CalNEXT
ENERGIZING CALIFORNIA'S FUTURE

Heat Pump Crankcase Heat Management

Final Report

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Executive Summary

The need for this project arises from field studies that indicate crankcase heaters (CCHs) and other auxiliary loads may use almost half the total energy of heat pumps (HPs) installed in California. There is a particular concern that sometimes CCHs operate when unnecessary. The objective of this study is to evaluate potential solutions to the CCH energy consumption issue and quantify potential savings from identified solutions.

Table 1 presents the key findings and recommendations of this research. Following the table, the project team provides a summary description of the key findings and recommendations. For more detail on these items, please see the body of the report. The project team assigned a priority level of high for recommendations that may immediately provide energy and emissions reduction or quantify potential future savings; and low priority for recommendations that are dependent on the findings of additional research, or research that could support future measure calibration.

Table 1: Summary of Findings and Recommendations

Findings	Recommendations	Priority
1. The current measure packages do not capture uncontrolled CCH operation.	a. Incorporate CCH control requirements in the existing HP measure packages.	High
	b. Conduct further research to investigate the prevalence and savings potential of unnecessary CCH operation.	High
	c. Consider development of a new retro commissioning (RCx) measure for existing HPs (may be subject to the result of Recommendation 1.b).	Low
2. The current measure packages assume all HPs have CCH.	Develop new measures for HPs specific without CCHs.	High
3. Primary data from commercial field studies are limited to one manufacturer in one building type.	Conduct further research at commercial sites to better understand if the modeled savings are representative of field conditions across all program applications.	Low

eTRM Measure Package Review & Benchmarking

The California Electronic Technical Reference Manual (eTRM) is effectively capturing CCH consumption, with the impacts varying by building type and climate zone. It is modeled that CCH operation only occurs when the temperature falls below 55°F, which reflects preferred field operation. This modeled CCH consumption estimates align with field studies in both residential and commercial sectors. However, the field studies indicate that in some cases CCHs may operate continually, causing unnecessary baseload consumption. The current measure packages do not capture uncontrolled CCH operation.

Market Assessment of HP products

The current measure packages assume all HPs have CCH, but interviews with manufacturers and distributors indicate that not all HPs include CCH. Additionally, current HP efficiency ratings may be misstating energy performance, as the current test procedures for ensuring that HPs comply with federal energy conservation standards do not fully reflect CCH operation. The California Energy Codes and Standards Program is currently drafting proposed 2025 Title 24 Code changes related to CCH control that will take effect beginning in 2026. In terms of market share, HPs make up 3 percent of residential heating systems and 31 percent of the commercial heating systems in California. These percentages are expected to grow rapidly with the statewide push for electrification.

DAC Impact Assessment

Low and middle-income households face a higher energy cost burden (which is the percent of income that a household spends on energy costs) compared with households who earn the area median income. Uncontrolled CCH operation could lead to additional and unnecessary energy costs of up to around $80 annually for low-income customers. TECH data shows that 7.8 percent of the participants were categorized as belonging to a disadvantaged community (DAC). Among these DAC sites, 81 percent of them are single family, while 19 percent of them are multifamily.

Recommendations

Based on this study, the project team proposed recommendations as follows:

- Update the existing HP measure packages to include a requirement for CCH controls. There is a limited window between now and 2026 when energy efficiency programs could **incorporate CCH control requirements in the existing HP measure packages**. Offering a rebate for HP projects that provide documentation showing compliance with CCH control requirements will ease the transition for market actors as they prepare for upcoming code changes.
    - If the lead investor-owned utilities (IOUs), SCE and SDG&E, are interested and have capacity to act quickly after the final report comes out, it may be possible for them to implement the CCH control requirement update to current measure packages in time for Program Year 2024 updates. This update might require energy modeling to determine savings but could be turned around more quickly without conducting modeling if the savings from the proposed 2025 Title 24 Code changes are applied.
    - Incorporating the requirement as a short-term program offering could support market actors as they prepare to transition for this to become code in 2026.

- Conduct further research to **investigate the prevalence and savings potential of unnecessary CCH operation.** This could lead to a potential development of a **new RCx measure** for optimizing CCH operation.
- Develop **new measure offerings for HPs specifically without CCHs.**
- Conduct further research at commercial sites to better understand if the modeled savings are representative of field conditions across all program applications.

Abbreviations and Acronyms

Acronym	Meaning
ACEEE	American Council for an-Energy Efficient Economy
ACUAC	Air-Cooled Unitary Air Conditioner
ACUHP	Air-Cooled Unitary Heat Pump
AEA	Association for Energy Affordability
ASHP	Air-Source Heat Pump
CCH	Crankcase Heater
CEC	California Energy Commission
COP	Coefficient of Performance
DAC	Disadvantaged Communities
DOE	Department of Energy
EE	Energy Efficiency
EER	Energy Efficiency Ratio
EnergyPlus	A building energy simulation software developed by the U.S. Department of Energy, used for modeling building energy performance.
EPIC	Electric Program Investment Charge
eQUEST	A building energy use analysis tool to perform detailed comparative analysis of building designs and technologies.
eTRM	Electronic Technical Reference Manual
GHG	Greenhouse Gas
HP	Heat Pump
HPWH	Heat Pump Water Heater
HSPF	Heating Seasonal Performance Factor

Acronym	Meaning
HTR	Hard-to-Reach
HVAC	Heating, Ventilation, and Air Conditioning
IEER	Integrated Energy Efficiency Ratio
IOU	Investor-Owned Utility
IVEC	Integrated Ventilation, Economizer, and Cooling
IVHE	Integrated Ventilation and Heating Efficiency
kWh	Kilowatt-hour
M&V	Measurement and Verification
MW	Megawatt
MZ	Multi Zone
OAT	Outdoor Air Temperature
PA	Program Administrator
REN	Regional Energy Network
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SEER	Seasonal Energy Efficiency Ratio
TPM	Technology Priority Map
VCHP	Variable Capacity Heat Pump
ZNE	Zero Net Energy

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Introduction

California's aggressive goals for greenhouse gas (GHG) reductions put heat pump (HP) technologies front and center with significant investment in HP space-heating systems through both California Public Utility (CPUC)-funded and legislatively mandated programs. HPs represent a key tool in meeting GHG goals and reducing adverse health impacts of burning fossil fuels in homes and are generally at least twice as efficient as fossil fuel-based systems like furnaces.

The California Electronic Technical Reference Manual (eTRM) has several individual measure packages that address deemed savings for HP-related technologies. This research project included reviewing a sample of these measure packages to determine if they are adequately addressing energy penalties from incorrect operation of crankcase heaters (CCHs) and defrost controls. This project identified the following gaps that exist in the current measure packages for residential and commercial air-source HP (ASHP) space-conditioning systems, which are important technologies for both EE and decarbonization efforts:

- The current measure packages do not capture uncontrolled CCH operation.
- The current measure packages assume all HPs have CCH.

The project team has the following recommendations for the California Technical Forum (Cal TF) and California investor-owned utilities (IOUs) for the ASHP measure packages:

- Incorporate CCH control requirements in the existing HP measure packages
- Conduct further research to investigate the prevalence and savings potential of unnecessary CCH operation, with the aim to inform and potentially develop a new retro commissioning (RCx) measure for existing HPs
- Develop new measure offerings for HPs specific without crankcase heaters

If implemented, these recommendations will enable a more accurate calculation of energy savings and associated penalties for HP retrofits, ensuring that new HP installations avoid issues with uncontrolled CCH, thus leading to improved savings.

This project aligns with the CalNEXT technology priority map (TPM) in the High-Efficiency Heating, Ventilation, and Air Conditioning (HVAC) HPs and HP Market Transformation areas. This report includes findings from the energy and market impacts assessment, including which measure packages may need updates and the scope of the problem to be addressed.

Objectives

The project objectives are to evaluate potential solutions to the CCH energy consumption issue and quantify potential savings from identified solutions, considering the following research questions:

- Is the issue specific to a particular manufacturer or type of HP?
- Are there HPs that do not have CCH that are relevant to California applications?
- Are there potential fixes that are easy to do in the field or the factory?

- Are potential fixes a software/programming solution or hardware upgrade?
- What sort of effective useful life (EUL) could we expect from the solution(s)?
- Can a standardized solution be implemented for all HPs?
- What are the potential costs of the solutions?

The expected outcomes of this project include:

- Identified gaps in the current measure packages for residential and commercial ASHP space-conditioning systems including:
  - Whether CCH, defrost controls and standby power are addressed in measure savings
  - Measure specifications that address these issues, or the lack thereof
  - Energy and Total System Benefit (TSB) savings impacts
- A market assessment of existing ASHP capabilities and potential solutions to address uncontrolled CCH, defrost or standby power usage
- Recommendations for updates to existing measure packages that eTRM governing bodies can consider for adoption
- Measure update impacts for hard-to-reach (HTR) and disadvantaged community (DAC) customers

Methodology and Approach

Project activities included reviewing energy and market impacts of incorrect CCH operation in the field as well as exploring solutions through analyzing existing datasets and energy models.

Literature Review

The project team reviewed existing studies conducted by organizations and experts such as the Association for Energy Affordability (AEA) Wilcox, et al., and many others. These studies were funded through the California Energy Commission (CEC) Electric Program Investment Charge (EPIC) Program, CEC codes and standards, and California IOU Statewide Codes and Standards Program. Additionally, the project team also examined relevant emerging technology studies in California and other regions across the United States (U.S.). The focus of the literature review was to quantify to the extent possible the following:

- Impact of the issue to existing ASHP installed in the field
- How many currently offered ASHPs have this issue
- How many new ASHPs will be installed in future years that may have this issue

Market Assessment

The project team conducted a market assessment to identify opportunities for addressing market needs in existing buildings. The project team has completed a review of the California residential and commercial HVAC system market and measure participation data; the project team and CP identified potential market impacts due to unnecessary CCH operation, with specific attention to underserved communities such as DAC and HTR customers.

Current State of HP Systems in the California Market

RASS DATA

The Residential Appliance Saturation Survey (RASS) is conducted in California, aiming to gather data about household demographics, energy usage, and appliances. The data provides a snapshot of the saturation of various energy-using appliances in residential buildings. The project team has identified the diverse HVAC systems in place for various residential building types. Key information that the project team collected includes the HVAC system types and their prevalence in different building types.

CEDARS CLAIMS DATA

The California Energy Data and Reporting System (CEDARS) is a data management and reporting system used by the CPUC and utilities. The data serves as a centralized repository for energy program data, including program performance metrics, program costs, and energy savings. To understand the measure package dynamics, the project team analyzed CEDARS claims data for the three-year spans of 2020–2022. Key information that the project team reviewed includes participation data of HP HVAC systems across the state.

TECH DATA

The TECH Working Data Sets provide anonymous data gathered from incentive applications submitted by TECH participating contractors as well as qualified product lists. The data is listed on a per-installation basis, so each row represents a unique installation of either a HP water heater (HPWH) or HP HVAC system. Similar to CEDARS claims data, the project team analyzed the market penetration and participation of the HP HVAC systems across the state for the residential sector.

CALIFORNIA COMMERCIAL SATURATION SURVEY

The California Commercial Saturation Survey (CSS) provides data on the baseline equipment characteristics in commercial facilities and insight into the saturation of energy-efficient technologies. The project team assessed the HVAC equipment data to determine the prevalence and market share of HP systems in the commercial sector.

ASHP Capabilities and Potential Solutions

The project team conducted a review of federal test procedures for CCH control as they apply to residential-sized or commercial-sized HP systems' performance efficiency. In addition to exploring the current state of federal test procedures, we present a discussion on draft Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Standards that may be adopted in future revisions to the federal test procedures. See the Initial Findings section on **Error! Reference source not found.** of this report for more detail.

Additionally, the project team conducted interviews with HP product manufacturers and distributors to better understand the various configurations of CCHs currently available in the market, and implications for how those CCH configurations may impact total system energy consumption. The interview guide is provided in

Appendix A: Interview Guide for HVAC Distributor and Manufacturer

eTRM Measure Package Review and Revision

The project team has reviewed existing measure packages and supporting documentation to evaluate whether the measures address CCH, defrost controls, and standby power usage in both the measure specifications and energy savings calculations.

Stakeholder Coordination and Project Management

TRC is leading the team delivering this project and is responsible for project deliverables. CalNEXT partners, Energy Solutions, and AESC, are supporting the project by providing technical expertise and staff to support project implementation.

We provided the opportunity for review and input by Cal TF staff and the lead program administrators. TRC coordinated with Cal TF staff and the measure review committee to identify existing data sources, dispositions, and reasons for existing measure package baseline systems. The project team also sought feedback from SDG&E and SCE regarding the preliminary findings and to identify specific data needs and gaps to address throughout the project.

Findings

This section describes the research findings, including an overview based on the literature review, a market assessment of ASHP capabilities, identified gaps in current measure packages, recommendations for updates, the impact of measure updates on HTR and DAC customers, and the associated feedback from stakeholders.

Literature Review

CCHs are necessary for HPs in conditions where the compressor sump is colder than other system components, which may cause liquid refrigerant to accumulate and damage the compressor without the CCH keeping it warm. HPs may be equipped with controlled CCH that activates based on specific parameters to optimize energy usage. Ideally, CCH should only function when the compressor is off. However, when HPs have uncontrolled CCH, the component may run continuously, regardless of whether the HP is in use or even when not necessary based on outdoor conditions. This uncontrolled condition can be due to inadequate control settings or improper installation in the field, leading to the CCH operating unnecessarily or for extended periods. Additionally, the Department of Energy's (DOE's) federal appliance standards regulate off-mode power (10 CFR §430.32(c)), including CCH, for residential air conditioners and HPs, but DOE does not regulate the on-mode power of CCH. The following discussion explores current literature findings regarding the impact of CCH inefficiency on existing ASHPs in the field, the prevalence of this inefficiency in current ASHP models, and projections about future ASHPs that might show the same inefficiency issues.

Impact on Existing ASHP in the Field

Recent studies have shown a potential problem with HPs installed in California homes in that they tend to use almost half of their energy on CCH, controls, and other vampire loads that are often not necessary in California's warm climates.

- A recent field study by the AEA for a zero net energy (ZNE) multifamily new construction project showed that CCH consumption in each apartment at a complex in Atascadero, CA (a mild central coast climate) was a fixed load of about 100 watts, consuming about 800 kWh/year, or half of the average systems' energy use (Dryden, A., G. Pfotenhauer, N. Stone, S. Armstrong). The building ended up not meeting its ZNE goals in large part due to this excessive CCH energy consumption.
- A study conducted by Wilcox et al. (2018) at a research house in central California also found that CCH was roughly half the total energy for the system's cooling energy use. The same study found that two units of different capacities (1 ton and 1.5 ton) from the same manufacturer operated CCH very differently. In the case of the 1-ton system, CCH operated only during cooling season but not during heating season. Conversely, for the 1.5-ton system, CCH operated in both heating and cooling modes and operated more during mild outdoor temperatures. Defrost operation was not found to be a major contributor to heating energy use in this field study.

A recent American Council for an Energy-Efficient Economy (ACEEE) paper (McHugh et al., 2022) that summarized these two reports along with additional data gathering summarized the worst-case scenario thus:

- CEC recommends the goal to install six million HPs by 2030.
- Field studies indicated 300 MW peak uncontrolled CCH (at 50 watts per HP). These uncontrolled crankcase heaters operate continuously to keep the compressor's oil warm, potentially consuming more energy than necessary.
- Field studies indicated 200 GWh per year of uncontrolled CCH (4,000 unnecessary hours/year at 50 W).

Prevalence in Current ASHP Models

Wilcox et al. (2018) presented data comparing ducted and ductless variable capacity HP (VCHP) systems and showed that the actual energy performance of the VCHP systems was often not in line with their seasonal EE ratio (SEER) ratings. The inefficiencies from the use of CCHs in ASHPs are evident in both ducted and ductless VCHP systems, which may imply that this could be a widespread issue in multiple types of ASHP systems. The energy demand of VCHP systems showed significant variations across houses being studied. For example, the ducted VCHP in a house used up to 61 percent more energy at certain times than a standard system. When the compressor was not operating, standby energy use (from onboard electrical parts, fans that run all the time, and CCH) contributed to the higher energy use seen in some VCHP units. An observation of the case study of multiple houses in this report (Wilcox et al., 2018) showed that nearly half of its expected yearly cooling energy came from constant power use and CCH.

Dryden et al. (2021) highlighted the inefficiencies stemming from the continuous use of CCHs in HVAC systems. The study revealed that CCHs were responsible for approximately 45 percent of the total annual HVAC load in a monitored project. It identified unexpected baseloads in split and ductless mini-split systems that were not factored into ZNE design or energy assessments. While some heaters are consistently active, leading to energy waste, the broader issue is the lack of transparent data from manufacturers. Designers often have to engage directly with manufacturers due to data inconsistencies or information that is not shared. The study suggests that widely accepted efficiency ratings (such as SEER and energy efficiency ratio (EER)) do not consider CCH consumption, which potentially misleads efficiency perceptions. To achieve real EE, there is a pressing need for greater transparency from manufacturers, improved design considerations, and enhanced user awareness about when and how CCHs should be deployed.

The literature sheds light on the prevalence of CCH inefficiencies in select VCHP units under certain conditions and offers general insights. Baseload data, including those for CCHs, are often not clearly documented across products. The current landscape also suggests the need to engage with individual manufacturers to discern specific baseload contributions. A more extensive study or additional review of literature would be needed to comprehensively address the prevalence of CCH inefficiency across a wide range of ASHP models.

As the number of ASHP installations grows in the coming years, it is important to understand and mitigate how many of the new ASHPs may have these CCH issues for forward planning. Wilcox et al. (2018) highlighted significant energy use by constantly operating fans and other components, including the CCH. Although the number of upcoming installations with these issues was not explicitly stated in the project report, the continued differences between SEER and heating seasonal performance factor (HSPF) ratings and field performance across multiple houses and configurations suggests that future installations might carry over these inefficiencies. Given the consistent observations in both older homes (1948 and 1953 builds) and newer homes (2005 build), the problem is not limited to older systems, indicating that newer installations carry the same risk.

Market Assessment of ASHP Capabilities

The project team conducted a market assessment to identify opportunities for addressing market needs in existing buildings. The following sections present California-specific market impacts due to the issue. Additionally, we discuss existing ASHP capabilities and present potential solutions to address uncontrolled defrost, CCH, and standby power usage.

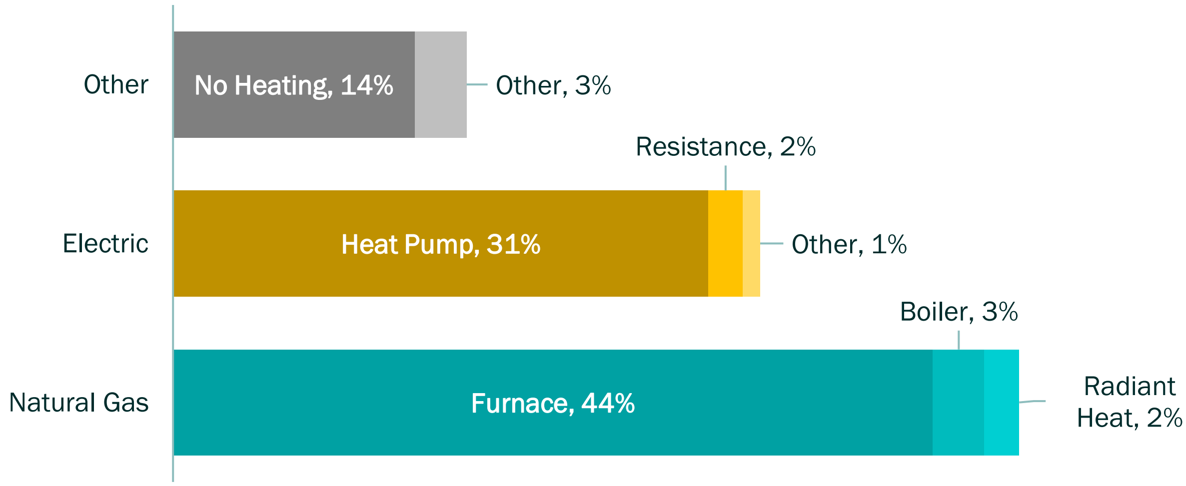
Current State of HP Systems in California

Direct emissions from residential and commercial buildings account for 12 percent of California's GHG emissions, predominantly originating from natural gas appliances like furnaces and water heaters. HP systems have gained significance in California in recent years as one of technologies that can help meet California's GHG targets, which aim for a 30 percent reduction in GHG emissions from 1990 levels by 2030 and a goal of GHG neutrality by 2045. The past decade has seen a rapid adoption of HP systems (McHugh, 2022). The market share for electric space heating grew from 7.6 percent in 2003 to 21.2 percent by 2019, while HPs experienced a 400 percent increase, from 0.8 to 4 percent over the same period (McHugh, 2022). However, the 2019 survey data indicates a market preference for gas as the primary heating source among households, accounting for approximately 70 percent of total heating solutions (RASS, 2019). This suggests significant opportunities to transform the heating market with HP systems.

The study showed single-zone (SZ) systems as the most common type of HVAC system, constituting 98 percent of the sites and 94 percent of the HVAC systems. Multi-zone systems (MZ) represented only around 6 percent of the total HVAC systems.

Electric heating makes up about 33 percent of commercial HVAC units, 93 percent of which are HPs. Overall, HPs make up 31 percent of commercial HVAC units. See Figure 1 for a distribution of HVAC units by heating fuel type.

Figure 1: Distribution of Commercial HVAC Units by Heating Fuel Type[1]



Manufacturer's Insights on CCH

A review of technical literature was conducted by Red Car Analytics (2022), focusing on major HP manufacturers in the U.S. market. The analysis of 32 HP models from over 11 manufacturers revealed a diverse approach to CCH implementation in the system. Approximately 50 percent of these models, predominantly using Copeland compressors, included CCH as a standard feature. In contrast, all in-house manufactured compressors and some other Copeland compressors did not incorporate CCH. Rotary type compressors universally had CCH, while single-stage scroll compressors generally did not, with some exceptions in variable speed models. Variable speed scroll compressors from two manufacturers did not have CCH. Most manufacturers recommended CCH for low ambient condition operation. The control mechanisms for CCH varied widely, with some heaters programmed for dual conditions (e.g., to operate during specified ambient air conditions and when the compressor is off). In some variable speed scroll compressors, a "motor stator" feature serves as a similar function to CCH by using motor windings to prevent refrigerant migration. This study highlights the varying HP design and CCH use, indicating that any solutions for reducing CCH energy consumption will need to be specific to the compressor type and model.

In addition to reviewing the memo of CCH product literature, the project team obtained further insights through discussions and email correspondence with four major HVAC manufacturers and two HVAC distributors about the incorporation of CCH in their products, summarized as follows.

UTILIZATION AND ALTERNATIVES

[1] 2014 Itron, CPUC, California Commercial Saturation Study, table 9-18.

There is a variation among manufacturers in the application of CCH or its alternatives. Not all HPs are equipped with CCH. One manufacturer stated that all their systems are equipped with CCH, and adjustments cannot be made in the field by technicians. One distributor mentioned that approximately 30 percent of products sold in California come with CCH, mainly for longer refrigerant line applications or colder climates. Another manufacturer specifically noted the use of an alternative “preheat” system instead of CCH, which serves a similar purpose but is built into the system and controlled under specific temperature setpoints to be energy efficient while maintaining the compressor. The preheat system operates when the temperature reaches 68°F by sending a signal to a low-wattage heating element inside the compressor to prevent liquid refrigerant accumulation and maintain suitable oil temperature for startup. This approach is integral to the equipment’s design and is automated in most controls, with some systems allowing for the feature to be disabled, if necessary, in the warm climate markets.

SOLUTIONS AND LONGEVITY

Solutions for reducing unnecessary CCH energy consumption are not standardized across all manufacturers and may not be feasible due to varying product designs. Some solutions can be integrated into the system’s hardware, while others might require software or programming adjustments. The EUL of HPs with integrated preheat control is considerably long. One manufacturer offers a 12-year warranty, indicating a strong confidence in the durability and reliability of their preheat system. In contrast, adjustments to CCH settings in the field could potentially affect product warranties, although this may vary by manufacturer and system design. Potential costs for solutions to mitigate CCH energy consumption were not explicitly detailed in the discussion responses and would likely vary based on whether the fix is a factory or field modification, or a software versus hardware update.

AWARENESS AND TRANSPARENCY

The industry’s awareness of CCH-related energy consumption issues appears limited, with none of the manufacturers and distributors reporting awareness of complaints from contractors or customers regarding excessive energy use by CCH. Transparency on CCH operations and their actual impact on energy consumption is not easily obtainable from manufacturers, and there seems to be some hesitancy to discuss the topic. One manufacturer noted that this is not a topic that they discuss regularly.

Federal Test Procedures

The following sections describe federal test procedures for CCH control as they apply to residential-sized or commercial-sized HP systems performance efficiency.

RESIDENTIAL

The current test procedures for ensuring that HPs[2] comply with federal energy conservation standards include AHRI Standard 210/240, which requires testing for CCH in off-mode for HPs with these control configurations[3]:

- CCH that lacks control and is not self-regulating
- CCH with a fixed power input, controlled by an ambient temperature sensor that is not affected by the heater
- CCH equipped with self-regulating control or where the temperature sensor is affected by the heater

A group of Joint Advocates[4] that includes some California IOUs have provided comments to the DOE related to HP test procedures. Among those comments, the IOUs recommended that the DOE considers methods to address CCH controls, noting that "neither the HSPF2 nor the SEER2 metrics reflect the energy use of auxiliary components, including fans and CCH, when the compressor is off, and the SEER2 and HSPF2 metrics therefore do not fully represent any difference in the efficiency of auxiliary equipment between systems" (DOE 2023-01-24 Energy Conservation Program).

In response to this comment, the DOE may further assess test procedures for HPs and has requested more information regarding auxiliary components that use energy and CCH operation in existing market-available HP units, including:

- What percentage of units on the market are shipped from the factory with CCH
- What percentage have CCHs installed in the field
- The percentage breakdown of controls used with units by those that are energized at full power during the compressor off cycle, those that also have an ambient thermostat to prevent use when temperature is high, and those that are self-regulating[5]

COMMERCIAL

Current federal test procedures for HPs require measuring two performance metrics, integrated EE ratio (IEER) and coefficient of performance (COP). However, the DOE has proposed to amend the current federal test procedures to include integrated ventilation, economizer, and cooling (IVEC) and integrated ventilation and heating efficiency (IVHE), which are new annualized metrics for HPs. The proposal is informed by a 2022 Air- Cooled Unitary Air Conditioner (ACUAC) and Air-Cooled Unitary Heat Pump (ACUHP) Working Group that reviewed the test procedures for these metrics and found that:

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[2] Appendix M to Subpart B of Part 430—Uniform Test Method for Measuring the Energy Consumption of Central Air Conditioners and Heat Pumps. Available at https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-430/subpart-B/appendix-Appendix%20M%20to%20Subpart%20B%20of%20Part%20430.

[3] AHRI Standard 210/240 2023 (2020) Standard for Performance Rating of Unitary Air-conditioning & Air-source Heat Pump Equipment, Appendix H. Off-Mode Testing – Normative, page 130. Available at https://www.ahrinet.org/system/files/2023-06/AHRI%20Standard%20210.240-2023%20%282020%29.pdf.

[4] Join Advocates include: Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison, the Appliance Standards Awareness Project (ASAP) and American Council for an Energy-Efficient Economy (ACEEE). As reported in https://www.regulations.gov/document/EERE-2022-BT-TP-0028-0001.

[5] Ibid.

"The current IEER metric includes crankcase heater power consumption only when operating at part-load compressor stages (i.e., for part-load cooling operation, crankcase heater power is included only for higher-stage compressors that are staged off, and it is not included for lower stage compressors when all compressors are cycled off). The COP metric does not include any crankcase heater power consumption.

In contrast, the IVEC and IVHE metrics include all annual crankcase heater operation, including when all compressors are cycled off in part-load cooling or heating, ventilation mode, unoccupied no-load hours, and in heating season (for ACUACs only) (ACUAC and ACUHP Working Group TP Term Sheet)."

Among the ACUAC and ACUHP Working Group recommendations is "hour-based weighting factors to account for CCH operation in unoccupied no-load cooling season hours for CUACs and CUHPs as well as heating season hours for CUACs."[6] AHRI has a draft standard 1340, which addresses the proposed recommendations and requirements of federal test procedures for HP systems with capacity greater than 65,000 Btu/h. The CCH component power value in the draft AHRI 1340 standard is as follows (AHRI Standard 1340(I-P)-202X Draft Standard):

CCH power when not included in compressor power $= C_d \times P_C$

CCH power when included in compressor power $= C_d \times (P_c - P_{CCH,NOC})$

Where:

$$C_d = -0.013 \times LF + 1.13$$

$$LF = \frac{TLP}{LP}$$

TLP = Target load percentage for the cooling bin

LP = Load percentage determined for the test

P_C = Compressor power

$P_{CCH,NOC}$ = Sum of the manufacturer-specified CCH power values for all compressors not operating during the test.

The lowest cooling bin specified for the TLP is 65°F entering air dry-bulb temperature. The current eTRM measure package model outputs indicate that CCH and defrost controls are only operating below 55°F. However, there may be implications for what the eTRM can include in the future depending on how the federal test procedures play out. The DOE is accepting comments on the proposed amendments to HP test procedures until October 15, 2023. The DOE has not yet posted the comments. We recommend monitoring this issue to see how the test procedures develop, and if there are any resulting changes that may require updates to the measure package assumptions, such as changing the CCH operating setpoint to align with new standards.

eTRM Measure Package Review

The project team conducted a review of selected eTRM measure packages to understand if and how the energy models used in the analysis are set up to run CCH and defrost controls. The measure packages we reviewed are Heat Pump HVAC Residential, Fuel Substitution, SWHC045-01 (EnergyPlus) and Packaged Heat Pump Air Conditioner, Commercial, Fuel Substitution, SWHC046-02

[6] Ibid. page 100.

(eQUEST). Both residential and commercial models use the DEER2020 building prototypes, and these findings likely apply to all similar measures that include HPs.

The project team first reviewed the model input files to confirm if and how the CCH and defrost controls were intended to be modelled. Subsequently, we ran the energy models in Climate Zones 3 and 15 as representative samples of climate zones across California to confirm the model outputs. The findings confirm the inclusion of CCH and defrost in the energy models, negating the need for further modeling to discern their potential energy impacts.

Residential

Regarding the residential case, we confirmed that the Heat Pump HVAC SWHC045-01 energy model is set up to run both CCH and defrost controls. Table 2 presents data for CCH and defrost power as well as operating hours by temperature bin. The model outputs indicate that CCH and defrost controls are only operating below 55 °F. The percentage of HP system energy contributed by defrost and CCH controls varies by climate zone:

- Climate Zone 3 is 26.6 percent annually (944 kWh), and as high as 67.2 percent in the heating season.
- Climate Zone 15 is 3.3 percent annually (352 kWh), and as high as 50.9 percent in the heating season.[7]

Table 2: Residential Defrost and CCH Modeled Operating Hours for CZ 3 and CZ 15[8]

OAT (°F)	Hours In Bin, CZ 3	Defrost Hours On, CZ 3	CCH Hours On, CZ 3	Hours In Bin, CZ 15	Defrost Hours On, CZ 15	CCH Hours On, CZ 15
25-30	0	0	0	2	2	2
30-35	21	21	8	12	12	12
35-40	68	68	67	59	59	59
40-45	282	65	282	153	44	153
45-50	866	0	866	323	0	323
50-55	1,783	0	114	583	0	86
>55	2,591	0	0	716	0	0
Total	**5,611**	**154**	**1,337**	**1,848**	**117**	**635**

[7] Based on output from the SWHC045-01 EnergyPlus energy model, the percent of heating end use energy contributed by defrost and CCH controls = $\frac{\sum \text{Heating Coil Defrost} + \sum \textit{Heating Coil Crankcase Heater}}{\sum \text{Heating Coil Defrost} + \sum \textit{Unitary System}}$.

[8] Data in the table are outputs from the SWHC045-01 EnergyPlus energy model.

The EnergyPlus inputs currently used in the measure package modelling for the residential measures are provided in

Appendix B:.

Commercial

Regarding the commercial case, the project team confirmed that the Packaged Heat Pump Air Conditioner SWHC046-02 energy model is set up to run both CCH and defrost controls. We were not able to directly pull hourly data for CCH power, but we deduced CCH power (Watts) via the “Auxiliary end-use energy (pumps)” Hourly Report Block available in eQUEST. We assumed, due to the simplicity of the model system (no pumps or additional equipment) and the patterns of output data, that this data stream must be reporting on CCH power. Additionally, we further tested the eQUEST CCH power condition by zeroing out all CCH power inputs, without changing any other parameters in the model, and then compared against the original model with default CCH power inputs. This strengthened the notion that CCH power is held within the abovementioned report block.[9]

The defrost power can be captured individually via the “Heat pump defrost energy (Btu)” Hourly Report Block. There is one nuance for the commercial defrost case: the eTRM model has defrost controls running via “Reverse Cycle”, rather than “Resistive.” This means that the model may not be utilizing the CCH heater specifically when in defrost mode. There was at least one instance when defrost controls were on but (assumed) CCH power was zero.

Table 3 presents data for CCH and defrost power as well as operating hours by temperature bin. The model outputs indicate that CCH and defrost controls are only operating below 55°F. The percent of HP system energy contributed by defrost and CCH controls varies by climate zone:

- Climate Zone 3 is 1.7 percent annually (377 kWh), and as high as 13 percent in the heating season.
- Climate Zone 15 is 0.3 percent annually (177 kWh), and as high as 62.1 percent in the heating season.[10]

Table 3: Commercial Defrost and CCH Modeled Operating Hours for CZ 3 and CZ 15[11]

OAT (°F)	Hours In Bin, CZ 3	Defrost Hours On, CZ 3	CCH Hours On, CZ 3	Hours In Bin, CZ 15	Defrost Hours On, CZ 15	CCH Hours On, CZ 15
25-30	0	0	0	0	0	0
30-35	19	6	18	11	0	11

[9] In the event of a more complex energy model that includes additional equipment such as pumps, it is likely not possible to capture pure crankcase power, as it will be summed under the “Auxiliary end-use energy (pumps)” report block along with pump power, and any other controls that may exist.

[10] Based on output from the SWHC046-02 eQuest energy model, the percent of heating end use energy contributed by defrost and CCH controls =

$$\frac{\sum \text{Auxiliary end-use energy (pumps)} + \sum \textit{Heat pump defrost energy}}{\sum \text{Auxiliary end-use energy (pumps)} + \sum \text{Heating end-use energy} + \sum \textit{Cooling end-use energy} + \sum \textit{Vent fan end use energy}}.$$

[11] Data in the table are outputs from the SWHC046-02 eQuest energy model.

OAT (°F)	Hours In Bin, CZ 3	Defrost Hours On, CZ 3	CCH Hours On, CZ 3	Hours In Bin, CZ 15	Defrost Hours On, CZ 15	CCH Hours On, CZ 15
35-40	66	11	66	75	0	75
40-45	239	0	238	308	0	308
45-50	804	0	803	518	0	91
50-55	1,695	0	275	661	0	0
>55	2,599	0	0	860	0	0
Total	**5,422**	**17**	**1,400**	**2,433**	**0**	**485**

The eQuest inputs currently used in the measure package modelling for the commercial measures are provided in

Appendix C: eQuest Inputs for Commercial Measures.

Modeled Versus Field Savings Benchmarking

We benchmarked the CCH consumption as modeled in the measure packages against field-verified CCH and defrost consumption values, as summarized in Table 4. Despite several limitations, the modeled energy consumption of SWCH045-01 measure package lies within the median range. However, benchmarking revealed that consumption widely varies, and the project team was not able to make a direct comparison due to different configurations between the modeled measure package and the available field data, such as differing climate zone, building type, number of units, and component breakdown of the consumption data.

Table 4: CCH Consumption Comparison between Modeled and Field Data

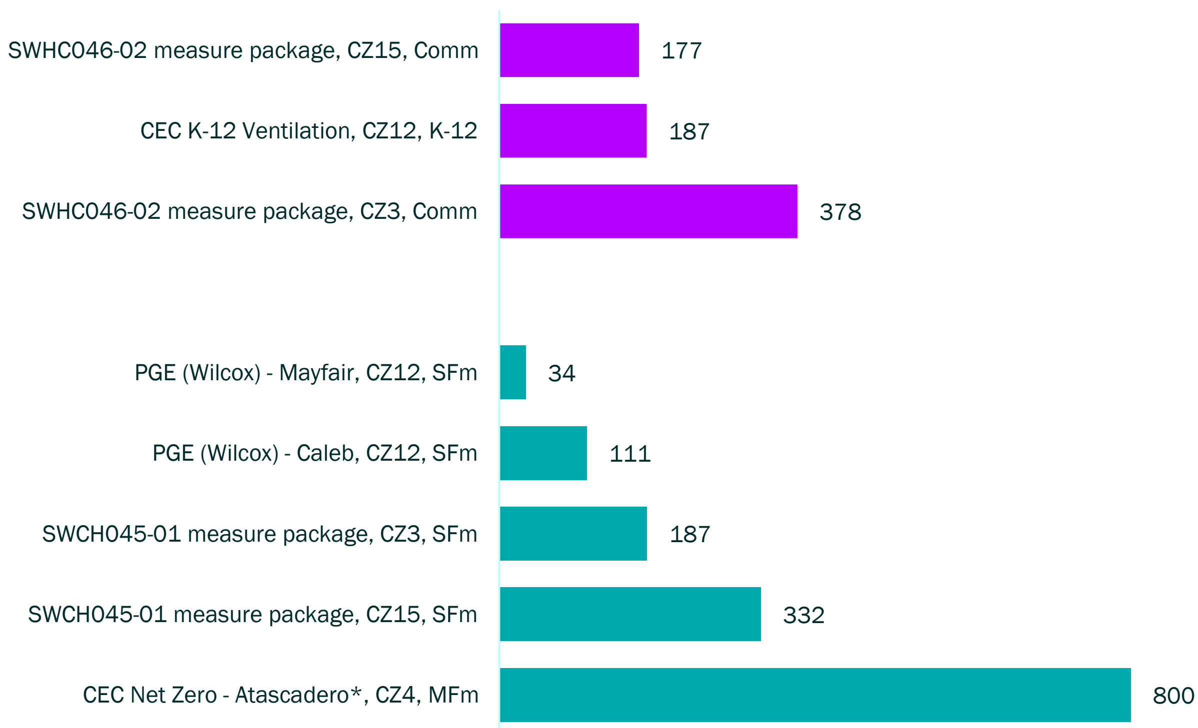
Study	Climate Zone	Building Type	Data Source	Annual CCH Consumption per HP (kWh/year)
CEC Net Zero - Atascadero	4	Multi Family	Field Measurement	800*
PGE (Wilcox) - Caleb	12	Single Family	Field Measurement	111
PGE (Wilcox) - Mayfair	12	Single Family	Field Measurement	34
SWCH045-01 measure package	3	Single Family	Energy Plus Model	332
SWCH045-01 measure package	15	Single Family	Energy Plus Model	187

*The Atascadero site consumption is a combination of CCH plus reversing valve and controls.

Source: The project team's literature review of field studies and measure package energy models.

Figure 2 shows the range of commercial and residential CCH consumption values. Based on the clarifications from the study author, the large energy consumption of 800 kWh/year in Atascadero was not exclusively tied to the CCH; a portion stems from the reversing valve and controls. While the study did not disaggregate the base load, some units at other projects were examined, and the reversing valves were found to have a load of approximately 8 to 9.5 W for one unit. A defrost cycle was present, but it only activated at temperatures below 35°F, thus it was not a significant factor to be considered in the study. CCH consumption at other sites, including Calistoga, Cloverdale, and Sunnyvale were not included in the field study report. Both Calistoga and Cloverdale possessed large central HP reverse cycle chillers equipped with CCHs. However, their impact on the overall load was not analyzed since such features are standard for large capacity equipment. At Sunnyvale, the units were tested for baseload, and a significant consumption was identified. The manufacturer termed it as a ‘preheat’ rather than a CCH. The consumption figures were not included in the final report as it remained under investigation at the time of the completion of the field study report.

Figure 2: Annual CCH Consumption (kWh per HP) Benchmarking



*The Atascadero site consumption is a combination of CCH plus reversing valve and controls.

Impact of Measure Updates on HTR and DAC Customers

The project team considered how the findings may impact HTR community and DAC customers.

The California Environmental Protection Agency (CalEPA) proposes the definition for DACs based on the analysis conducted by California Communities Environmental Health Screening Tool (CalEnviroScreen), which incorporates a variety of different indicators to account for environmental conditions and people’s vulnerability to environmental pollutants. Based on the CalEnviroScreen database, 28.7 percent of the population were designated as disadvantaged communities.

TECH data also includes the DAC information based on the CalEnviroScreen database for the enrolled cites. It shows 7.8 percent of the participants were categorized as DAC. Among these DAC sites, 81 percent of them are single family, while 19 percent of them are multifamily. For single family buildings, the predominant HVAC system is split unitary equipment; however, mini-split is the predominant HVAC system for multifamily buildings.

- RASS data does not provide any DAC information, instead, they provided household income. The income categories are as follows: Low Income (< $25,000), moderate Income ($25,000–

$74,999), and high income (> $75,000). Among all the homes that use primary electric heating, 20 percent of them are low-Income households.

The extent to which measure updates will impact costs for HTR community and DAC customers depends on factors such as climate zone, electric utility rate, rate of participation in HP program offerings, and whether or not CCH are present in the HPs. California Alternate Rates for Energy (CARE) offers discounted rates for low-income households, and rates vary depending on utility, rate schedules, and household consumption. When CCH is present in HP systems and performing as modeled in current measure packages, we estimate that the cost associated with CCH operation for customers eligible for CARE discounts ranges from about $45 to $80 annually.[12] The proposed Title 24 Code changes related to CCH control include estimated savings for single-family and multifamily homes. First year savings per single family home (2,100/2,700 weighted new construction) range from 26 to 249 kWh per year, and per multifamily home savings range from 7 to 167 kWh per year. These savings could reduce energy costs for customers on a CARE rate by $2 to $77 annually.[13]

---

[12] CCH operating costs are estimated by applying blended CARE rates as published in PG&E, SCE, and SDG&E's rate comparisons to the modeled energy consumption of CCH as described in the Modeled Versus Field Savings Benchmarking section of this report. The utility rate comparisons are available here: https://www.pge.com/en_US/residential/customer-service/other-services/alternative-energy-providers/community-choice-aggregation/community-choice-aggregation.page#comparecca, https://www.sce.com/customer-service/Community-Choice-Aggregation, and https://www.sdge.com/customer-choice/community-choice-aggregation/joint-rate-comparison.

[13] Cost savings are estimated by applying CARE rates to the estimate Title 24 CCH savings from table 36.

Conclusion and Recommendations

The findings reveal gaps in existing measure packages regarding CCH. Despite the importance of proper CCH control in preventing energy waste from unnecessary operation, there are no requirements set for this in the measure packages. Additionally, the modeled measures assumed that all HPs come with CCH. In contrast, this study found that not all HPs in the market by major manufacturers include a CCH component, such as when specified for mild winter climates or in cases with short refrigerant line runs. There is also an absence of RCx measures for addressing uncontrolled CCH.

The following recommendations include updates to existing measure packages, new measure development, and further research opportunities that eTRM governing bodies can consider addressing the issue of CCH operation in HP systems. The project team assigned a priority level of high for recommendations that may immediately provide energy and emissions reduction or may quantify potential future savings; and low priority for recommendations that are dependent on the findings of additional research or research that could support future measure calibration.

Recommendation 1, High Priority: Update the existing HP measure packages to include a requirement for CCH control requirements.

For new HPs, we recommend adding an eligibility requirement to the current HP measures to ensure that new installations of program-rebated HPs include documentation of proper CCH control management. This requirement will ensure that systems with CCH will have proper control of CCH operation, avoid unnecessary GHG emissions, and reduce operating costs for system owners. We recommend aligning this requirement with the requirements included in the upcoming 2025 Title 24 Code related to CCH control management. These documentation requirements related to CCH controls may require special consideration for ensuring a mechanism is in place to obtain this information in various program delivery approaches (downstream, midstream, and upstream).

If the lead IOUs, SCE and SDG&E, are interested and have capacity to act quickly after the final report comes out, it may be possible for them to implement the CCH control requirement update to current measure packages in time for PY24 updates. This update might require energy modeling to determine savings but could be turned around more quickly without conducting modeling if the savings from the proposed 2025 Title 24 Code changes can be applied. Incorporating the requirement as a short-term program offering could support market actors as they prepare to transition for this to become code in 2026.

Recommendation 2, High Priority: Conduct further research to investigate the prevalence and savings potential of unnecessary CCH operation for existing HPs.

An RCx measure would help address unnecessary CCH operation and could be a low-cost means to address the issue in HPs that are already present and operating in the field. However, based on interviews with manufacturers, it is possible that adjustments to CCH settings in the field could potentially affect product warranties. We recommend conducting further research to investigate the prevalence and savings potential of unnecessary CCH operation and explore possible solutions to warranty concerns. This could lead to a potential development of a new RCx measure for optimizing CCH operation.

Recommendation 3, High Priority: Develop new measure offerings within existing measure packages for HPs specified without CCHs.

The new offerings would be similar to existing HP measures, but the savings estimates would come from modeling with the CCH switched off. Documentation requirements for participation of these measures in EE programs would include confirmation that shipped or installed equipment has no CCH installed. We recommend that these measures be limited to HP installations in warmer climate zones where there is little to no risk of compressor temperatures dropping to levels that would cause adverse system impacts.

Recommendation 4, Low Priority: Conduct further research at commercial sites to better understand if the modeled savings are representative of field conditions across all program applications.

Our review of the current eTRM measure packages indicates that CCH operation is currently included in measure-level impacts. Additionally, the modeled CCH consumption estimates align with field observations for CCH operation in residential and commercial sites. However, the commercial study was limited to systems below 35,000 Btu/hour capacity from a single manufacturer at two sites in the K-12 education segment and did not capture system operation across all building types. We recommend conducting additional research to gather primary data for CCH operation at commercial sites, and benchmarking those findings against the eTRM measure packages to better understand if the modeled savings are representative of field conditions across all program applications.

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Appendix A: Interview Guide for HVAC Distributor and Manufacturer

1. CCH operation and design
    a. What percentage of units on the California market are shipped from the factory with CCHs?
    b. What percentage of your California customers have CCHs that you sell/install in the field?
    c. Can you provide some insights into the breakdown of control mechanisms used with your units? Specifically, could you share the percentage distribution between controls that operate at full power during the compressor off cycle, those equipped with an ambient thermostat to limit usage in high-temperature conditions, and those that are self-regulating?
    d. Do you have any challenges with the current CCH operation and design? If yes, what are the challenges? Probe: Have you heard any issues with it from the manufacturer’s side or from the customers? Are these specific to brands?
    e. How does the CCH operate? Probe: Is there any variability in CCH operations across different unit capacities in your product lineup? How does each configuration impact energy consumption?
    f. How does the CCH operation contribute to your system’s overall efficiency?
    g. Are there specific models or types of HPs you sell that do not incorporate a CCH but are still suitable for California applications?

2. Potential solutions and impacts
    a. Are you exploring any potential solutions to address the energy consumption issues related to CCH? If yes, what are they?
    b. Are these potential solutions more hardware-related, software/programing adjustments, or both?
    c. Can these fixes be implemented easily either in the field or directly at the factory?
    d. Is it possible to develop a standardized solution that can be applied across all HP models?
    e. Are there any specialized skills or knowledge required to implement the solutions in the field? (Who can do this? E.g., contractor or contractor receiving special approval/training from the manufacturer)
    f. Can you provide a ballpark estimate of cost for implementing the solutions?
    g. Do these solutions impact current equipment warranty? If yes, how?
    h. What EUL can be expected from these solutions?

3. Engagement/transparency

a. Can you explain the process for getting manufacturer's product data related to the system's operation and efficiencies?

b. How do you envision manufacturers, designers, researchers, and other stakeholders collaborating to optimize the use of CCHs?

c. What types of guidelines or recommendations do you provide to end-users about the optimal usage of CCHs in HVAC systems?

Appendix B: EnergyPlus Inputs for Residential Measures

DEER Prototype Template - SFm-1 Story-1985-HP root file

- This is per multi speed HP, Keywords (Crankcase Heater, Defrost):

```
Coil:Heating:DX:MultiSpeed,
  DXHP EL_ Heating Coil,   !- Name
  ,                        !- Crankcase Heater Capacity {W}
  10,                      !- Maximum Outdoor Dry-Bulb Temperature for Crankcase Heater Operation {C}
  Defrost_EIR_FT,          !- Defrost Energy Input Ratio Function of Temperature Curve Name
  5,                       !- Maximum Outdoor Dry-Bulb Temperature for Defrost Operation {C}
  ReverseCycle,            !- Defrost Strategy
  Timed,                   !- Defrost Control
  0.058333,                !- Defrost Time Period Fraction
  ,                        !- Resistive Defrost Heater Capacity {W}
  HPACCOOLPLFFPLR,         !- Speed 1 Part Load Fraction Correlation Curve Name
  HPACCOOLPLFFPLR,         !- Speed 2 Part Load Fraction Correlation Curve Name
```

- This is per single speed HP, Keywords (Crankcase Heater, Defrost):

```
Coil:Heating:DX:SingleSpeed,
    DXHP EL_ Heating Coil,   !- Name
    HPACCOOLPLFFPLR,         !- Part Load Fraction Correlation Curve Name
    ,                        !- Defrost Energy Input Ratio Function of Temperature Curve Name
    -5.0,                    !- Minimum Outdoor Dry-Bulb Temperature for Compressor Operation {C}
    ,                        !- Outdoor Dry-Bulb Temperature to Turn On Compressor {C}
    5.0,                     !- Maximum Outdoor Dry-Bulb Temperature for Defrost Operation {C}
    200.0,                   !- Crankcase Heater Capacity {W}
    10.0,                    !- Maximum Outdoor Dry-Bulb Temperature for Crankcase Heater Operation {C}
    Resistive,               !- Defrost Strategy
    Timed,                   !- Defrost Control
    0.166667,                !- Defrost Time Period Fraction
    20000;                   !- Resistive Defrost Heater Capacity {W}
```

- This is per cooling coil, Keywords (Ancillary):

```
DXGF EL_ Cooling Coil,   !- Cooling Coil Name
     ,                   !- Ancillary On-Cycle Electric Power {W}
     ,                   !- Ancillary Off-Cycle Electric Power {W}
```

Appendix C: eQuest Inputs for Commercial Measures

- CCH: In the BDL File and the INP File that govern the model (Keywords Crnk):

```
PARAMETER
        "CrnkEIR" = 0.0024467 ..
PARAMETER
        "CrnkMAXT" = 50 ..
```

  "CrnkEIR" is Crankcase Energy Intensity Ratio and scales based on compressor operation. The alternative that is used in place of "CrnkEIR" is Crankcase Heat, inputted in kW. These options are also in the eQuest GUI at the Heat Pump System Level, under "Cooling" tab, "Unitary Power" tab, bottom left-hand corner.

- Defrost: In the BDL File and INP File that govern the model (keywords DEFROST):

```
DEFROST-TYPE = REVERSE-CYCLE
DEFROST-CTRL = ON-DEMAND
```

  In the eQuest GUI at the Heat Pump System Level, under "Heating" tab, "Supp Heat/Defrost" tab selections can be made for "Defrost Type" (Reverse Cycle, etc.), "Defrost Control" (On Demand, etc.), "Maximum Defrost Temperature", and "Defrost Runtime Frac"