to cold climate HPs. However, if sized correctly, all-electric variable speed HPs can meet heating loads in most of California. While dual-fuel HPs may be a viable technology in parts of California, several national and regional organizations are already working with manufacturers to develop and deploy this technology in cold climates. CalMTA has therefore chosen to focus on other aspects of RTU performance and does not plan to focus specifically on promoting the adoption of dual-fuel HPs.

As noted above, CalMTA has identified increased use of resistance backup heating (and associated grid impacts) as a negative impact of heating electrification using code-minimum HP RTUs. To minimize the use of resistance backup heating – and therefore reduce the impact of electrification on heating season electricity loads in California – CalMTA has incorporated variable speed compressors and remote monitoring into the CRTU MTI product definition.

3.4.2 Energy or heat recovery ventilator (E/HRV)

California's Title 24 Energy Code contains prescriptive energy recovery requirements by climate zone and percent outdoor air at full design airflow. Early modeling indicated that energy/heat recovery ventilators (ERV/HRV) are more beneficial in colder climates, resulting in low modeled energy savings for most of California. RTUs have also traditionally been low-cost replacements, and adding an ERV/HRV can significantly increase the cost of the unit by as much as $20,000, based on cost quotes received as part of this effort.

3.4.3 Fan efficiency/variable speed fans

Fan efficiency is regulated by federal energy standards. Federal standards adopted in 2024, with an effective date of 2029 for air-cooled commercial package air conditioners and HPs, incorporate increased fan efficiency; the new IVEC metric better accounts for fan energy use when cooling and economizing.[19] By targeting a 20% increase in cooling efficiency, CalMTA will indirectly target fan efficiency without the need to explicitly include this feature. Furthermore, most RTUs with variable capacity or variable speed compressors already include variable speed fans.

However, in practice, not all RTUs with variable speed fans include internal logic to support fan modulation, causing them to operate at full speed to meet ventilation requirements during occupied hours. Updates to internal logic algorithms and integration of strategies such as demand-controlled ventilation (DCV) can increase operational efficiency in RTUs with variable speed fans. CCC can help alleviate these limitations and take advantage of variable speed fans that are included in these units.

3.4.4 Enclosure insulation

Initial energy modeling found that adding insulation to the enclosure did not result in significant savings in California. Additionally, this could potentially result in changes to the size of RTU products, which could impact upfront costs.

[19] The new IVEC metric modifies the external static pressure and scales for the presence of economizing equipment to better represent real duct systems and ventilation components.

3.4.5 Low leakage dampers/low leakage enclosure

California's Title 24 Energy Code contains prescriptive requirements for economizer outdoor air and return air dampers that allows a maximum leakage rate of 10 cubic feet per minute per square foot (cfm/ft^2) at 250 Pascals. Due to this requirement, modeled energy savings were very low for California. Likewise, low leakage enclosures offer the greatest savings in heating-dominated climates, and CalMTA's initial modeling found low statewide potential energy savings in California.

3.4.6 Sizing heat pump capacity to 100% of heating load

Although commercial buildings in California generally have higher *annual* cooling loads than heating loads, peak heating load can sometimes exceed peak cooling load, especially in existing buildings. Since HP compressors serve both heating and cooling loads, compressors sized to the cooling load can be undersized for the heating load, increasing reliance on resistance heating—especially during the coldest hours of the year. Although CalMTA models showed that right-sizing HP compressors could slightly reduce reliance on resistance heating, sizing is highly dependent on the building's existing ventilation design and conditioning needs, and the added expense of a larger compressor may not be warranted. CalMTA instead will focus on strategies to identify and manage excessive resistance heating, including through CCC.

3.5 Energy efficiency landscape

This section describes the activities of other market actors across the US who are actively investigating non-residential RTU measures and any major findings from research activities.

Table 4. Active RTU initiatives in the United States

Program/Organization	**Description**
California Heat Pump Partnership (CAHPP)	The CAHPP launched in 2024 to help California achieve the goal of installing six million HPs by 2030, which includes both space and water heating equipment. Planned activities include improving customer economics, streamlining the sales and installation process, accelerating market adoption, and increasing market visibility.[20]
CalNEXT	CalNEXT has numerous approved projects focused on HVAC, including testing simplified HVAC controls in retrofits, laboratory testing of variable capacity HPs to develop building energy modeling performance maps, high efficiency RTU focus pilot, HP RTU demonstration, integrated HVAC RTU remote monitoring systems, controllers for inverter-drive compressors, and other HVAC measures.[21]

[20] California Heat Pump Partnership

[21] CalNEXT Approved Projects

Program/Organization	Description
	These projects are an opportunity for CalMTA to collaborate with CalNEXT.
Air-Conditioning, Heating, and Refrigeration Institute (AHRI)	The Commercial Unitary Standards Technical Committee began working on AHRI Standard 1390, Commercial Smart Grid Interface, which covers communication protocols.[22] This may be an opportunity to provide input into the creation of the standard.
ENERGY STAR	ENERGY STAR released a voluntary Light Commercial HVAC specification effective January 1, 2023, which requires products to be roughly 8% more efficient than the federal standard.[23] This voluntary specification will likely be updated in the next few years to align with the 2029 federal standards for small and large commercial unitary air conditioners (CUAC).
Northwest Energy Efficiency Alliance (NEEA)	NEEA's Efficient RTU program aims to "increase the efficiency of RTUs installed in the Northwest" with a focus on mixed-fuel and dual-fuel RTUs. The program, targeting areas with colder climates than California, has developed two tiers. The first tier requires cabinet insulation, reduced damper leakage, and a minimum thermal efficiency of 81%, while tier 2 requires the unit to meet tier 1 and either achieve a condensing level of efficiency (>=90%) or be equipped with an HRV/ERV system.[24]
Nicor	NEEA and Nicor Gas have been collaborating since 2020 on an ERTU product. They are also part of the CEE AC/HP working group. Nicor has also developed two tiers, with the first tier requiring insulation and reduced damper leakage, but it does not include thermal efficiency. The second tier requires that the product meet the Tier 1 requirements, as well as include heat or energy recovery, and the furnace must achieve a condensing level of efficiency (>=90%).[25] The product specification is not final and may change before it is adopted.
Minnesota Center for Energy and Environment (MN CEE)	The MN CEE works closely with the Minnesota Efficient Technology Accelerator (ETA), which develops individual market transformation initiatives for targeted technologies and approaches. ETA and MN CEE have developed a Next Gen Rooftop Unit (formerly known as high-performance RTU) that focuses on HP technology and ERVs.[26]

[22] Equipment Performance Standards Update AHRI Standard 1390-202x (SI/I-P)

[23] ENERGY STAR Light Commercial Heating & Cooling for Partners

[24] Efficient Rooftop Unit Field Study

[25] Efficient Rooftop Units: Logic Model and Market Progress Indicators

[26] Next Gen RTUs

Program/Organization	Description
Consortium for Energy Efficiency (CEE)	The CEE has developed a specification for unitary HP systems.[27] The specification creates four distinct tiers of product performance with Tier 0 representing products with a planned obsolescence either for the product or due to updated federal standards. Tier 1 aligns with ENERGY STAR while Tier 2 goes above ENERGY STAR metrics. The Advanced Tier represents a stretch target that has an aspirational performance meant to attract early adopters. The CEE Advanced tier IEER requirements are 19% above current federal minimum for units less than 65,000 Btu/h, 25% for units greater than or equal to 65,000 Btu/h and less than 135,000 Btu/h, and 24% for units greater than or equal to 135,000 Btu/h and less than 240,000 Btu/h. The specification also includes optional energy management and DR criteria.
DOE Commercial Building Heat Pump Technology Challenge Specification	The DOE Building Technology Office released a specification focused on RTUs in cold climates. In addition to the specification, the DOE Commercial Building Heat Pump Accelerator works on increasing adoption through the Commercial Building Heat Pump Campaign (recently renamed to the Commercial Building HVAC Campaign), through 2027.[28] Several manufacturers have joined as partners including Aaon, Trane, Daikin, Lennox, Monaire, Rheem, York (Johnson Controls), and Carrier.[25]

4 Research objectives and methodology

This section provides details on CalMTA's research objectives and methods used to answer key questions while developing the CRTU MTI. These methods included energy modeling, field study, manufacturer and stakeholder engagement, and literature review.

4.1 Research objectives

The following describes the key research objectives and questions investigated by the CalMTA team while conducting the Product Assessment.

1) Understand the broad set of opportunities to improve RTU performance, including features currently promoted by other efficiency advocates in California and the rest of the US.

2) Understand which efficiency measures have the greatest impact on energy consumption and electricity demand for RTUs across California's varied climate zones.

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[27] CEE Commercial Unitary Air-conditioning and Heat Pumps Specification

[28] Better Building's Commercial Building Heat Pump Accelerator

3) Evaluate currently available RTUs to understand availability, maturity, and any product development needed for products from multiple manufacturers to meet the CRTU MTI product definition; assess the timeline for integration of different features identified in the product definition.
4) Prioritize market-ready RTU features and attributes that can be integrated into products while minimizing cost to consumers.
5) Quantify utility bill impact for each of the key Target Technology features in the product definition.
6) Evaluate the potential for app-based remote monitoring and connected commissioning tools to identify and resolve inefficient operation.
7) Understand manufacturer perspectives, priorities, and potential for alignment with original equipment manufacturers (OEM).
8) Identify technical barriers and potential solutions to increase the adoption of high-performance CRTUs.

4.2 Research methods

4.2.1 Energy modeling and analysis to refine CRTU MTI product definition

Although simpler than some commercial HVAC equipment, single-zone RTUs offer many opportunities for improvement, and have therefore drawn the attention of efficiency advocates and market transformation organizations across the U.S., some of whom are also in the process of developing specifications for advanced/efficient RTUs. In the interest of collaboration, CalMTA evaluated several of the RTU features and specifications identified by these other organizations, as well other features identified through independent research and analysis.

The objective of this evaluation was to identify a unique set of features that would provide the greatest benefits to California ratepayers, given California's unique climate and energy markets. The final CRTU MTI product definition in Section 3 was developed using the results of this analysis.

The CalMTA team relied primarily on energy modeling for this evaluation, but also considered other factors such as input from manufacturers and other market actors to ensure that the key features and attributes identified in the CRTU MTI product definition are available in the market, align with OEM business models and product development cycles, and can realistically be integrated into a wider range of products over the course of the MTI.

Furthermore, California's electricity grid faces unique challenges that impact decisions about what features and attributes hold the most value to ratepayers and system operators. These include:

9) High statewide summer peak electricity loads, driven primarily by air conditioning.

10) High penetration of energy from variable renewable sources that do not always align with electricity demand, especially during the coldest hours of the year.

11) Relatively low statewide annual heating loads for commercial buildings.

12) High penetration of natural gas fuel for space heating in existing buildings.

13) Policies and programs driving electrification of transportation, space conditioning, and water heating, increasing demand for electricity.

14) Local constraints on electrical infrastructure at the building, transformer, and distribution scale.

4.2.2 Energy modeling to assess statewide impacts

Following the first phase of energy modeling to support the development of the CRTU MTI product definition, a subsequent phase of building energy modeling was conducted to assess statewide impacts and support the development of Total System Benefit (TSB) calculations.

Both phases of energy modeling were performed using EnergyPlus, the open-source DOE software, with American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1-2004 DOE reference building models to represent typical commercial buildings with single-zone RTUs that would be replaced (rather than new construction). These models were selected as a reasonable set of models to define an existing building construction set while also leveraging models available in EnergyPlus. A detailed description of the energy modeling can be found in Appendix B, Attachment 2.

4.2.3 Field study/technology demonstration

CalMTA worked with the Western Cooling Efficiency Center (WCEC) at UC Davis to conduct a demonstration study at a building on the UC Davis Campus. The study improved the team's understanding of barriers and opportunities for replacing conventional, mixed-fuel RTUs with variable speed HP RTUs offering CCC. The WCEC personnel worked with UC Davis facilities staff to identify an RTU that was nearing the end of its useful life. The proposed replacement unit was specified to include variable speed compressor, remote monitoring capability, and efficient cooling; several distributors provided bids for several different products. This allowed the CalMTA team to gain insight into the decision-making process for selecting a replacement product that includes switching the fuel for building heating.

Detailed monitoring of the unit allowed commissioning practices to be assessed and heating and cooling performance to be quantified in different modes of operation. CalMTA and WCEC personnel monitored the unit throughout the summer months under different control settings to learn more about the value of different RTU features. A more detailed discussion of the methods and findings will be published at the conclusion of the study.

4.2.4 Manufacturer, stakeholder, and expert engagement

The CalMTA team met with representatives from Trane, Carrier, CaptiveAire, Aaon, and Daikin to better understand the technology available, potential product improvements, and to gain insights into the business decisions made by manufacturers.

4.2.5 Literature review

The CalMTA team compiled and reviewed reports, publications, and industry white papers that considered all aspects of HVAC performance, including hardware and software. Studies were obtained from existing resource repositories, the CEE Resource Library, the Better Buildings Alliance, the California Energy Commission (CEC) website, DOE national laboratories, American Council for an Energy-Efficient Economy (ACEEE) website, and sources found through general internet searches. While the list of studies reviewed was not exhaustive, it provided existing knowledge to inform our product definition, findings, and recommendations.

5 Technical barriers and opportunities to broader adoption

5.1 Barriers and opportunities of currently available products

5.1.1 Inconsistent user experience and capabilities for different remote monitoring and CCC platform controls

RTU manufacturers are at different stages of developing remote monitoring packages and service offerings. Some of the software is not user-friendly and/or the manufacturer documentation included with the product is unclear. This presents an opportunity for CalMTA to encourage manufacturers to focus more on the user-interface of the products offered as well as developing training materials.

5.1.2 "Black box" factory control logic/proprietary data labeling

RTU manufacturers are protective of control algorithms and sequences of operations used in RTUs, limiting the ability of third-party advocates to ensure that energy performance is optimized. Federal test procedures provide a partial solution, since lab-measured performance does not require knowledge of control logic. However, test procedures only measure the performance of new equipment under controlled conditions.

Remote monitoring can optimize long-term operational performance by using sensors to monitor points within an RTU. However, the systems currently offered by manufacturers use proprietary data-labeling schemes that make it difficult for third parties (such as utility programs or building controls companies) to identify performance issues and faults. CalMTA can work with manufacturers to use a standardized representation of data with open-source tools, such as Brick or Haystack.

5.1.3 Limited availability of three-phase RTUs with variable speed compressors

Currently, most RTUs with variable speed compressors are single-phase units targeted at the residential market or dedicated outdoor air system (DOAS) units designed for buildings with high ventilation rates. A few exceptions, such as the Daikin Rebel, offer a variable speed inverter compressor on a three-phase HP RTU.

5.1.4 Electrical capacity constraints for HP RTUs

Since electrical capacity for existing mixed-fuel RTUs is typically sized to meet only the cooling load, replacing a mixed-fuel RTU with a HP can be challenging. Although commercial buildings in California tend to have higher cooling loads, this is not always the case. Some older buildings with poor envelopes have higher annual heating loads, and many of them have higher peak heating loads, which drive sizing calculations. Furthermore, even in cases where a HP would have sufficient capacity to meet peak heating load, HVAC contractors often install "backup" strip heating, which better mimics the instantaneous heat provided by gas furnaces, helping to avoid callbacks.

In some cases, this constraint can be addressed by reducing or eliminating resistance heating. Using a variable speed HP (a.k.a., cold climate HP) can provide heat under higher loads and lower ambient conditions, reducing the need for ER heating.

5.1.5 Physical space and structural requirements

When replacing an RTU on an existing building, the building structure and space must support the proposed unit. Typically, RTU replacements are like-for-like, which means that considering the size or weight of the unit is unnecessary, as the new unit will easily fit the existing curb with weight kept consistent within model categories.

While some manufacturers are attempting to design HP RTUs with the same footprint as existing mixed-fuel RTUs, many high-end products are targeted towards new construction and custom applications, and do not prioritize curb compatibility for ease of replacement. RTUs can either sit on a manufactured curb or a platform, but replacing an existing unit with a different brand or model, regardless of fuel type, will often require a curb adapter. The curb adapter is an added expense and can increase energy consumption by adding additional pressure drop to get air into the space.

Although the industry perceives the higher weight of HPs (over mixed-fuel RTUs) as a barrier, this may be based on assumptions from regions with higher heating loads. In fact, research from

Energy 350 found that specifications for 2- to 5-ton units showed that HPs weigh less than mixed-fuel units, on average.[29]

5.1.6 Heating season performance/supplemental heating

HP efficiency is impacted by outdoor air temperature, which is why performance is often reported at several testing conditions (often 47°F and 17°F). In colder climate zones, HP RTUs may need ER back-up. This could pose a challenge if the building's electrical capacity cannot handle additional load. The average minimum temperature at which HP RTUs remain efficient is highly dependent on the type of system, climate zone, and whether the unit is designed for cold climates. Efficiency and heating capacity begin to drop at 40°F, on average, and struggle significantly under 25°F. Backup ER heating is often triggered at this time, further reducing the efficiency of the HP RTU. Previous research in California has found that with the exception of climate zone 16, the hours of supplemental heating operation are minimal in non-residential units.[30] A National Renewable Energy Laboratory (NREL) study based on annual effective heating coefficient of performance (COP) calculated for ComStock simulations found that 6% of heating electricity input in California is used for supplemental heating.[31]

5.1.7 Thermostat selection

For the potential energy savings of variable speed compressors to be fully realized, a customer generally must use the proprietary thermostat offered by the manufacturer, which customers often complain is not as user-friendly as third-party thermostats like Pelican. Third-party thermostats are limited in the number of stages they can control, and many features and benefits are often lost due to a lack of adequate two-way communication.[32] A research study by Energy 350 found that only three out of the five major manufacturers offer more than one communicating thermostat that is compatible with variable capacity, and manufacturers do not have plans to open the communication up to third-party suppliers.[33]

To overcome this barrier, CalMTA could support the expanded development of adapters that allow variable-capacity HP RTUs to be controlled by a third-party thermostat without reducing

[29] Feasibility Assessment for Heat Pumps at Equipment Replacement

[30] 2025 Nonresidential HVAC Heat Pump Baseline Report

[31] Impact Analysis of Transitioning to Heat Pump Rooftop Units for the U.S. Commercial Building Stock

[32] ACEEE. 2024. Smart Thermostats plus Heat Pumps: Incompatible? Or just need counseling?

[33] Energy 350. Variable Speed Heat Pump Smart Thermostat Findings

efficiency.[34] Another option is that some HVAC manufacturers are adding more of the "brains" to the unit, allowing it to work with a third-party 24v thermostat. It's unclear if non-residential RTUs are also moving in this direction.

5.1.8 Cloud connectivity and security risks

Most commercial buildings in California are equipped with internet access, making CCC relatively easy to implement. However, some building owners may be hesitant to use WiFi or even Ethernet connectivity to connect a thermostat or RTU controls, due to the potential security risks, while others may find connecting the system too complicated or time-consuming.

To address this potential risk, some manufacturers include cellular modems and a cellular data plan that streamlines the process of connecting a new RTU to the cloud and creates a direct connection that does not expose the rest of the building's network to security risks.

5.1.9 Commissioning gaps

Research from field studies has found that there are many HVAC units being installed improperly. When the HVAC unit is a HP, this may cause the unit to short-cycle or fail to stage properly, resulting in higher rather than lower energy costs to the customer. A 2018 NREL study found that 65% of residential HVAC units are installed improperly or are performing sub-optimally.[35] CalMTA can directly address this barrier by encouraging the adoption of CCC.

5.1.10 Refrigerant transitions

Stricter regulations are phasing out many common refrigerants like R410. For example, California Senate Bill 1206 prohibits the sale of hydrofluorocarbons (HFCs) that exceed a global warming potential (GWP) of 2,200 starting January 1, 2025, 1,500 GWP starting January 1, 2030, and 750 GWP starting January 1, 2033. This is made more complicated because the methods of calculating GWP are revised in each Intergovernmental Panel on Climate Change (IPCC) report, which has resulted in R32 refrigerant moving from under 750 GWP to over 750 GWP. This creates a level of uncertainty for manufacturers looking to commit to a technology/design in the mid- to long-term.

Currently, R410A (GWP: 2,088) and R134a (GWP: 1,430) are the most common refrigerants in use. CalMTA should not pursue products whose specs show R410A refrigerant. R410A is a higher GWP refrigerant that will be replaced by newer, lower-GWP alternatives. The most popular

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[34] Johnson Controls released a universal Thermostat Adapter in 2022 that allows variable capacity residential HVAC systems from York, Luxaire, Coleman, and Champion to be controlled by a third-party thermostat without a reduction in efficiency. See: Universal Thermostat Adapter

[35] Develop field test methods and analytical techniques to assess HVAC fault impacts and a simplified commissioning method

alternative refrigerant for these products is currently R32 and R454b.[36] R32 has become widely adopted in Asia as the next refrigerant of choice in Residential HP/AC applications. Natural refrigerants are often cited as the future of refrigerant technology. Natural refrigerants such as transcritical CO_2, propane, isobutane, and ammonia all have a GWP close to 0. These products are ideal for policies aiming to reduce GHG emissions, although there are concerns around toxicity and flammability that are slowly being addressed.

5.1.11 Interconnection/interoperability

Currently, integrated remote monitoring systems in RTUs have no standardization in terms of nomenclature or internal logic. Some manufacturers offer control devices only as an aftermarket product while other manufacturers have a full suite of offerings, including a service platform with a user interface and notifications. This presents an opportunity for CalMTA to collaborate with manufacturers to promote the adoption of a standardized data naming convention such as Brick schema, Project Haystack, ASHRAE 223P, or AHRI Standard 1380.[37,38,39,40]

5.1.12 Low cost of sensors

Recent advancements and cost reductions for sensors and increased digital connectivity make it easier than ever to adopt RTUs with onboard sensors and cloud-based analytics.

6 Codes, standards, and policies

Many codes, standards, and policies can be an effective leverage point to drive market transformation and can help to lock in savings in a transformed market, while others can create complexity and a temporary barrier or limitation to adoption of the Target Technology.

6.1 Federal standards

Packaged RTUs are governed by Federal Appliance Standards, which focus on the efficiency metrics of the product. Federal preemption under the Energy Policy and Conservation Act (EPCA) prohibits individual states from creating regulations that are more stringent than the federal minimum efficiencies and specifications for RTUs. There are separate federal test procedures and standards governing RTUs with cooling capacity of less than 65,000 Btu/h and RTUs with cooling

[36] The facts about R-32 and R-454B

[37] Brick Schema

[38] Project Haystack

[39] ASHRAE Standard 223P

[40] AHRI Standard 1380

capacity between 65,000 Btu/h and 760,000 Btu/h. Minimum efficiency standards for products between 65,000 Btu/h and 760,000 Btu/h are further divided into three groups, shown in Table 4. The upper limit of 240,000 Btu/h (20 tons) aligns with the CRTU MTI product definition. Three-phase RTU products under 65,000 Btu/h are rated using the same test procedure and metric used for single-phase residential packaged equipment. The cooling efficiency minimum for single-phase residential RTUs is the same as three-phase RTUs.

DOE must review existing test procedures for all covered products and equipment every seven years and publish a notice of proposed standards every six years, with a final rule two years after that. Since the efficiency of commercial RTUs is federally regulated, the CEC is "preempted" from creating more stringent performance standards than the federal standards, so Title 20 and federal standards are the same for units less than 65,000 Btu/h, and Title 24 Energy Code and federal standards are the same for units between 65,000 Btu/h and 760,000 Btu/h. Current efficiency requirements and metrics for four different size categories are shown in Table 4.

Table 5. Minimum federal efficiency standards for HP single package HVAC products

Size Category	Current Efficiency Metrics	2029 Updated Efficiency Metrics	Test Procedure
<65,000 Btu/h	13.4 SEER2	13.4 SEER2	AHRI 210/240
≥ 65,000 Btu/h and < 135,000 Btu/h	14.1 IEER 3.4 COP	13.4 IVEC 6.2 IVHE	AHRI 340/360
≥ 135,000 Btu/h and < 240,000 Btu/h	13.5 IEER 3.3 COP	13.1 IVEC 6.0 IVHE	
≥ 240,000 Btu/h and < 760,000 Btu/h	12.5 IEER 3.2 COP	12.1 IVEC 5.8 IVHE	

The Title 24 Energy Code may create more-stringent requirements for products that are not covered by a federal product class, as well as certain attributes of federally regulated products that are not directly regulated by federal standards.

6.1.1 Federal standards for air cooled, three-phase, small commercial AC and HPs with cooling capacity less than 65,000 Btu/h

The current energy conservation standards were effective August 1, 2023, with compliance required on and after January 1, 2025. The standards require a product to meet a minimum SEER2 for cooling and Heating Seasonal Performance Factor 2 (HSPF2) for HP space heating, metrics that were introduced in the most recent test procedure based on AHRI 210/240. The test procedure better accounts for the energy consumption of variable-capacity units by testing at five points with different outdoor air temperature and loads and then creating bins by interpolating those points. The energy consumption during standby and other compressor-off hours is not counted in the current test procedure.

An updated test procedure has been proposed based on AHRI 1600, which would introduce two new metrics: seasonal cooling and off-mode rating efficiency (SCORE) and seasonal heating and off-mode rating efficiency (SHORE). Testing to these new metrics is not required until updated standards are developed, which is not expected in the near term. The new test procedure accounts for standby power as well as capturing crankcase heating and control power during compressor-off periods.

6.1.2 Federal standards for air-cooled commercial package AC and HPs with cooling capacity greater than 65,000 Btu/h

The current energy conservation standards for products greater than or equal to 65,000 Btu/h and less than 760,000 Btu/h were negotiated in 2015 and took effect on January 1, 2023. The standards adopted the Integrated Efficiency Ratio (IEER), which was introduced in the most recent test procedure based on AHRI 340/360. The standards require a product to meet a minimum IEER and coefficient of performance (COP). A new test procedure and energy conservation standards were negotiated between DOE, manufacturers, and energy efficiency stakeholders in a process that ended in March 2023. DOE published a Final Rule with an effective date of September 17, 2024. The test procedure and energy conservation standards will go into effect on January 1, 2029, and be in effect at least through December 31, 2034. The standards require a product meet a minimum IVEC and Integrated Ventilation and Heating Efficiency (IVHE), metrics that were introduced in the most recent test procedure based on AHRI 1340. The new test procedure better accounts for crankcase heating, control, ventilation fans, and benefits of fan power when economizing.

Due to the difference in the test procedures, there is not a strong correlation between IEER and IVEC, as seen in Figures 3 and 4.[41] For example, Figure 3 shows that two different models both rated at 15 IVEC would achieve 16 IEER and 22 IEER, respectively.

[41] Technical Support Document: Air-Cooled Commercial Unitary Air Conditioners and Commercial Unitary Heat Pumps

Figure 3. IEER to IVEC relationship for small AC and HP units between 65,000 Btu/h and 135,000 Btu/h based on the aggregate dataset used during the most recent federal rulemaking proceedings[41]

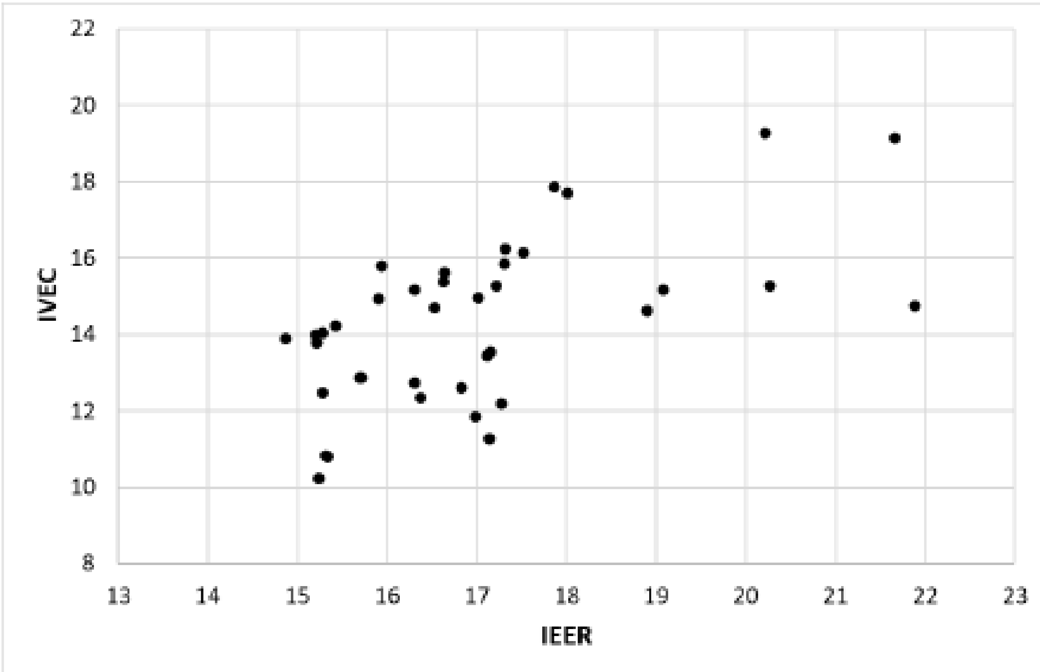
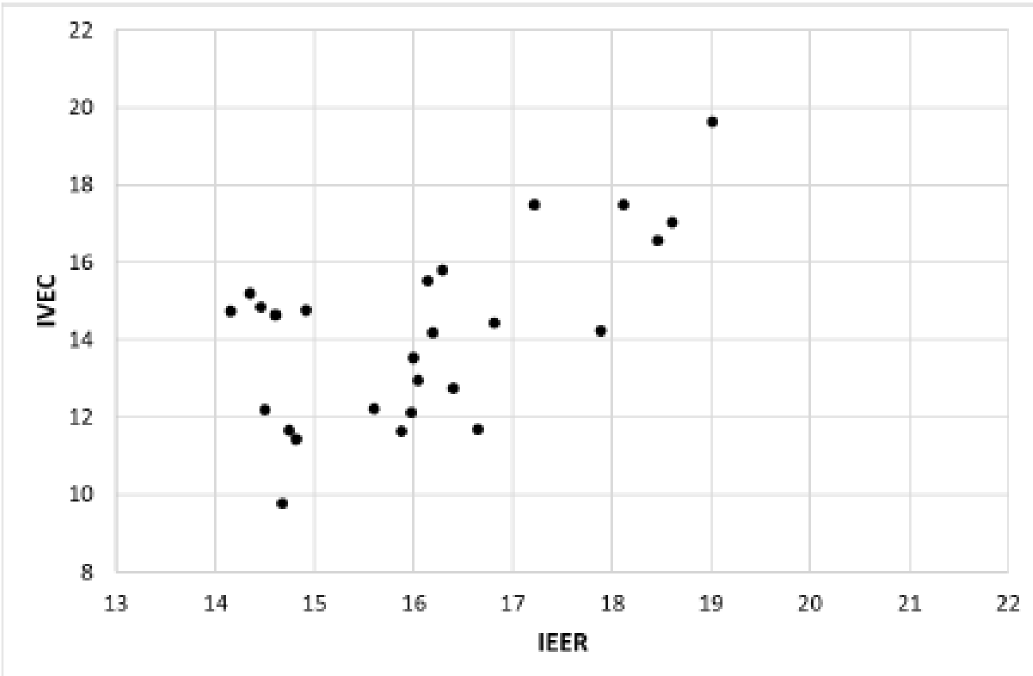


Figure 4. IEER to IVEC relationship for small AC and HP units greater than 135,000 Btu/h and less than 240,000 Btu/h based on the aggregate dataset used during the most recent federal rulemaking proceedings[41]



The 2029 updated federal standards estimate that the total energy savings over 30 years is a savings of 10% relative to current products on the market, although some manufacturers may begin testing to the IVEC minimum earlier than the federal standard effective date of January 1, 2029.[42]

6.1.3 Federal standards process timeline

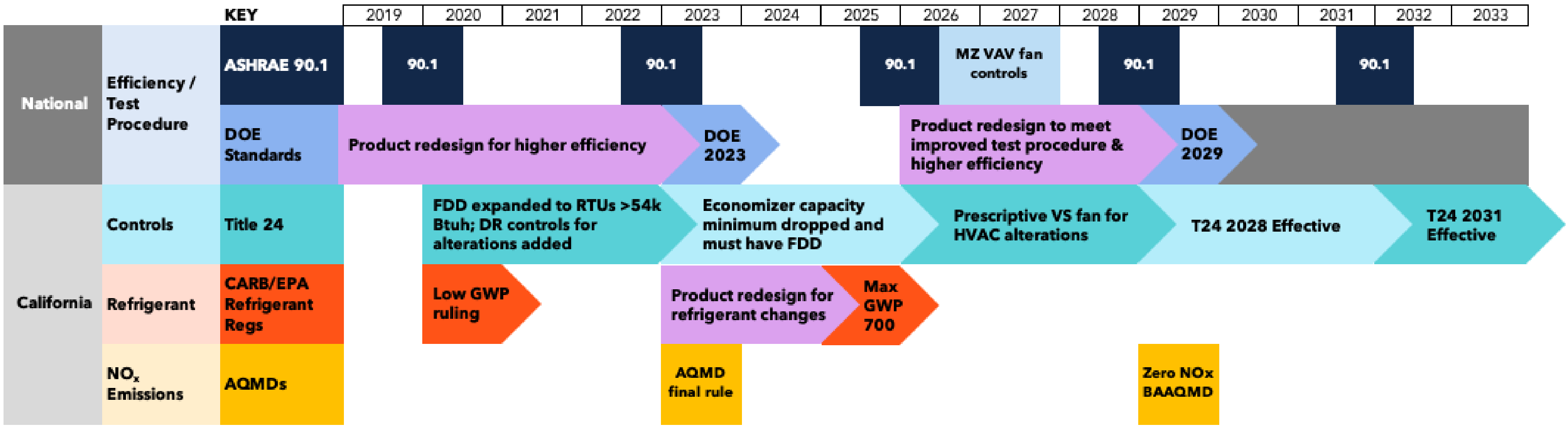
There are numerous RTU activities that affect product design and the market, including federal standards rulemaking, ASHRAE 90.1 updates, EPA rulings, and local regulations and energy or building code updates, such as California Air Resource Board (CARB) rules, which limit the time manufacturers have to evaluate and redesign current products to meet new energy efficiency standards or state rules, as shown on Figure 5. Understanding this timeline will help CalMTA work within the existing product evaluation and design structure to reduce burden on RTU manufacturers. However, political uncertainty could extend the timeline for future updates to

[42] DOE Finalizes Energy Efficiency Standards for Distribution Transformers That Protect Domestic Supply Chains and Jobs, Strengthen Grid Reliability, and Deliver Billions in Energy Savings

federal standards, potentially providing more opportunity to engage with manufacturers on product development.

ASHRAE 90.1 generally leads product efficiency improvements. Once ASHRAE publishes an updated model code, the DOE has 12 months to conduct its review and publish its determination. After a determination is published, states have two years to adopt the new model code that meets or exceeds ASHRAE 90.1. California uses ASH90.1 as a reference point with the latest version of ASHRAE 90.1 reviewed and evaluated on whether adopting provisions "at least as stringent" as ASHARE 90.1 is cost effective and consistent with California's climate goals.

Figure 5. Snapshot of regulatory proceedings influencing product development



6.2 California standards

6.2.1 Title 20 appliance standards

As noted above, RTU efficiency is preempted by federal standards. CA Title 20 incorporates the DOE standards as a "backstop;" if the DOE were to stop covering products for any reason, the Title 20 standards would become effective. Title 20 has begun to take on flexible demand appliance standards (FDAS), which are typically focused on how much energy can be shifted at certain times rather than on energy efficiency.

6.2.2 Title 24 energy code

While California is preempted from creating more stringent energy standards for the whole box RTU, regulations can be developed that cover a component or aspect of RTU performance that is not recognized as a federally covered product, such as an economizer. California can also develop prescriptive compliance options that exceed the federal minimum if there is another viable compliance option that does not exceed the federal minimum. A project can demonstrate compliance with Title 24 via the prescriptive method that defines a specific set of building and HVAC components or via the performance method that allows builders to trade-off between different components, allowing much greater flexibility and therefore lower construction costs (although an energy model must be developed to prove that the project does not exceed the energy emissions of the same building built to the prescriptive standards). The California Energy Code has adopted different requirements for new construction and alterations. New construction code already requires or encourages several of the features encompassed in the product definition, which led to a focus on alterations to maximize the impacts of the MTI.

For new construction, Title 24 code prescriptively requires HPs for single-zone, direct expansion space-conditioning systems with a rated cooling capacity 240,000 Btu/h or less serving retail, grocery, office, financial institution, warehouses, and library building spaces in nearly the entire state.[43] Conversely, for an alteration scenario, installing an AC with furnace is still allowed for all building types and climate zones. This allows the MTI to target existing buildings with HPs to maximize impacts.

There are several sections in Title 24 that regulate components of RTU performance. Of interest for the MTI product definition are economizer functionality, including FDD and thermostat capabilities for DR.

- Economizers are prescriptively required for cooling air handlers with a design total mechanical cooling capacity of greater than 33,000 Btu/h in new construction and greater than 54,000 Btu/h in alterations. The economizer must also have controls so that the economizer operation does not increase building heating energy use during normal operation, is capable of providing partial cooling, is designed and equipped with a high-limit shut off, and maximum leakage from the air economizer dampers. Title 24 requires RTU economizer FDD in new construction, but alterations of space-conditioning systems or components are exempt from this requirement.
- Economizer outdoor air and return air dampers must prescriptively have a maximum leakage rate of 10 cfm/ft^2 at 1.0 inch of water.
- If an economizer is prescriptively required, the direct expansion unit is greater than 65,000 Btu/h, and the capacity of the mechanical cooling is directly based on occupied space temperature, the unit must have two stages of mechanical cooling. If the capacity of

[43] Climate zones 1 and 16 allow mixed-fuel HVAC systems of 240,000 Btu/h or less for select new construction building types.

mechanical cooling is not based on occupied space temperature, the unit must have at least three stages of cooling for units greater than or equal to 65,000 Btu/h and less than 240,000 Btu/h.

- Prescriptively, ER heating systems shall not be used for space heating in new construction or alterations, with several exceptions. It is mandatory that HPs with supplemental ER heaters be installed with controls.
- Exhaust air heat recovery is prescriptively required for HVAC systems (including RTUs) depending on the climate zone, percentage of outside air, and minimum cfm rates.
- Single-zone RTUs above 5.4 tons prescriptively must have fans that are capable of reduced airflow and reduced power at a minimum % reduction in flow rate. The code also encourages the use of variable speed fans by allowing higher peak power if the design includes a variable speed fan.
- New or replacement RTUs in new construction or alterations must install demand responsive controls, which must be OpenADR 2.0a or 2.0b or certified by the manufacturer that the thermostat is able to respond to a DR signal and have a bi-directional communication pathway and must also adhere to JA5 Technical Specifications for Occupant Controlled Smart Thermostats described in Joint Appendix 5 of Title 24, Part 6. Requirements include manufacturer certification and functional specifications including setback capabilities, event responses, and user interfaces. However, the requirements are limited to DR capability—there is no requirement that the thermostat be connected to the internet and no acceptance test required to verify functionality.

6.2.3 Low compliance rates with California energy code in the replacement market

The Title 24 Energy Code is an effective tool for new construction, but poor code compliance in equipment change-outs show that improving the rate of adoption in the replacement market will require different tactics. Studies have found that HVAC equipment changeouts are rarely permitted, with rates ranging from 3 to 33%, although the focus of many of the studies has been primarily on residential.[44,45,46] Improper installations lead to increased energy bills, customer complaints, and in some cases, lawsuits.

[44] Final Report: 2014-16 HVAC Permit and Code Compliance Market Assessment

[45] HVAC Permitting: A Study to Inform IOU HVAC Programs

[46] Final 2021 Integrated Energy Policy Report Volume I Building Decarbonization

7 Competitive landscape

7.1 Incumbent technologies and practices

The target technology for CalMTA's CRTU MTI includes product improvements that offer alternatives to both conventional equipment and services. Features such as remote monitoring can potentially supplement or displace existing practices, such as HVAC service contracts that require routine inspections of equipment. As such, the incumbent technologies described below include conventional rooftop equipment, control systems, and service practices.

Table 6. Strengths and weaknesses of incumbent technology and practices

Incumbent Technology/Practice	Strengths	Weaknesses
Mixed-fuel RTUs	• Familiar to customers and contractors • Per unit of energy cost is lower for natural gas compared to electricity • Low upfront cost compared to variable capacity HPs • Infrastructure already in place in most existing commercial buildings • Less complex to commission and set up controls than variable capacity HPs • Furnace and AC can be sized individually to building loads and climate • Widely available • Consistent heating performance across a wide range of ambient conditions • High supply air temperatures can rapidly heat	• Higher GHG emissions • Heating efficiency is much lower than HPs • Limited efficiency gains possible—condensing furnaces are more efficient, but condensate waste is difficult to manage in commercial buildings, and efficiency gains are still very limited, relative to HPs • Require natural gas connection, adding cost in new construction • Gas leaks and combustion byproducts pose potential health and safety risks • More complex than fixed capacity HPs due to additional equipment (furnace)

	spaces • Low electrical consumption during the heating season	
Fixed capacity and two-stage HPs	• Lower upfront cost compared to variable capacity HPs • Less complex controls system • Less sensitive to power quality than variable speed HPs • Can be less expensive than mixed-fuel RTUs, depending on heating capacity	• Compressor cycling losses are higher compared to variable speed • Louder than inverter-driven compressors • Less efficient than variable capacity HPs in part load conditions • Mismatch between heating and cooling loads can decrease efficiency in some climates (due to poor part-load performance) • Less precise temperature control than variable capacity equipment • Less flexibility to maintain occupant comfort during peak demand events (vs. variable capacity HPs)
Programmable Thermostats	• Widely available • Slightly less expensive than OEM thermostats • Easy to use • Already installed in many commercial buildings	• Cannot effectively control variable speed products • Cannot adapt to occupancy, weather changes, or internal heat gains in real time • Settings are easy to override • No connectivity or off-site visibility to setpoints, schedules, or faults
RTU service contracts	• Conventional approach that customers and contractors are comfortable with • Help to identify issues and ensure efficient operation in RTUs • Can be a reliable business model and revenue stream for HVAC contractors	• Typically include routine site visits to inspect and test equipment, increasing cost to customers and vehicle emissions from service trucks. • Faults and inefficient operation can go undetected between site visits • Potentially higher maintenance costs as problems

		can only be discovered during routine maintenance or when the unit fails • Many customers don't see the value in maintenance contracts and do not call service provider until equipment fails • Problems and inefficient operation cannot usually be diagnosed without a site visit

7.2 Alternative(s) to target technology

In contrast to the widely adopted incumbent technologies described above, there are several alternative technologies that offer some of the same benefits that CalMTA's Target Technology offers, and which building owners may also consider when upgrading or electrifying their HVAC system. However, most of these technologies require the installation of additional equipment, while the Target Technology can achieve the same benefits through a relatively simple like-for-like replacement of an existing RTU.

Table 7. Strengths and weaknesses of alternative technologies and practices

Alternative Technology/Practice	Strengths	Weaknesses
Variable Refrigerant Flow (VRF)	• All-electric solution for small and medium commercial heating and air conditioning • Highly efficient • Flexible design • Precise temperature control	• Not a like-for-like replacement solution for buildings with RTUs – requires installation of an entirely new system • Does not provide outdoor air ventilation, which must be provided by a separate unit (typically DOAS) • Long, site-built refrigerant lines are more susceptible to leakage than factory-sealed refrigeration systems • High upfront and maintenance costs • Not suitable for all building types

		• Maintenance requires specialized knowledge • Proprietary control logic—not easily integrated with other systems or BMS/EMS • Proprietary controls and equipment spread throughout building lock users into one manufacturer's ecosystem
Dedicated Outdoor Air System (DOAS)	• Can be highly efficient if it includes energy recovery • Better humidity control • Helps meet ventilation code requirements • Good solution for buildings with high outdoor ventilation rates (restaurants, labs, etc.) • Several all-electric variable capacity HP options available • Fraction of outdoor air can be adjusted • Can be used in combination with RTUs or VRF to provide ventilation	• Efficient units are expensive • 100% outdoor air and humidity control features not necessary for many building types and climates • Integration with other space conditioning equipment can be complex • Larger than a ducted HVAC system • System must be carefully designed to meet building needs
BMS	• Can detect some performance issues in RTUs • Detailed and real-time data helps save energy and reduce operating costs • Makes it easier for customers to	• Expensive – not always cost effective for small and medium businesses, especially sites with a small number of RTUs • Requires installation and maintenance by specialized controls contractor

	participate in utility DR programs	• Offers greater value to buildings with large integrated systems (e.g., multi-zone variable air volume systems[47]) • Limited performance data accessible through BMS; not typically integrated with sensors in RTUs.
AFDD retrofit products	• Can be installed on existing RTUs • Offers similar functionality to new RTUs with factory-installed sensors and CCC	• Higher equipment and labor cost than factory-installed AFDD sensors and software. • Not part of standard equipment replacement process – requires building owner to purchase a separate product and service. • May not integrate easily with existing BMS or RTU control logic. • Facility teams may not have training to act on diagnostics. • Can generate excessive or redundant alerts overwhelming maintenance teams. • Limited capabilities relative to factory-installed equipment, more likely to require on-site intervention to address faults detected by the system.

[47] Packaged rooftop units can be configured as multi-zone variable air volume systems with terminal units that regulate the temperature of air to different zones within a building. Multi-zone VAV systems are not included in CalMTA's CRTU Product Definition.

8 Product performance

This section discusses various aspects of the Target Technology product performance, including energy consumption, energy intensity, and peak demand, as well as GHG emissions, product reliability, and impact on customer bills. Finally, the CalMTA team calculated building-scale avoided costs to illustrate long-term benefits to California of adopting different advanced RTU technologies. More information about statewide avoided cost impacts and modeling can be found in Appendix B, Attachment 2.

8.1 Climate considerations

There is a wide variation in the type and quantity of HP RTUs currently installed in each of California's 16 CEC climate zones (CZ). The two coldest climates (CZ 16 and CZ 1) have less than 1% of the total HP RTUs, by capacity, installed in California. Although energy modeling incorporated data from all 16 CEC CZs, CalMTA's analysis focused on the identification of product features that will provide the highest statewide benefits.

8.2 Energy consumption/unit energy impacts/peak electrical

Energy modeling was the primary means of assessing product performance used for this report. Building energy modeling was performed using EnergyPlus, the open-source DOE software, with 2004 DOE reference building models to represent typical commercial buildings with single-zone RTUs that would be replaced rather than new construction. These models were selected as a reasonable set of models to define an existing building construction set while also leveraging models available in EnergyPlus. The building prototypes selected for the analysis were chosen based on the greatest number of sites installing RTUs and include:

- Quick service restaurant
- Warehouse
- Primary school
- Medium office (single story)
- Retail strip mall

All building types, except for the medium office and warehouse, were based on DOE prototypes. 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 then matched the controls and setpoints in the fine storage area.[48] This modification allows a whole building assessment of a conditioned warehouse rather than a small fraction of the floor space.

A detailed description of how the unit energy impacts (UEIs) were developed for this MTI can be found in Appendix B, Attachment 2.

8.3 Greenhouse gas emissions

The energy modeling analysis assumed two different baselines: an all-electric baseline and a mixed-fuel baseline. For the mixed-fuel to HP measures, GHG savings comprised at least two-thirds of the overall avoided costs. GHG savings for the all-electric baseline to HP measures ranged from 38% to 56% with an average of 41% when adopting all measures.

8.4 Bill impacts

Energy efficiency measures using the same fuel will typically result in bill savings for consumers. Fuel substitution, however, can be more complicated due to the difference in price for electricity versus natural gas, also known as the spark gap.[49] There is currently a relatively large spark gap in California, with electricity costing 5x or more than natural gas for the same amount of energy. Therefore, upgrading from electrical resistance heating to a HP RTU should almost certainly result in a reduction in utility bills for the user, while upgrading from a mixed-fuel unit to a HP RTU could result in higher energy costs depending on the efficiency of the existing and replacement units. For CalMTA's study of bill impacts, the team used present-day time of use (TOU) electricity and tiered natural gas rates published by California's four investor-owned utilities (IOU).

8.4.1 Methodology

The bill analysis evaluated cost impacts based on various commercial rates. Each IOU has different rate structures defined largely by customer size. Electric rates tend to be based on maximum demand while gas is based on monthly consumption. The analysis recognized the potential impact on demand charges from retrofitting a mixed-fuel HVAC system to a HP. Thus, demand impacts are inclusive within the results. Additional modeling details can be found in Appendix B, Attachment 2.

The hourly energy simulation outputs are based on an average of five DOE building prototypes in all 16 CEC CZs and by weighting based on square footage. 15-minute TOU rate tariffs and demand

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[48] The DOE prototype building includes a "bulk storage area," which assumes a very wide band of temperature fluctuation. To better represent the space conditioning systems used in distribution centers and light industrial applications found in California warehouse space, the bulk storage area was modified to match the tighter temperature control specifications used in the "fine storage area" of the DOE prototype.

[49] The spark gap (also known as the spark ratio) is the ratio in cost to the customer of 1 kWh of electricity to the cost of 1 kWh of natural gas. This is a common metric for assessing the economic practicality of fuel substitution.

charges were applied to the facility-level electric load shapes to estimate the electric cost impacts. Gas tariffs were applied using a cumulative consumption approach to estimate gas cost impacts.

While a spectrum of rates was analyzed, not every possible tariff is included. Instead, an evaluation of tariffs relevant to commercial buildings expected to have RTU products provided a basis for the results. The analysis includes several tariff rate structures for PG&E, SCE, SCG, and SDG&E. The final bill impacts did not differ significantly among the tariff rate structures, so the bill impacts were averaged.

8.4.2 Results

Results summarized in Table 5 represent the total bill impacts for each modeled scenario. Negative values indicate bill savings while positive values indicate an increase to customer bills.

Results are presented as a percentage reduction or increase of the dollar amount of estimated customer bills on a whole building basis. Since whole-building energy consumption includes lighting, water heating, plug loads, and miscellaneous loads, the percentages are lower than they would be if calculated solely for HVAC energy use. This is also why the percentage reduction for gas bills is less than 100% in the electrification scenarios.

Although two of the electrification scenarios resulted in a small net increase in total energy bills, this analysis suggests that the spark gap is less of a concern for commercial HVAC than it is in other sectors, such as single-family residential. The modest increases and bill savings vs. the mixed-fuel baseline can be attributed to two primary factors:

1) Annual heating loads for commercial buildings in California are relatively low. So, although the percentage decrease in gas bills is quite high, the baseline cost of gas heating is quite low, and the increase in electricity bills for heating electrification is also relatively small. Note the only service territory with increased total annual bills is PG&E, which also has the highest heating loads of the IOUs.
2) Peak load reductions result in outsized bill reductions due to TOU rates and demand charges. Demand charges, which are driven primarily by cooling energy consumption, can make up a large percentage of electricity bills for California commercial customers. Therefore, measures like improved cooling efficiency result in reduced demand charges, partially or completely offsetting the cost of electrification of heating—even though annual electricity consumption is increased.

Table 8. Average annual total facility bill impact by proposed measure, fuel type, and utility

Fuel Type	Case	Electric			Gas			Total *		
		PG&E	SCE/ SCG	SDG&E	PG&E	SCE/ SCG	SDG&E	PG&E	SCE/ SCG	SDG&E
All-Electric	COP 20	-4%	-4%	-3%	0%	0%	0%	-4%	-4%	-3%
	COP 20 + VS	-8%	-7%	-6%	0%	0%	0%	-8%	-7%	-6%
	CCC	-2%	-1%	-1%	0%	0%	0%	-2%	-1%	-1%
	App-startup	-1%	-1%	-1%	0%	0%	0%	-1%	-1%	-1%
	All	-10%	-8%	-7%	0%	0%	0%	-9%	-8%	-7%
Mixed Fuel	COP 20	3%	-2%	-1%	-63%	-40%	-39%	0%	-3%	-2%
	COP 20 + VS	-1%	-6%	-4%	-63%	-40%	-39%	-5%	-7%	-5%
	CCC	7%	1%	1%	-63%	-41%	-40%	3%	-1%	0%
	App-startup	7%	2%	2%	-63%	-40%	-40%	4%	0%	0%
	All	-2%	-6%	-5%	-63%	-41%	-40%	-5%	-8%	-6%

Notes

Negative values (green text and shading) indicate bill savings while positive values (red text and shading) indicate an increase to customer bills.

* Commercial building utility costs are dominated by electric utility cost. While gas savings are a large percentage, they contribute a small amount to the overall bill impacts in a mixed-fuel scenario.

COP 20: 20% increase in full-load compressor efficiency over code minimum cooling efficiency. Improved compressor efficiency also improves HP heating efficiency.

VS: variable speed compressor

App-startup: app-based startup commissioning

CCC: remote monitoring, AFDD+, and connected commissioning

8.5 Product reliability

Controls for variable capacity HP RTUs are more complex than fixed-capacity, mixed-fuel RTUs, introducing more potential for suboptimal performance. Furthermore, in contrast to mixed-fuel RTUs, HP compressors operate in both heating and cooling seasons, potentially shortening the lifespan of that component. However, eliminating the gas furnace eliminates that component as a potential point of failure.

Due to the higher potential for suboptimal performance of variable capacity RTUs, it is more important that they are installed and commissioned correctly, and that performance issues can be detected and resolved remotely. Connected commissioning, remote monitoring, and cloud-based AFDD are therefore even more valuable for advanced RTU products. These tools provide installers, service providers, and building managers more insight into performance and tools to correct performance issues throughout the life of the product.

CalMTA did not research the product reliability of the Target Technology in detail. Generally, RTUs are a mature product with both increasing reliability and effective useful life (EUL).

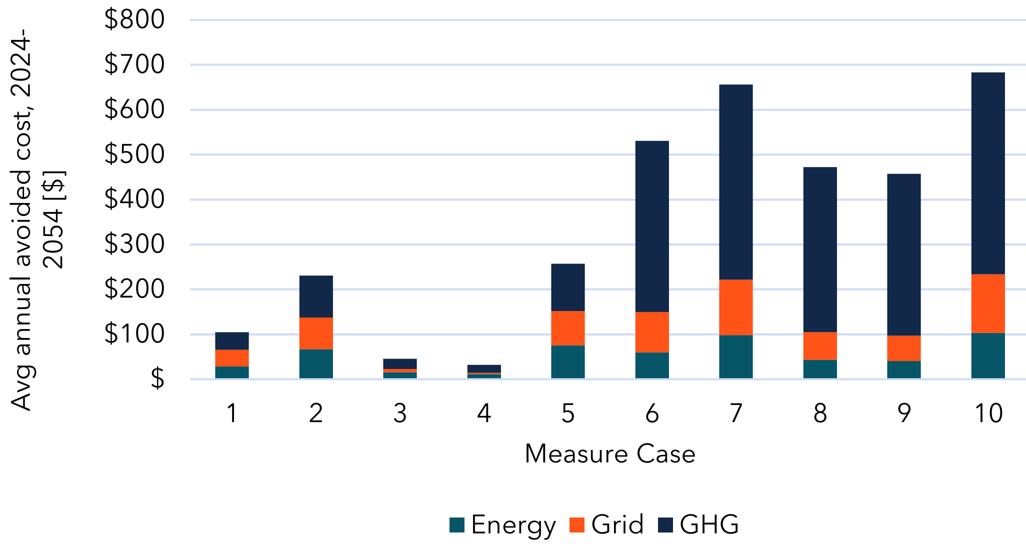
8.6 Avoided costs

This project used the CPUC's Avoided Cost Calculator, which provides a robust framework for evaluating the impact of fuel substitution and energy efficiency measures. The ACC estimates system-level utility costs of providing electric or gas on an hourly basis in $/kilowatt-hour (kWh) and $/therm. The avoided cost factors were multiplied by the modeled hourly unit energy savings (UES) outputs to develop annual avoided costs for each measure. The avoided costs were batched into three categories: energy benefits, grid benefits, and GHG benefits, which are the categories that are used for TSB reporting in the MTI Plan.

The avoided cost benefit for each measure case was calculated based on a start date of 2024[50] and extending through the estimated useful life of the appliance. The avoided cost benefit for each measure case is shown on Figure 6, broken down by energy, grid, and GHG benefits.

[50] The ACC includes hourly cost projections over a span of 30 years. Market adoption and cost-effectiveness modeling will incorporate those hourly values based on the expected timing of impacts, but for simplicity the figures presented here represent an average of the 30-year values calculated by the ACC.

Figure 6. Annual average avoided cost benefit by measure case, 2024-2054



A detailed description of how avoided costs were calculated and details on each of these measure cases were developed for this MTI can be found in Appendix B, Attachment 2.

9 Product objectives

Products meeting CalMTA's CRTU MTI product definition are available; however, there are currently few products that incorporate all features and attributes – and most of the products that meet the definition are premium products with other features that add cost without significantly improving performance or energy savings in California. Furthermore, the approach taken by manufacturers towards some features (such as CCC) is inconsistent, creating different, and potentially negative, end-user experiences with some products.

The product plan identifies short-, medium-, and long-term objectives focused on bringing more products to market, reducing the incremental cost for CalMTA-compliant CRTU products, advancing and enhancing certain features, and creating a more consistent end-user experience.

The objectives outlined below cannot realistically be implemented and accomplished through direct interventions and strategies that will be included in the MTI plan. Instead, these items should be viewed as potential actions that could be implemented by one or more groups including, but not limited, to CalMTA.

9.1 Objectives

9.1.1 Short-term product objectives

In the short term (1-3 years), the MTI could seek to achieve the following objectives:

- Establish best practices or specifications for remote monitoring, connected commissioning, and AFDD+, including user interface and alerts.
- Determine which standards for interoperability, communication interfaces, and/or load flexibility to adopt, if any.
- Identify key capabilities for CCC that align with and support OEM and HVAC service provider business models.
- Understand product development barriers and opportunities to integrate variable speed compressors into CRTUs with more than 65,000 Btu/h of cooling capacity.
- Develop product list mapping IEER to IVEC performance for products that have been tested to both standards.
- Develop product specifications, tiers, and QPLs for RTUs with some/all of the performance features identified in the product definition.

9.1.2 Medium-term product objectives

In the medium-term (4-8 years), the MTI could seek to achieve the following objectives:

- Work with RTU manufacturers to encourage open standards for interoperability and load flexibility.
- Work with RTU manufacturers to incorporate sensors and CCC into a broad suite of HP RTU products capturing the 2-minute market with minimal effect on pricing.
- Work with manufacturers so CRTU products provide easy-to-use customer and contractor remote interfaces with seamless and reliable connectivity.
- Ask manufacturers to develop connected commissioning tools that reduce or eliminate the need for on-site Acceptance Testing and data platforms to support compliance with Title 24 requirements.
- Update product tiers and specifications to align with the implementation of federal IVEC requirements effective January 1, 2029.
- Identify strategies to reduce fan energy consumption in RTUs equipped with variable speed fans.

9.1.3 Long-term product objectives

In the long-term (8-10+ years), the MTI could seek to achieve the following objectives:

- RTUs adhere to manufacturer installation best practices, product faults are detected, and ongoing performance can be optimized.
- Establish variable speed HP CRTUs that exceed 2029 minimum IVEC by at least 20% and include CCC as the predominant RTU product installed in both the custom and 2-minute replacement market.