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Comment Received From: Sensible Technologies, Inc aka Hydronic Specialties Co
Submitted On: 6/12/2020
Docket Number: 19-BSTD-03

Single Family Enhanced Air-to-Water Heat Pump Compliance Options

To Whom It May Concern,

I am an industry related stakeholder requesting the California Energy Commission (CEC) to approve an interim approach that allows the use of a standard efficiency heat pump for compliance instead of the AWHP inputs that greatly undervalues performance.

We canâ€™t wait for the 2022 code cycle which will be applied in 2023.
We need the above recommendation approved now.

1. Approve an interim approach that allows Air-to-Water Heat Pumps' Title 24 compliance value to be the same as standard efficiency Air-to-Air Heat Pumps.
2. Approve Multi-Function of AWHP allowing an interim UEF of 4.0 for Domestic Hot Water Heating. The UEF can be modified as the technology matures and more data is presented.
3. When software updates permit, add the differential performance between fixed speed compressors and variable speed compressors.
4. Approve AWHP with the ductless option, except of course when the AWHP is used with a ducted system in unconditioned space.

Supporting data is found in this CASE STUDY report under review by CEC (a report that contains data):
Enhanced Air-to-Water Heat Pump Compliance Options
(https://title24stakeholders.com/wp-content/uploads/2019/06/Res_2022_T24_CASE-Report_Draft_SF_AWHP.pdf)

If we are to achieve mandated goals of efficiency, decarbonization, CO2 reduction, reducing the use of greenhouse gas potential by using less refrigerants, electrification; we must make it easier to implement Air-to-Water Heat Pumps. Right now the choke point is in how the CEC values AWHPs. My above proposal is a step in the right direction. As other performance issues such as EERâ€™s fixed at 11.7, while the AHRI EER for Chiltrix CX34 is over 20, also needs addressing. Based on this, the Chiltrix is over 40% more efficient in cooling. Translate that into amps and the summer time load would be much more manageable for the grid operators. Given that there are growing hours per year for cooling, we need to tackle each point step by step.

Best regards;

John Grose
President

Sensible Technologies, Inc.
Hydronic Specialties Company
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Additional submitted attachment is included below.

Codes and Standards Enhancement (CASE) Initiative 2022 California Energy Code

Enhanced Air-to-Water Heat Pump Compliance Options

2022-SF-HVAC1-D | Single Family HVAC | May 2020 DRAFT CASE REPORT

Frontier Energy, Inc.

Please submit comments to info@title24stakeholders.com by June 12, 2020

This report was prepared by the California Statewide Codes and Standards Enhancement (CASE) Program that is funded, in part, by California utility customers under the auspices of the California Public Utilities Commission.

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Authors:	Marc Hoeschele and James Haile, Frontier Energy, Inc.
Project Management:	California Statewide Utility Codes and Standards Team: Pacific Gas and Electric Company, Southern California Edison, San Diego Gas & Electric Company, Sacramento Municipal Utility District, Los Angeles Department of Water and Power.

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Executive Summary

This is a draft report. The Statewide CASE Team encourages readers to provide comments on the proposed code changes and the analyses presented in this draft report. When possible, provide supporting data and justifications in addition to comments. Suggested revisions will be considered when refining proposals and analyses. The Final CASE Report will be submitted to the California Energy Commission in August 2020. For this report, the Statewide CASE Team is requesting input on the following:

1. *Differentiation of air-to-water heat pump performance based on fixed or variable speed compressor characteristics*
2. *Proposed Home Energy Rating System (HERS) verification requirements*
3. *Need for supplemental dehumidification for air-to-water heat pumps using radiant ceiling panels for space conditioning delivery*

Email comments and suggestions to info@title24stakeholders.com *by* ***Friday June 12th, 2020****. Comments will not be released for public review or will be anonymized if shared.*

Introduction

The Codes and Standards Enhancement (CASE) Initiative presents recommendations to support the California Energy Commission's (Energy Commission) efforts to update the California Energy Efficiency Building Standards (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. Three California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison – and two Publicly Owned Utilities – Los Angeles Department of Water and Power and Sacramento Municipal Utility District (herein referred to as the Statewide CASE Team when including the CASE Author) – sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to improve energy efficiency and energy performance in California buildings. This report and the code change proposals presented herein are a part of the effort to develop technical and cost-effectiveness information for proposed requirements on building energy-efficient design practices and technologies.

The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2022 Title 24 website for information about the rulemaking schedule and how to participate in the process: https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency.

The overall goal of this Draft CASE Report is to present a code change proposal for residential air-to-water heat pumps (AWHPs). The report contains pertinent information supporting the code change. Since the focus of the AWHP measure is a software enhancement, the key information on the rationale for the change is explained in Appendix D.

Measure Description

Background Information

AWHPs are an emerging all-electric heating, ventilation, and air conditioning (HVAC) solution that historically has had limited market penetration in the California residential market but should see increased interest with the growing attention on low carbon space conditioning systems. The outdoor unit contains the compressor and a refrigerant-to-water heat exchanger that transfers energy to a hydronic loop for space conditioning (and for some systems, water heating). The AWHP technology is currently recognized in Title 24, Part 6, but the existing compliance software implementation is based on an interim solution incorporated in 2016 which does not accurately reflect real performance. This current compliance pathway, using the California Building Energy Code Compliance for Residential Building Software (CBECC-Res) software, generally results in a significant compliance penalty, requiring the builder to implement additional energy efficiency measures to demonstrate compliance when using AWHPs.

Recent utility-sponsored research has been underway at one of four homes in a Central Valley Research House (CVRH) project in Stockton, California. This heavily instrumented lab “test” house has had four different AWHPs installed and tested since 2015. In addition to the AWHP systems that have been tested, high efficiency reference (forced air heat pumps) have been monitored to develop a reference case for comparison. The installed AWHPs have been coupled to radiant ceiling panels which utilize the heated (or cooled) water to deliver energy to conditioned space via ceiling-mounted panels which contain tubing and heat transfer fins to radiate energy to the living space below. An advantage of this delivery approach is the ability to deliver energy with little or no distribution losses. Field data from the CVRH site forms the basis of this proposed 2022 CBECC-Res software modification.

Proposed Code Change

The proposed code change is a compliance option intended to increase the flexibility of complying with the Title 24, Part 6 Standards. By improving AWHP space conditioning modeling within CBECC-Res, builders would have additional flexibility and options in demonstrating compliance. The proposed change would differentiate performance between AWHPs that have variable speed compressors and those that have fixed speed compressors. The Statewide CASE Team also assessed whether modifications should be made to AWHPs which provide three function operation (combining both space conditioning and water heating functions) but determined that the existing recognition of AWHP water heating performance in the compliance software is adequate until the technology matures further and better data characterizing performance is available.

In addition to enhanced modeling of AWHP performance, this proposal also recognizes hydronic radiant ceiling panels as a viable distribution type for AWHPs.

The primary market for the technology is single family homes, although there is potential applicability for low-rise residential buildings. It is appropriate for new construction, additions, and alterations.

Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and which sections of standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manual, and compliance documents that would be modified as a result of the proposed change(s).

Table 1: Scope of Code Change Proposal

Measure Name	Type of Requirement	Modified Section(s) of Title 24, Part 6	Modified Title 24, Part 6 Appendices	Would Compliance Software Be Modified	Modified Compliance Document(s)
Enhanced AWHP Compliance Option	Compliance Option	N/A	Residential Appendix – New section to be added (RA3.4.5) for radiant ceiling panels	Yes. (ACM Reference Manual section 2.4.5.1 to be modified)	CF2R-MCH-01-E and CF3R-MCH-33-H (new)

Market Analysis and Regulatory Assessment

The residential AWHP market in California is relatively small with current estimates of annual sales at less than a thousand units. This is due to a variety of factors including the widespread popularity among most builders and mainstream mechanical contractors of conventional central forced air HVAC systems. In recent years, variable capacity heat pumps (VCHPs), commonly known as mini-splits, are gaining market share especially in additions and alterations. A significant barrier to AWHPs exists in the current modeling of heating and cooling system performance in the compliance software. An interim measure has been in place for modeling the AWHP technology under the 2019 standards, but under most situations the technology is penalized, creating a strong disincentive relative to other HVAC technologies. Appendix D presents modeling results from the current 2019 method.

The California Appliance Efficiency Regulations, Title 20, maintains a database of products tested and certified by AWHP manufacturers called the Modernized Appliance Efficiency Database System (MAEDbS). Currently five manufacturers are offering 11 single-phase electric service AWHP models suited for residential applications.

Hydronic specialty contractors are currently most familiar with the AWHP technology. If the AWHP market grows in the coming years with the adoption of new AWHP modeling methods and continually increasing interest in building electrification, mainstream HVAC contractors would gain familiarity with the technology. Currently the manufacturers and equipment distributors are playing a key role in providing design support to the industry.

Radiant ceiling panels coupled with AWHPs represent a related aspect of this hydronic technology. These panels are installed at the ceiling and utilize heated or chilled water to radiantly transfer heat from the panels to the living space below. Radiant delivery offers numerous advantages in terms of comfort and ease of zoning, but costs are generally higher than forced air systems limiting the technology to higher end custom homes. As market demand increases, costs for radiant panels should come down.

There are no significant regulatory issues associated with this software change.

Cost Effectiveness

As a proposed compliance option modification, demonstration of cost effectiveness is not required.

Statewide Energy Impacts: Energy, Water, and Greenhouse Gas (GHG) Emissions Impacts

Since the AWHP measure is a compliance option, the measure is not expected to demonstrate statewide energy savings since any attributable measure savings would likely be used as a tradeoff under the performance approach.

Water and Water Quality Impacts

The proposed measure is not expected to have any impacts on water use or water quality, excluding impacts that occur at power plants.

Compliance and Enforcement

Overview of Compliance Process

The Statewide CASE Team worked with stakeholders to develop a recommended compliance and enforcement process and to identify the impacts this process would have on various market actors. The compliance process is described in Section 2.5. Impacts that the proposed measure would have on market actors is described in Section 3.3 and Appendix E. The key issues related to compliance and enforcement are summarized below:

- Education and training: The mainstream HVAC contractor and HERS Rater community is not generally familiar with AWHPs or radiant ceiling panels. Training is needed to inform these stakeholders on the technology, and any required HERS verification elements.
- Coordination between designers and the trades: As this is an emerging technology, the designer should take additional care in thoroughly communicating design details and HERS verification requirements to all participating parties.

Field Verification and Diagnostic Testing

Several HERS verification elements are proposed. For AWHPs, the HERS inspection shall verify the make and model number of the installed AWHP to determine if the product listing on the MAEDbS is consistent in terms of the unit being fixed or variable compressor speed.

For radiant panels, there are several proposed HERS verifications:

The HERS Rater shall verify that the installed panel area in the dwelling unit is sufficient to meet the Manual J design loads based on the radiant panel manufacturer's specified heating and cooling capacities at nominal rated conditions.

If the compliance documents show that radiant ceiling panels are to be installed with "hydronic delivery in conditioned space", the HERS Rater shall verify that the installed attic ceiling insulation meets the prescriptive requirements for that climate zone; that all relevant quality insulation installation (QII) ceiling insulation requirements listed in RA3.5. are met; and, that all hydronic piping is insulated to the levels specified in Section 120.3 and installed in conditioned space (with an exception for up to 10 feet of pipe from the dwelling to the outdoor unit). All these requirements must be met and field verified for compliance recognition of the hydronic delivery in conditioned space credit for radiant ceiling panels.

Section 2.5 provides additional information on these requirements.

1. Introduction

This is a draft report. The Statewide CASE Team encourages readers to provide comments on the proposed code changes and the analyses presented in this draft report. When possible, provide supporting data and justifications in addition to comments. Suggested revisions will be considered when refining proposals and analyses. The Final CASE Report will be submitted to the California Energy Commission in August 2020. For this report, the Statewide CASE Team is requesting input on the following:

1. *Differentiation of air-to-water heat pump performance based on fixed or variable speed compressor characteristics*
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The Statewide CASE Team submits code change proposals to the Energy Commission, the state agency that has authority to adopt revisions to Title 24, Part 6. The Energy Commission will evaluate proposals submitted by the Statewide CASE Team and other stakeholders. The Energy Commission may revise or reject proposals. See the Energy Commission's 2022 Title 24 website for information about the rulemaking schedule and how to participate in the process: https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency.

The overall goal of this Draft CASE Report is to present a code change proposal for residential air-to-water heat pumps (AWHPs). The report contains pertinent information supporting the code change.

When developing the code change proposal and associated technical information presented in this report, the Statewide CASE Team worked with a number of industry stakeholders including manufacturers, equipment distributors, Title 24 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during a public stakeholder workshop that the Statewide CASE Team held on October 10, 2019 (Statewide Codes and Standards Team 2019).

The following is a brief summary of the contents of this report:

- Section 2 provides a description of the measure and its background. This section also presents a detailed description of how this code change is accomplished in the various sections and documents that make up the Title 24, Part 6 Standards.
- Section 3 – In addition to the Market Analysis section, this section includes a review of the current market structure. Section 3.2 describes the feasibility issues associated with the code change, including whether the proposed measure overlaps or conflicts with other portions of the building standards, such as fire, seismic, and other safety standards, and whether technical, compliance, or enforceability challenges exist.
- Section 4 – Energy Savings presents the per-unit energy, demand reduction, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate per-unit energy, demand reduction, and energy cost savings. As a compliance option software enhancement, this measure is not required to show energy savings results.
- Section 5 – This section includes a discussion and presents analysis of the materials and labor required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs like equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis. As a compliance option software enhancement, this measure is not required to show cost effectiveness results.
- Section 6 – First-Year Statewide Impacts presents the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2022 code takes effect. This includes the amount of energy that would be saved by California building owners and tenants and impacts (increases or reductions) on material with emphasis placed on any materials that are considered toxic by the State of California. Statewide water consumption impacts are also reported in this section. As a compliance option, this measure is not required to show statewide impacts. As a compliance option software enhancement, this measure is not required to show cost effectiveness results.

- Section 7 – Proposed Revisions to Code Language concludes the report with specific recommendations with ~~strikeout~~ (deletions) and <u>underlined</u> (additions) language for the Standards, Reference Appendices, Alternative Calculation Manual (ACM) Reference Manual, Compliance Manual, and compliance documents.
- Section 8 – Bibliography presents the resources that the Statewide CASE Team used when developing this report.
- Appendix A: Statewide Savings Methodology, Appendix B: Embedded Electricity in Water Methodology, and Appendix C: Environmental Impacts Methodology are not required for this proposed change, which is a compliance option software enhancement.
- Appendix D: California Building Energy Code Compliance (CBECC) Software Specification presents relevant proposed changes to the compliance software and the supporting rationale.
- Appendix E: Impacts of Compliance Process on Market Actors presents how the recommended compliance process could impact identified market actors.
- Appendix F: Summary of Stakeholder Engagement documents the efforts made to engage and collaborate with market actors and experts.
- Appendix G: Synopsis of CVRH Radiant Ceiling Panel Condensation Research.

2. Measure Description

2.1 Measure Overview

Air-to-water heat pumps (AWHPs) are a vapor compression HVAC technology that provides space conditioning and, in some cases, domestic hot water (DHW) heating.[1] AWHPs feature electrically powered compressors that utilize outdoor air as the heat source (or sink) and deliver heated or cooling water via a refrigerant-to-water heat exchanger to meet the space conditioning (and in some cases DHW) load. As a hydronic-based system, space conditioning delivery options include standard or low profile fan coil units, ceiling or wall mounted fan coils, radiant floor systems, and radiant ceiling panels (Chiltrix 2019) (Frontier Energy 2019). In addition to enhancing the current CBECC-Res modeling of AWHPs, this measure proposes to recognize radiant ceiling panels as a viable AWHP delivery option and adds necessary HERS verifications.

As an all-electric HVAC equipment type, AWHPs can play a role in supporting the state of California's movement to a low-carbon future. Since all refrigeration components are contained in the outdoor unit, AWHPs have significant advantages in terms of precise factory refrigerant charging and avoidance of any field refrigerant connections which are more prone to future refrigerant leakage issues and potential contamination when refrigerant servicing or recharging is needed. This has long term performance benefits over the lifetime of the equipment and should ultimately be recognized in future updates to the Title 24, Part 6 Standards. Since the refrigerant is fully contained in the outdoor unit, this product type is also potentially more amenable to future AWHP products utilizing low global warming potential refrigerants which may not be appropriate for indoor use (such as flammable refrigerants). Additionally, hydronic AWHP systems coupled with a larger storage tank provides for the opportunity to utilize thermal storage for off-peak charging during times of excess photovoltaic or wind energy which thereby can mitigate evening peak electrical demands. All of these beneficial attributes contribute to interest in this technology as an increasing viable HVAC solution in the years ahead.

The proposed change for the 2022 code cycle is to improve the existing AWHP space conditioning modeling algorithm currently used in the CBECC-Res compliance software. The existing algorithm was added in 2016 as an interim method to allow the technology to be explicitly modeled within Title 24, Part 6. The current software implementation is

[1] The DHW performance of AWHPs is currently recognized in CBECC-Res. The Statewide CASE Team is not proposing any changes to the existing DHW methodology in the compliance software at this time.

overly conservative and represents a significant barrier to the technology's advancement in the marketplace.

Extended field monitoring has been undertaken over the last five years at a research lab house located in Stockton, California. Data has been collected for multiple AWHPs coupled with radiant ceiling panels for thermal delivery to the house. The collected data from the site represents the most detailed California specific residential AWHP dataset and forms the basis of the proposed enhanced AWHP modeling algorithm. The findings from the first few years of monitoring can be found in two technical reports hosted at the Emerging Technology Coordinating Council (Frontier Energy 2018) (Frontier Energy 2019). These two reports provide significant detail on the basis of developing this code change proposal.

The measure is limited to single phase residential AWHP equipment used in single family and low-rise multifamily building types, additions and alterations in all 16 California climate zones.

New HERS verifications are necessary to verify AWHP and radiant ceiling panel installation. For the AWHP, the HERS Rater shall verify make and model number and confirm whether the installed system has a fixed or variable speed compressor(s) and whether that information is consistent with the CF2R compliance documentation. For the radiant ceiling panels, the HERS Rater shall verify that installed panel area can satisfy the Manual J design loads (specified in compliance documents) given the installed panels specified heating and cooling capacity at standard conditions. If the CF2R specifies a "hydronic delivery in conditioned space" radiant ceiling panel installation, then the following must be HERS verified:

- Prescriptive ceiling insulation levels are installed;
- Ceiling quality insulation installation (QII) requirements are met[2]; and
- All hydronic piping shall be properly insulated and all piping supplying the radiant panels be in conditioned space (excluding up to ten feet of piping from the outdoor unit to conditioned space).

Radiant ceiling panels are a delivery option that is not common in this country, especially in residential applications. However, these systems have been popular in Europe for decades. The popularity of radiant floor heating in the United States has increased since the 1980s, particularly in heating-only climates and high-end custom homes. Radiant ceiling panels offer advantages over floor delivery in that floor surface coverings do not impact heat transfer and can also be retrofitted to existing homes. Despite these benefits, radiant ceiling systems continue to face initial market entry

[2] QII requirements ensure that the insulation has been properly installed, with minimal installation defects.

barriers in the United States. The greatest of these barriers has been the risk adverse nature of the construction industry and homebuyer market. Although concerns about panel leaks may be an immediate reaction, sprinkler systems and plastic potable attic water piping systems are no different in terms of risk. Panels offer the potential for condensation from the panel surface if the surface temperature falls below the indoor dew point temperature for an extended period. In California's dry climate, this is a rare condition. Nevertheless, production builders would likely be initially cautious in this regard and may consider the need for supplemental dehumidification. Appendix G provides some additional background information on the condensation issue and advocates for not requiring for accounting of any additional radiant panel supplemental dehumidification energy given the dry California climate and rare need for dehumidification.

Software enhancements would be required to modify the existing AWHP modeling algorithm. Given that the technology currently has very limited market share in the California residential sector, the Statewide CASE Team proposes a simplified modeling approach within the CBECC-Res compliance software at this time. The simplified approach proposes applying heating and cooling energy savings factors to the hourly CBECC-Res calculated energy use of a prescriptive standard air source heat pump (minimum efficiency heat pump meeting the Federal Standards).

The proposed software approach is recommended for several reasons. First, the Energy Commission's software team's resources are limited and a measure such as AWHP with limited market penetration is lower on the priority list as a software enhancement need. Second, the Energy Commission's recent approval of variable capacity heat pump compliance credits through the performance path utilized a similar approach given the observed variability in field performance due to a variety of factors (California Energy Commission 2019). Third, the currently limited number of residential AWHPs listed in the MAEDbS (11 listed units) suggests that if the technology gains traction in the years ahead, product offerings and participating manufacturers may change significantly. If that is the case, it would be prudent at that time to revisit AWHP modeling and better reflect the available products and observed installation configurations.

2.2 Measure History

AWHPs represent a niche technology in California's residential HVAC marketplace. In new homes, mainstream residential HVAC contractors install primarily gas furnaces with split system air conditioning systems. As interest in electrification has increased, more developers are installing or at least considering electric technologies such as central forced air heat pumps and variable capacity mini-split heat pumps. Hydronic systems, typically featuring gas fired water heaters or boilers are more common in low-rise multifamily projects, but less common in single family homes. Hydronic systems featuring electrically driven HVAC equipment are currently even less prevalent, but the increased focus on all-electric strategies will be furthering this effort to some degree. Another significant driver of electrification in the coming years will be California municipalities that have adopted all-electric reach codes[3]. The cumulative impact of these various factors will become clearer in the next few years.

AWHPs have not been considered in prior Title 24, Part 6 rulemakings but were added to the CBECC-Res compliance software in 2016 in response primarily to stakeholder concern about the inability to gain recognition for the technology under California Energy Code. Beginning July 2016, the Energy Commission began listing AWHPs in the MAEDbS. At the time of this writing, there are 11 AWHP units listed in the MAEDbS are compatible with residential single-phase electrical service. Only three of these use variable speed compressors with the other eight products being are single or dual speed compressor units (California Energy Commission 2017). There is currently no minimum performance standard required for AWHPs under Title 20.

In 2015, PG&E began sponsorship of the Central Valley Research Home (CVRH) project which featured four leased lab houses in Stockton, California (located approximately 60 miles south of Sacramento). These homes had been part of an Energy Commission Public Interest Energy Research (PIER) project initiated in 2011 (Proctor 2018). The four homes of different vintage (1950's to early 2000's) had been extensively instrumented under the PIER project and had also undergone deep energy retrofits targeting both envelope and HVAC issues. Retrofitted HVAC equipment included high efficiency conventional HVAC equipment with ducts located in conditioned space. With these high-performance test houses available as a resource at the end of the PIER project, PG&E decided to step in and fund research on two emerging HVAC technologies: VCHPs and AWHPs coupled with radiant ceiling panels. Three of the four homes have been tested over the years with VCHP equipment assessing a range of configurations and controls, while the fourth home has been dedicated to the AWHP evaluations.

Specific to the AWHP experimentation, the field monitoring effort has focused on the performance of the radiant ceiling panels in terms of thermal comfort and energy performance (when coupled with an AWHP). Over the four years, four different AHWPs have been tested and installation nuances related to buffer tanks, zoning, three function water heating performance, and summer thermal storage operation have been tested. Data collection has occurred under a rotating schedule whereby the installed

[3] Reach codes are requirements adopted by local jurisdictions that are more stringent than Title 24, Part 6.

conventional (high performance) HVAC systems have also been tested to provide comparative performance data under similar weather conditions. Reporting of the first two and a half years of monitoring have been posted at the Emerging Technology Coordinating Council website, with additional reporting currently in development (Frontier Energy 2018) (Frontier Energy 2019). It is important to highlight that the installed reference systems were high efficiency HVAC equipment (with ducts in conditioned space) that were installed, and performance optimized by one of the leading California home performance contractors.

2.3 Summary of Proposed Changes to Code Documents

The sections below summarize how the Standards, Reference Appendices, Alternative Calculation Method (ACM) Reference Manuals, and compliance documents would be modified by the proposed change. See Section 7 of this report for detailed proposed revisions to code language.

2.3.1 Summary of Changes to the Standards

The proposed software enhancement would not modify the standards.

2.3.2 Summary of Changes to the Reference Appendices

This proposal would modify the sections of the Reference Appendices identified below. See Section 7.3 of this report for the detailed proposed revisions to the text of the reference appendices.

RA3.4.5- Radiant Ceiling Panels (Conditioned Space Installation Verified): A new section is proposed for the Residential Appendix to define verification requirements for radiant ceiling panels.

2.3.3 Summary of Changes to the Residential ACM Reference Manual

This proposal would modify the following sections of the Residential ACM Reference Manual as shown below. See Section 7.4 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

Section 2.4.6.1. Distribution Types: Table 11 (HVAC Distribution Types and Location Descriptions) and Table 12 (Summary of Verified Air-Distribution Systems) would be updated to accommodate hydronic radiant ceiling panels.

2.3.4 Summary of Changes to the Residential Compliance Manual

The proposed code change would modify the following section of the Residential Compliance Manual:

- Section 4.7.9 Non-ducted Systems would be updated to reflect inclusion of hydronic radiant ceiling panels.

See Section 7.5 of this report for the detailed proposed revisions to the text of the compliance manuals.

2.3.5 Summary of Changes to Compliance Documents

The proposed code change would modify the compliance documents listed below. Examples of the revised documents are presented in Section 7.6.

- **CF2R-MCH-01-E: Space Conditioning Systems, Ducts, and Fans**– Would define whether installed AWHP has fixed or variable speed compressor; if radiant ceiling panels installed would require data on panel heating and cooling capacities, total panel area installed, and HERS verification requirements.
- **CF2R-MCH-33-E: Hydronic Radiant Ceiling Panels** – New compliance document would be developed to document HERS verification requirements are met.

2.4 Regulatory Context

2.4.1 Existing Requirements in the California Energy Code

AWHPs are recognized as an existing compliance option under the 2019 Title 24, Part 6 Standards. AWHP equipment that is installed in California must be listed in the MAEDbS. Radiant ceiling panels are currently not recognized under the 2019 standards.

2.4.2 Relationship to Requirements in Other Parts of the California Energy Code

There are no relevant requirements in other parts of the California Energy Code.

2.4.3 Relationship to Local, State, or Federal Laws

There are no relevant local, state, or federal laws. Reach codes that are being adopted by multiple California jurisdictions do overlap with this measure to the extent that they encourage or require all-electric building solutions, such as AWHPs.

2.4.4 Relationship to Industry Standards

Title 20 requires that manufacturers list their AWHP products and that they be tested in accordance with the ANSI/AHRI Standard 550/590 test procedures (Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle) (ANSI/AHRI 2011).

2.5 Compliance and Enforcement

When developing this proposal, the Statewide CASE Team considered methods to streamline the compliance and enforcement process and how negative impacts on market actors who are involved in the process could be mitigated or reduced. This section describes how they would comply with the proposed code change as well as the compliance verification process. Appendix E presents how the proposed changes could impact various market actors.

The activities that need to occur during each phase of the project are described below:

- **Design Phase:** The mechanical designer needs to complete a Manual J load calculation, evaluate equipment options, and determine what type of hydronic delivery would be used. In the case of three function AWHPs providing both space conditioning and water heating, the designer must evaluate equipment sizing recognizing the potential of simultaneous heating and water heating loads (manufacturers would provide design guidance). Since the AWHP compressors are five times (or more) larger than conventional residential heat pump water heaters, the recovery times for bringing storage back up to temperature after large hot water draws are correspondingly shorter, minimizing the impact of any conflicts due to simultaneous water heating and space conditioning loads.

  Space conditioning delivery options include forced air fan coils, wall and ceiling mount low profile fan coils, radiant floors, and radiant ceiling panels. For ducted forced air fan coils, delivery can be via ducts in conditioned or unconditioned space. Based on the building's calculated design load and manufacturer's data, the designer shall specify the equipment details, which may include buffer tanks, expansion tanks, and air separators. If radiant panels are installed, panel layouts by room are needed to determine the needed panel area. With radiant panels, the designer should evaluate the need for either supplemental dehumidification or a dew point controller that limits panel supply water temperature when conditions warrant[4]. Where appropriate, consideration needs to be given to controlling indoor dew point temperature to address unwanted condensation on radiant panels. Under most situations in California, the need for any supplemental dehumidification would be rare, if at all. Radiant panel manufacturers can provide guidance to designers in this regard.

  Plans should clearly specify equipment and whether the AWHP is fixed or variable speed compressor. Energy consultant should complete Title 24, Part 6 calculations to determine compliance.

- **Permit Application Phase:** In the plan review process, the plans examiner should determine if the specified AWHP model is fixed or variable speed and is correctly modeled in the compliance documentation. If hydronic radiant ceiling panels are installed, the plans examiner should verify if the Conditioned Space

[4] These controllers adjust the panel supply water temperature in response to the room indoor air dew point temperature.

Installation Verified credit has been taken, and if so, that prescriptive ceiling insulation levels are specified, QII has been specified, and that installed ceiling panel area is sufficient to meet the Manual J design loads.

- **Construction Phase:** The AWHP technology is not well known by mainstream HVAC contractors in California. Since it is a system that heats or cools water, hydronic or specialty HVAC contractors currently are more familiar with the technology. Radiant ceiling panels are also an emerging technology. The designer and builder must work closely with the installers as they gain experience with the technology and the HERS verification requirements. However, installation of the panels is relatively straightforward given the panel layout and panel plumbing design developed in the design phase. Commissioning of the radiant panel system is a new step as well.
- **Inspection Phase:** The HERS Rater would be required to verify that installed AWHP equipment features either a fixed or variable speed compressor. If radiant ceiling panels are installed, additional HERS inspections are recommended. The HERS Rater shall verify through visual inspection that installed ceiling panel area is sufficient to meet the Manual J design loads given the installed panel's specified heating and cooling capacity at standard conditions. If the CF2R-MCH-33-E compliance document specifies a "hydronic delivery in conditioned space" radiant ceiling panel installation, then the following must be verified:
    - Prescriptive ceiling insulation levels are installed
    - Ceiling QII requirements are met
    - All hydronic piping shall be properly insulated, and all piping located in conditioned space

The main change in the compliance verification process for this measure relates to designers and HERS Raters gaining experience with the technology and the new HERS verification requirements. Currently specialty hydronic contractors are doing the bulk of the AWHP installations, but if the technology gains traction mainstream, HVAC contractors would also enter the market. HERS verification elements are not complicated but would still require training. No additional effort is required for building officials, as HERS Raters would be completing the verifications.

3. Market Analysis

3.1 Market Structure

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. It then considered how the proposed standard may impact the market in general as well as individual market actors. Estimates of market size and measure applicability were identified through research and outreach with stakeholders including utility program staff, Energy Commission staff, and a wide range of industry actors. In addition to conducting personalized outreach, the Statewide CASE Team discussed the current market structure and potential market barriers during a public stakeholder meeting that the Statewide CASE Team held on October 10, 2019 (Statewide Codes and Standards Team 2019).

The residential AWHP market is not very mature in California at this time. It is largely confined to custom home projects where clients either do not have natural gas available, want to move away from forced air HVAC systems, or have a desire to pursue all-electric strategies. A major Northern California hydronics equipment distributor suggests that current AWHP sales are on the order of hundreds of units per year statewide. A significant technology barrier cited by stakeholders is the current compliance process which does not fairly recognize performance relative to the prescriptive standard air source heat pump (ASHP). With the improved recognition for AWHPs proposed under Title 24, Part 6, John Grose of Hydronic Specialties sees a bright future for the technology given increasing interest in low carbon space conditioning technologies. Although the California market is currently small, AWHPs are a more prevalent technology in other parts of the world (Market Watch 2018).

3.2 Technical Feasibility, Market Availability, and Current Practices

The AWHP market is currently supported by specialty hydronic contractors who are particularly active in the Tahoe and Sierra Nevada foothill regions, as well as coastal California. Mainstream HVAC contractors are less likely to be familiar with AWHPs or radiant ceiling panels as production homes are more focused on traditional HVAC solutions featuring central forced air designs (gas furnace with split system air conditioner or ASHP).

The MAEDbS maintains a listing of AWHPs. Current Title 20 listed manufacturers of single-phase products suitable for residential include Aermec, Chiltrix, Multiaqua, PHNIX, and Spacepak.

Several design firms provide AWHP designs for residential AWHP projects. These hydronic designs often feature fan coil or radiant floor designs, but radiant ceiling panels are seen in about 15 percent of their designs.

One aspect of AWHPs that is difficult to quantify, but likely a real effect, is long term persistence of energy savings. Since AWHP refrigerant systems are fully contained in the outdoor unit and carefully factory charged,[5] it is not unreasonable to expect that over time these systems would deliver more consistent and stable performance than field assembled and charged conventional HVAC equipment. The Title 24, Part 6 standards do not currently reflect any long-term performance degradation as HVAC equipment ages, but this is a topic that warrants consideration for future code cycles. A Florida field research study (Fenaughty and Parker 2018) of residential central forced air vapor compression systems found median air conditioner performance degradation to be 5.2 percent per year and that refrigerant leaks were found in 19 percent of failed units.

The use of radiant ceiling panels impacts comfort and space conditioning delivery for occupants. Heated panel surfaces in winter (and cooled surfaces in summer) contribute to occupant perceived improved thermal comfort. In general, improved mean radiant temperature in a space will typically result in an ability to slightly relax the space conditioning setpoint to maintain equivalent occupant comfort. This translates to slightly lower wintertime indoor air temperatures needed with a warmer ceiling surface, and conversely, slightly higher summer setpoints are desirable with a cooler ceiling surface. Proponents of radiant delivery tout this benefit as well as the uniformity of temperature relative to conventional forced air systems where space temperatures fluctuate due to equipment cycling (radiant panels cycle as well, but panel mass dampens the thermal effect). Radiant ceiling panels do require a slightly different occupant control pattern if the homeowner wants to use a sizable daytime or nighttime setback/setup. Either shallower setbacks/setups, or more time needs to be factored into setting home and away comfort conditions as the radiant panels do not provide immediate thermal response if they have been off for an extended period (approximately one hour additional time to start up, but correspondingly an earlier shutoff is also possible).

A final consideration of radiant ceiling panels relates to potential condensation issues in the cooling operating mode. In California's largely dry summer climate, this is not a principal concern, yet special situations (high internal moisture generation from a large aquarium, or very low cooling setpoint expectations) should certainly warrant a closer evaluation from designers on whether some sort of supplemental dehumidification is

[5] In contrast with mainstream split system air conditioners and forced air heat pumps which must be field charged which adds complexity and increased risk of refrigeration contamination with non condensables (air, water vapor, nitrogen).

needed. California’s low rise residential mechanical ventilation requirements specified under Title 24, Part 6 would solve most potential moisture issues. In addition, short durations of higher outdoor humidity (contributing to higher indoor humidity) can be accommodated to some degree by the buffering effort of drywall and other home furnishings (books, clothes).

3.3 Market Impacts and Economic Assessments

3.3.1 Impact on Builders

Builders of residential and commercial structures are directly impacted by many of the proposed code change proposals. It is within the normal practices of these businesses to adjust their building practices to changes in building codes. When necessary, builders engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

California’s construction industry is comprised of about 80,000 business establishments and 860,000 employees (see Table 2).[6] In 2018, total payroll was $80 billion. Nearly 60,000 of these business establishments and 420,000 employees are engaged in the residential building sector, while another 17,000 establishments and 344,000 employees focus on the commercial sector. The remainder of establishments and employees work in industrial, utilities, infrastructure, and other heavy construction (industrial sector).

[6] Average total monthly employment in California in 2018 was 18.6 million; the construction industry represented 4.5 percent of 2018 employment.

Table 2: California Construction Industry, Establishments, Employment, and Payroll, 2018

Construction Sectors	Establishments	Employment	Annual Payroll (billions $)
Residential	**59,287**	**420,216**	**$23.3**
Residential Building Construction Contractors	22,676	115,777	$7.4
Foundation, Structure, & Building Exterior	6,623	75,220	$3.6
Building Equipment Contractors	14,444	105,441	$6.0
Building Finishing Contractors	15,544	123,778	$6.2
Commercial	**17,273**	**343,513**	**$27.8**
Commercial Building Construction	4,508	75,558	$6.9
Foundation, Structure, & Building Exterior	2,153	53,531	$3.7
Building Equipment Contractors	6,015	128,812	$10.9
Building Finishing Contractors	4,597	85,612	$6.2
Industrial, Utilities, Infrastructure, & Other	**4,103**	**96,550**	**$9.2**
Industrial Building Construction	299	5,864	$0.5
Utility System Construction	1,643	47,619	$4.3
Land Subdivision	952	7,584	$0.9
Highway, Street, and Bridge Construction	770	25,477	$2.4
Other Heavy Construction	439	10,006	$1.0

Source: (State of California, Employment Development Department n.d.)

The proposed change to the enhanced air-to-water heat pump compliance option would likely affect builders but would not impact firms that focus on construction and retrofit of industrial buildings, utility systems, public infrastructure, or other heavy construction. The effects on the residential building industry would not be felt by all firms and workers, but rather would be concentrated in specific industry subsectors. Table 3 shows the residential building subsectors we expect to be impacted by the changes proposed in this report. The impacted subsectors include contractors associated with HVAC activities and the associated electrical contractors supporting potential electrification activities. Since the AWHP technology would supplant another residential HVAC technology, the overall impacts of this measure would be small. Normally, the Statewide CASE Team's estimates of the magnitude of these impacts would be shown in Section

3.4 Economic Impacts, but since this measure is a software enhancement, Section 3.4 content is not provided for this Draft CASE Report.

Table 3: Size of the California Residential Building Industry by Subsector, 2018

Residential Building Subsector	Establishments	Employment	Annual Payroll ($)
New single family general contractors	10,968	55,592	$3,684,569,780
New multifamily general contractors	406	5,333	$490,673,677
New housing for-sale builders	180	2,719	$279,587,102
Residential Remodelers	11,122	52,133	$2,973,873,865
Residential Electrical Contractors	6,095	37,933	$2,175,638,943
Residential plumbing and HVAC contractors	8,086	66,177	$3,778,328,951

Source: (State of California, Employment Development Department n.d.)

3.3.2 Impact on Building Designers and Energy Consultants

Adjusting design practices to comply with changing building codes practices is within the normal practices of building designers. Building codes (including the California Energy Code) are typically updated on a three-year revision cycle and building designers and energy consultants engage in continuing education and training in order to remain compliant with changes to design practices and building codes.

Businesses that focus on residential, commercial, institutional, and industrial building design are contained within the Architectural Services sector (North American Industry Classification System 541310). Table 4 shows the number of establishments, employment, and total annual payroll for Building Architectural Services. The proposed code change proposals would potentially impact all firms within the Architectural Services sector. The Statewide CASE Team anticipates the impacts for enhanced air-to-water heat pump compliance option to affect firms that focus on single family (and to a lesser extent, multifamily) construction.

There is not a North American Industry Classification System (NAICS)[7] code specific for energy consultants. Instead, businesses that focus on consulting related to building energy efficiency are contained in the Building Inspection Services sector (NAICS 541350), which is comprised of firms primarily engaged in the physical inspection of residential and nonresidential buildings.[8] It is not possible to determine which business establishments within the Building Inspection Services sector are focused on energy efficiency consulting. The information shown in Table 4 provides an upper bound indication of the size of this sector in California.

Table 4: California Building Designer and Energy Consultant Sectors, 2018

Sector	Establishments	Employment	Annual Payroll (millions $)
Architectural Services [a]	3,704	29,611	$2,906.7
Building Inspection Services [b]	824	3,145	$223.9

Source: (State of California, Employment Development Department n.d.)

a. Architectural Services (NAICS 541310) comprises private-sector establishments primarily engaged in planning and designing residential, institutional, leisure, commercial, and industrial buildings and structures;
b. Building Inspection Services (NAICS 541350) comprises private-sector establishments primarily engaged in providing building (residential & nonresidential) inspection services encompassing all aspects of the building structure and component systems, including energy efficiency inspection services.

3.3.3 Impact on Occupational Safety and Health

The proposed code change does not alter any existing federal, state, or local regulations pertaining to safety and health, including rules enforced by the California Division of Occupational Safety and Health (Cal/OSHA). All existing health and safety rules would remain in place. Complying with the proposed code change is not

[7] NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy. NAICS was development jointly by the U.S. Economic Classification Policy Committee (ECPC), Statistics Canada, and Mexico's Instituto Nacional de Estadistica y Geografia, to allow for a high level of comparability in business statistics among the North American countries. NAICS replaced the Standard Industrial Classification (SIC) system in 1997.

[8] Establishments in this sector include businesses primarily engaged in evaluating a building's structure and component systems and includes energy efficiency inspection services and home inspection services. This sector does not include establishments primarily engaged in providing inspections for pests, hazardous wastes or other environmental contaminates, nor does it include state and local government entities that focus on building or energy code compliance/enforcement of building codes and regulations.

anticipated to have adverse impacts on the safety or health of occupants or those involved with the construction, commissioning, and maintenance of the building.

3.3.4 Impact on Building Owners and Occupants (Including Homeowners and Potential First-Time Homeowners)

Residential Buildings

According to data from the U.S. Census, American Community Survey (ACS), there were nearly 14.3 million housing units in California in 2018 and nearly 13.1 million were occupied (see Table 5). Most housing units (nearly 9.2 million were single-family homes (either detached or attached), while about 2 million homes were in building containing two to nine units and 2.5 million were in multi-family building containing 10 or more units. The U.S. Census reported that 59,200 single-family and 50,700 multi-family homes were constructed in 2019.

Table 5: California Housing Characteristics, 2018

Housing Measure	Estimate
Total housing units	14,277,867
Occupied housing units	13,072,122
Vacant housing units	1,205,745
Homeowner vacancy rate	1.2%
Rental vacancy rate	4.0%
Units in Structure	**Estimate**
1-unit, detached	8,177,141
1-unit, attached	1,014,941
2 units	358,619
3 or 4 units	783,963
5 to 9 units	874,649
10 to 19 units	742,139
20 or more units	1,787,812
Mobile home, RV, etc.	538,603

Source: (2018 American Community Survey n.d.)

Table 6 shows the distribution of California homes by vintage. About 15 percent of California homes were built in 2000 or later and another 11 percent built between 1990 and 1999. The majority of California's existing housing stock (8.5 million homes – 59 percent of the total) were built between 1950 and 1989, a period of rapid population and economic growth in California. Finally, about 2.1 million homes in California were built before 1950. According to Kenney et al, 2019, more than half of California's existing multifamily buildings (those with five or more units) were constructed before 1978 when there were no building energy efficiency standards (Kenney 2019).

Table 6: Distribution of California Housing by Vintage, 2018

Home Vintage	Units	Percent	Cumulative Percent
Built 2014 or later	343,448	2.4%	2.4%
Built 2010 to 2013	248,659	1.7%	4.1%
Built 2000 to 2009	1,553,769	10.9%	15.0%
Built 1990 to 1999	1,561,579	10.9%	26.0%
Built 1980 to 1989	2,118,545	14.8%	40.8%
Built 1970 to 1979	2,512,178	17.6%	58.4%
Built 1960 to 1969	1,925,945	13.5%	71.9%
Built 1950 to 1959	1,896,629	13.3%	85.2%
Built 1940 to 1949	817,270	5.7%	90.9%
Built 1939 or earlier	1,299,845	9.1%	100.0%
Total housing units	**14,277,867**	**100%**	

Source: (2018 American Community Survey n.d.)

Table 7 shows the distribution of owner- and renter-occupied housing by household income. Overall, about 55 percent of California housing is owner-occupied and the rate of owner-occupancy generally increases with household income. The owner-occupancy rate for households with income below $50,000 is only 37 percent, whereas the owner occupancy rate is 72 percent for households earning $100,000 or more.

Table 7: Owner- and Renter-Occupied Housing Units in California by Income, 2018

Household Income	Total	Owner Occupied	Renter Occupied
Less than $5,000	391,235	129,078	262,157
$5,000 to $9,999	279,442	86,334	193,108
$10,000 to $14,999	515,804	143,001	372,803
$15,000 to $19,999	456,076	156,790	299,286
$20,000 to $24,999	520,133	187,578	332,555
$25,000 to $34,999	943,783	370,939	572,844
$35,000 to $49,999	1,362,459	590,325	772,134
$50,000 to $74,999	2,044,663	1,018,107	1,026,556
$75,000 to $99,999	1,601,641	922,609	679,032
$100,000 to $149,999	2,176,125	1,429,227	746,898
$150,000 or more	2,780,761	2,131,676	649,085
Total Housing Units	**13,072,122**	**7,165,664**	**5,906,458**
Median household income	**$75,277**	**$99,245**	**$52,348**

Source: (2018 American Community Survey n.d.)

Understanding the distribution of California residents by home type, home vintage, and household income is critical for developing meaningful estimates of the economic impacts associated with proposed code changes affecting residents. Many proposed code changes specifically target single-family or multi-family residences and so the counts of housing units by building type shown in Table 5 provides the information necessary to quantify the magnitude of potential impacts. Likewise, impacts may differ for owners and renters, by home vintage, and by household income, information provided in Table 6 and Table 7.

3.3.5 Impact on Building Component Retailers (Including Manufacturers and Distributors)

The current California market for residential AWHP equipment is small with annual sales of less than 1,000 units. This is due both to challenges with the current compliance modeling method, as well as limited familiarity of builders and mainstream residential HVAC contractors with the technology. Increasing electrification efforts throughout California will also increase AWHP visibility. If the technology gains traction in the years ahead, California sales will increase and local distributors will expand.

3.3.6 Impact on Building Inspectors

Table 8 shows employment and payroll information for state and local government agencies in which many inspectors of residential and commercial buildings are employed. Building inspectors participate in continuing training to stay current on all aspects of building regulations, including energy efficiency. Although additional HERS verification measures are proposed for radiant ceiling panels, there is little or no impact anticipated for building inspectors. The Statewide CASE Team, therefore, anticipates the proposed change would have no impact on employment of building inspectors or the scope of their role conducting energy efficiency inspections.

Table 8: Employment in California State and Government Agencies with Building Inspectors, 2018

Sector	Govt.	Establishments	Employment	Annual Payroll (millions $)
Administration of Housing Programs[a]	State	17	283	$29.0
	Local	36	2,882	$205.7
Urban and Rural Development Admin[b]	State	35	552	$48.2
	Local	52	2,446	$186.6

Source: (State of California, Employment Development Department n.d.)

a. Administration of Housing Programs (NAICS 925110) comprises government establishments primarily engaged in the administration and planning of housing programs, including building codes and standards, housing authorities, and housing programs, planning, and development.

b. Urban and Rural Development Administration (NAICS 925120) comprises government establishments primarily engaged in the administration and planning of the development of urban and rural areas. Included in this industry are government zoning boards and commissions.

3.3.7 Impact on Statewide Employment

As described in Sections 3.3.1 through 3.3.6, the Statewide CASE Team does not anticipate significant employment or financial impacts to any particular sector of the California economy. As a compliance option, this measure would substitute one HVAC technology with another with anticipated modest impacts on employment in California.

3.4 Economic Impacts

As a compliance option software enhancement measure, economic impacts are not required.

4. Energy Savings

Demonstrated energy savings are not required to be provided for a compliance option software enhancement. Appendix D provides information on the current 2019 compliance modeling of AWHPs, development of the proposed modeling methodology, and the energy impacts of the proposed AWHP software modification. Results are briefly summarized here based on the proposed savings methodology.

As of the Draft CASE Report's date of publication, the Energy Commission has not released the final 2022 TDV factors that are used to evaluate TDV energy savings and cost effectiveness. The energy analysis presented in this report used the TDV factors that were released in the 2022 CBECC- Res research version that was released in December 2019. These TDV factors were consistent with the TDV factors that the Energy Commission presented during their public workshop on compliance metrics held October 17, 2019 (California Energy Commission 2019). The electricity TDV factors did not include the 15 percent retail adder and the natural gas TDV factors did not include the impact of methane leakage on the building site, updates that the Energy Commission presented during their workshop on March 27 , 2020. Presentations from Bruce Wilcox and NORESCO during the March 27, 2020 workshop indicated that the 15 percent retail adder and methane leakage would result in most energy efficiency measures having slightly higher TDV energy and energy cost savings than using the TDV factors without these refinements. As a result, the TDV energy savings presented in this report are lower than the values that would have been obtained using TDV with the 15 percent retail adder and methane leakage, and the proposed code changes will be more cost effective using the revised TDV. The Energy Commission notified the Statewide CASE Team on April 21, 2020 that they were investigating further refinements to TDV factors using 20-year global warming potential (GWP) values instead of the 100-year GWP values that were used to derive the current TDV factors. It is anticipated that the 20-year GWP values may increase the TDV factors slightly making proposed changes that improve energy efficiency more cost effective. Energy savings presented in kWh and therms are not affected by TDV or demand factors.

When the Energy Commission releases the final TDV factors, the Statewide CASE Team will consider the need to re-evaluate energy savings and cost-effectiveness analyses using the final TDV factors for the results that will be presented in the Final CASE Report.

4.1 Key Assumptions for Energy Savings Analysis

Appendix D provides a complete description on the development of the proposed modeling approach.

4.2 Energy Savings Methodology

4.2.1 Energy Savings Methodology per Prototypical Building

The Energy Commission directed the Statewide CASE Team to model the energy impacts using specific prototypical building models that represent typical building geometries for different types of buildings. The prototype buildings that the Statewide CASE Team used in the analysis are presented in Table 9. The 2,100 and 2,700 ft^2 single family prototypes have been used for standards development over many code cycles. The models are developed with 2019 prescriptive requirements included, so that the impacts of any measure would be determined relative to that new construction baseline.

Table 9: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis

Prototype Name	Number of Stories	Floor Area (square feet)	Description
2,100	one	2,100	single story house with attached garage, pitched roof, attic. 9-ft ceilings, 1 ft overhang, front door, garage door
2,700	two	2,700	2-story home with attached 2-car garage. 9-ft ceilings, 1-ft between floors, 1-ft overhang

The Statewide CASE Team estimated energy and demand impacts by simulating the proposed code change using the 2022 Research Version of the California Building Energy Code Compliance (CBECC) software for residential buildings (CBECC-Res).

4.2.2 Statewide Energy Savings Methodology

For a compliance option the assumption is that any credit associated with the measure would be offset by relaxing other measures, negating any net energy savings. Therefore, zero statewide savings are estimated for this compliance option.

4.3 Per-Unit Energy Impacts Results

Although there are no statewide impacts anticipated from this compliance option measure, per unit impacts are reported here to characterize the level of energy savings for the measure in isolation. Energy savings and peak demand reductions per unit are presented in Table 10 for the proposed 2022 variable speed AWHP modeling (2 percent heating savings factor, 8 percent cooling savings factor). The results are shown for a single-family prototype based on 45 percent weighting of the 2,100 single story prototype and 55 percent weighting of the 2,700 two story prototype. Impacts shown are relative to a prescriptive minimum air source heat pump with all features consistent with a 2019 prescriptively compliant new home. The fixed speed AWHP proposed model does not have any associated savings, resulting in zero impacts in all climate zones. The per-unit energy savings figures do not account for naturally occurring market adoption or compliance rates.

For the variable speed AWHP technology, per-unit savings for the first year are expected to range from 13 to 382 kWh/yr depending upon climate zone. Demand reductions are expected to range between 0.00 kW and 0.23 kW depending on climate zone.

Table 10: First-Year Energy Impacts Per Home– 2,430 ft^2 Prototype All-Electric Building

Climate Zone	Electricity Savings (kWh/yr)	Peak Electricity Demand Reductions (kW)	Natural Gas Savings (therms/yr)	TDV Energy Savings (TDV kBtu/yr)
1	81	0.00	N/A	2,480
2	51	0.00	N/A	3,048
3	24	0.00	N/A	823
4	39	0.02	N/A	2,767
5	24	0.00	N/A	730
6	16	0.02	N/A	1,464
7	13	0.01	N/A	824
8	62	0.07	N/A	3,510
9	64	0.07	N/A	3,682
10	95	0.09	N/A	4,911
11	161	0.11	N/A	7,798
12	74	0.03	N/A	4,584
13	190	0.14	N/A	8,401
14	149	0.10	N/A	6,227
15	382	0.23	N/A	14,216
16	107	0.02	N/A	3,612

5. Cost and Cost Effectiveness

Costs and cost effectiveness are not required to be provided for a compliance option software enhancement. The code change proposal would not modify the stringency of the existing California Energy Code, so the Energy Commission does not need a complete cost-effectiveness analysis to approve the proposed change.

6. First-Year Statewide Impacts

Statewide impacts are not required to be provided for a compliance option software enhancement. As an all-electric HVAC strategy, AWHPs support California's greenhouse gas reduction goals.

7. Proposed Revisions to Code Language

7.1 Guide to Markup Language

The proposed changes to the standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2019 documents are marked with red underlining (new language) and ~~strikethroughs~~ (deletions).

7.2 Standards

There are no proposed changes to the standards.

7.3 Reference Appendices

RA3.4.5- Hydronic Radiant Ceiling Panels (Conditioned Space Installation Verified): A new section is proposed to define verification requirements for radiant ceiling panels.

RA3.4.5 Hydronic Radiant Ceiling Panels (Conditioned Space Installation Verified)

Hydronic radiant ceiling panels are located within conditioned space, but to be eligible for conditioned space delivery system treatment under the compliance software, the following eligibility criteria must be verified by a HERS Rater on the Certificate of Verification.

(a) The installed radiant ceiling panel area must be greater than or equal to the maximum of:

 i. The Manual J design heating load (Btu/hour) for the dwelling unit divided by the manufacturer's specified panel heating capacity (Btu/hour-ft^2) at standard rating conditions.

 ii. The Manual J design cooling load (Btu/hour) for the dwelling unit divided by the manufacturer's specified panel cooling capacity (Btu/hour-ft^2) at standard rating conditions.

(b) All hydronic piping must meet the insulation requirements specified in Section 120.3(c).

(c) Other than the piping from the outdoor HVAC unit (if applicable) to conditioned space, all hydronic piping supplying the ceiling panels shall be located within conditioned space and be HERS verified to have pipe insulation fitting tightly to the pipe, with all elbows and tees fully insulated.

(d) Installed ceiling insulation must meet the climate zone prescriptive ceiling insulation requirements.

(e) QII verification as per RA3.5 must be completed.

7.4 ACM Reference Manual

Section 2.4.6.1 of the Residential ACM Reference Manual should be updated to more clearly accommodate radiant ceiling panels.

Table 2: HVAC Distribution Type and Location Descriptors

Name	HVAC Distribution Type and Location Description
Ducts located in attic (Ventilated and Unventilated)	Ducts located overhead in the attic space.
Ducts located in a crawl space	Ducts located under floor in the crawl space.
Ducts located in a garage	Ducts located in an unconditioned garage space.
Ducts located within the conditioned space (except < 12 linear ft)	Ducts located within the conditioned floor space except for less than 12 linear feet of duct, furnace cabinet, and plenums - typically an HVAC unit in the garage mounted on return box with all other ducts in conditioned space.
Ducts located entirely in conditioned space	HVAC unit or systems with all HVAC ducts (supply and return) located within the conditioned floor space. Location of ducts in conditioned space eliminates conduction losses but does not change losses due to leakage. Leakage either from ducts that are not tested for leakage or from sealed ducts is modeled as leakage to outside the conditioned space.
Distribution system without ducts (none)	~~Air~~ Distribution systems without ducts such as ductless split-system air-conditioners and heat pumps, window air-conditioners, through-the-wall heat pumps, wall furnaces, floor furnaces, radiant electric panels, combined hydronic heating equipment, hydronic radiant floors, hydronic radiant ceiling panels, electric baseboards, or hydronic baseboard finned-tube natural convection systems, etc.
Ducts located in outdoor locations	Ducts located in exposed locations outdoors.
Verified low-leakage ducts located entirely in conditioned space	Duct systems for which air leakage to outside is equal to or less than 25 CFM when measured in accordance with Reference Residential Appendix RA3.1.4.3.8.
Ducts located in multiple places	Ducts with different supply and return duct locations.

Table 3: Summary of Verified Distribution Systems

Measure	*Description*	*Procedures*
Verified Duct Sealing	Mandatory measures require that space-conditioning ducts be sealed. Field verification and diagnostic testing are required to verify that approved duct system materials are used and that duct leakage meets the specified criteria.	*RA3.1.4.3*
Verified Duct Location, Reduced Surface Area and R-value	Compliance credit can be taken for improved supply duct location, reduced surface area, and R-value. Field verification is required to verify that the duct system was installed according to the duct design, including location, size and length of ducts, duct insulation R-value, and installation of buried ducts.[1] For buried duct measures, verified quality insulation installation (QII) is required as well as duct sealing.	*RA3.1.4.1, 3.1.4.1.1*
Low-Leakage Ducts in Conditioned Space	When the standards specify use of the procedures in Section RA3.1.4.3.8 to determine if the space-conditioning system ducts are located entirely in directly conditioned space, the duct system location is verified by diagnostic testing. Compliance credit can be taken for verified duct systems with low air leakage to the outside when measured in accordance with Reference Appendices, Residential Appendix Section RA3.1.4.3.8. Field verification for ducts in conditioned space is required. Duct sealing is required.	*RA3.1.4.3.8*
Hydronic Delivery in Conditioned Space	Compliance credit can be taken for hydronic delivery systems with no ducting or piping in unconditioned space. For radiant ceiling panels, the verifications in Section RA3.4.5 must be completed to qualify.	*RA3.4.5*
Low-Leakage Air-Handling Units	Compliance credit can be taken for installing a factory-sealed air-handling unit tested by the manufacturer and certified to the Energy Commission to have met the requirements for a low-leakage air-handling unit. Field verification of the air handler model number is required. Duct sealing is required.	*RA3.1.4.3.9*
Verified Return Duct Design	Verification to confirm that the return duct design conforms to the criteria given in Table 150.0-B or Table 150.0-C. as an alternative to meeting 0.45 or 0.58 W/CFM fan efficacy of Section 150.0(m)0.	*RA3.1.4.4*
Verified Bypass Duct Condition	Verification to determine if system is zonally controlled and confirm that bypass ducts condition modeled matches installation.	*RA3.1.4.6*

7.5 Compliance Manuals

Chapter 4.7.9 of the Residential Compliance Manual would need to be revised to include Radiant Ceiling Panels as a non-ducted delivery system option.

Section 4.7.9 of the Residential Manual addresses non-ducted systems that do not use ducts to heat or cool spaces. This section currently contains general language on how these non-ducted systems are treated. It is proposed that a new section 4.7.9.1 be added to address Hydronic Radiant Ceiling Panels. This new section would clarify how the panels could be treated either as equivalent to prescriptive forced air ducted delivery or, if all eligibility criteria are met for demonstrating compliance with hydronic delivery in conditioned space (see draft RA3.4.5), as forced air ducted systems with ducts in conditioned space.

7.6 Compliance Documents

Compliance document CF2R-MCH-01-E would need to be revised as shown below.

H. Installed Heat Pump System – Split System Condensing Unit or Package Unit Equipment				
01	02	03	04	05
SC System ID/Name from CF1R	SC System Description of area Served CF1R	Condenser or Package Unit Manufacturer	Condenser or Package Unit Model Number	Compressor Speed (fixed or variable)

…

O. HERS Verification Requirement for Radiant Ceiling Panels Coupled with Air-to-Water Heat							
01	02	03	04	05	06	07	08
SC System ID/Name from CF1R	Radiant Ceiling Panel Rated Heating	Radiant Ceiling Panel Rated Cooling	Installed Radiant Ceiling Panel	Prescriptive Ceiling R-value Installed?	QII Inspection for Ceiling Insulation	Installed Radiant Panel Area Exceeds	All panel hydronic piping insulated

…

O. HERS Verification Requirement for Radiant Ceiling Panels Coupled with Air-to-Water Heat Pump Unit

01 Space conditioning system ID/Name from CF1R

02 Rated capacity from radiant ceiling panel manufacturer's literature

03 Rated capacity from radiant ceiling panel manufacturer's literature

04 Total area of ceiling panels installed (ft^2)

05 Yes or No

06 Yes or No

07 Yes or No (Does installed panel area exceed the maximum of a) Manual J design heating load/ Rated heating capacity from radiant ceiling panel specification sheet, and b) Manual J design sensible cooling load/ Rated cooling capacity from radiant ceiling panel specification sheet

08 Yes or No (All panel hydronic piping located in conditioned space and fully insulated as per Section 120.3(c) requirements)

Note: if 05-08 are all indicated as "Yes", the installation qualifies for hydronic delivery in conditioned space treatment.

Compliance document CF3R-MCH-33-H would need to be developed to document radiant ceiling panel verifications. Proposed content is shown here.

CERTIFICATE OF VERIFICATION		CF3R-MCH-33-H
Hydronic Radiant		(Page 1 of 2)
Project Name:	Enforcement Agency:	Permit Number:
Dwelling Address:	City:	Zip Code:

A. Hydronic Radiant Ceiling Panels- General Information		
01	Dwelling Unit Name	
02	Building Type	
03	Manual J Design Heating Load (Btu/h)	
04	Manual J Design Sensible Cooling Load (Btu/h)	
05	Radiant Ceiling Panel Manufacturer	
06	Radiant Ceiling Panel Specified Heating Capacity at Rated Conditions (Btu/h-ft^2-°F)	
07	Radiant Ceiling Panel Specified Cooling Capacity at Rated Conditions (Btu/h-ft^2-°F)	
08	Minimum Ceiling Panel Area Required (ft^2)	
09	Installed Panel Surface Area (ft^2)	
10	Installed Ceiling Panel Area Exceeds Minimum Required Area? (Yes or No)	
11	All Radiant Panel Hydronic Piping Meets Requirements in 120.3(c) (Yes or No)	

B. Hydronic Radiant Ceiling Panels- Conditioned Space Delivery Option		
01	Installed Ceiling Insulation Level Above Radiant Panels (R-value)	01
02	Installed Ceiling Insulation Meets or Exceeds Prescriptive Requirement (Yes or No)	
03	Ceiling Insulation Passes QII Requirements (RA3.5) (Yes or No)	
04	All Hydronic Piping Supplying Radiant Panels Within Conditioned Space (Yes or No)	
05	All Pipe Insulation Fits Tightly with All Elbows and Tees Fully Insulated (Yes or No)	

CERTIFICATE OF VERIFICATION		CF3R-MCH-33-H
Hydronic Radiant Ceiling Panels		(Page 2 of 2)
Project Name:	Enforcement Agency:	Permit Number:
Dwelling Address:	City:	Zip Code:

DOCUMENTATION AUTHOR'S DECLARATION STATEMENT	
1. I certify that this Certificate of Verification documentation is accurate and complete.	
Documentation Author Name:	Documentation Author Signature:
Company:	Date Signed:
Address:	CEA/HERS Certification Information (if applicable):
City/State/Zip:	Phone:

RESPONSIBLE PERSON'S DECLARATION STATEMENT

I certify the following under penalty of perjury, under the laws of the State of California:

1. The information provided on this Certificate of Verification is true and correct.
2. I am the certified HERS Rater who performed the verification identified and reported on this Certificate of Verification (responsible rater).
3. The installed features, materials, components, manufactured devices, or system performance diagnostic results that require HERS verification identified on this Certificate of Verification comply with the applicable requirements in Reference Appendices RA2, RA3, and the requirements specified on the Certificate of Compliance for the building approved by the enforcement agency.
4. The information reported on applicable sections of the Certificate(s) of Installation (CF2R) signed and submitted by the person(s) responsible for the construction or installation conforms to the requirements specified on the Certificate(s) of Compliance (CF1R) approved by the enforcement agency.

<table>
<tr><td colspan="2">5. I will ensure that a registered copy of this Certificate of Verification shall be posted or made available with the building permit(s) issued for the building and made available to the enforcement agency for all applicable inspections. I understand that a registered copy of this Certificate of Verification is required to be included with the documentation the builder provides to the building owner at occupancy.</td></tr>
<tr><td colspan="2">BUILDER OR INSTALLER INFORMATION AS SHOWN ON THE CERTIFICATE OF INSTALLATION</td></tr>
<tr><td colspan="2">Company Name (Installing Subcontractor, General Contractor, or Builder/Owner):</td></tr>
<tr><td>Responsible Builder or Installer Name:</td><td>CSLB License:</td></tr>
<tr><td colspan="2">HERS PROVIDER DATA REGISTRY INFORMATION</td></tr>
<tr><td>Sample Group Number (if applicable):</td><td>Dwelling Test Status in Sample Group (if applicable)</td></tr>
<tr><td colspan="2">HERS RATER INFORMATION</td></tr>
<tr><td colspan="2">HERS Rater Company Name:</td></tr>
<tr><td>Responsible Rater Name:</td><td>Responsible Rater Signature:</td></tr>
<tr><td>Responsible Rater Certification Number w/ this HERS Provider:</td><td>Date Signed:</td></tr>
</table>

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Appendix A: Statewide Savings Methodology

As a compliance option software enhancement, Appendix A is not required.

Appendix B: Embedded Electricity in Water Methodology

There are no on-site water savings associated with the proposed code change.

Appendix C: Environmental Impacts Methodology

As a compliance option software enhancement, Appendix C is not required.

Appendix D: California Building Energy Code Compliance (CBECC) Software Specification

Introduction

The purpose of this appendix is to present proposed revisions to the CBECC software for residential buildings (CBECC-Res) along with the supporting documentation that the Energy Commission staff, and the technical support contractors would need to approve and implement the proposed software revisions.

The proposed software changes relate to the current modeling of air-to-water heat pumps (AWHPs) within the compliance software. The existing modeling approach was added to CBECC-Res in 2016 as an interim solution to allow proponents of the AWHP technology to demonstrate Title 24 compliance. Prior to 2016, the software did not recognize AWHPs, providing a significant barrier to the use of the technology.

AWHPs represent a relatively new technology to the California residential HVAC marketplace. The technology is more prominent in other parts of the world where hydronic systems are more common. AWHPs utilize a self-contained refrigeration system with the compressor and refrigerant-to-water heat exchanger located in the outdoor unit. The outdoor unit circulates heated or cooled water (or glycol) to various delivery system options including fan coils, radiant floors, or radiant panels. In addition to space conditioning, many AWHPs provide domestic water heating as well. Given that the technology is currently very limited in its application in California, the Statewide CASE Team feels that the best approach at this time is to remove additional compliance barriers for the technology without adding significant complexity to software development activities given the constraints on Energy Commission resources. If the technology begins to gain market share in the years ahead and equipment offerings expand, it may be prudent to revisit the proposed modeling approach.

Key advantages of the AWHP technology solution include:

- Factory installed refrigeration systems eliminate field refrigerant piping connections, reducing leakage potential, refrigerant mischarging issues, possible introduction of non-condensables.
- AWHPs utilize hydronic delivery featuring small diameter piping which facilitates installation of the distribution piping in conditioned space. Incorporating insulated three-quarter inch piping in conditioned space is much easier (and cheaper) to implement than installing conventional forced air ducts in sealed chases or soffits within conditioned space.
- Hydronic systems are much more conducive to zoning that forced air systems and integrate well with more advanced AWHP system concepts such as adding

thermal storage to decouple peak space conditioning loads (typically coincident with high grid electrical demand) from compressor operation.

- Several of the currently available AWHPs have variable speed capability which allows the unit to better match operation to the imposed load, without frequent compressor cycling. It is anticipated that future AWHP product offerings would lead to an increasing number of variable speed systems on the market.
- Some of the available AWHP products provide three function capability integrating water heating with space conditioning. The higher capacity of the AWHP relative to water heating heat pump water heaters (since AWHP is sized to meet space conditioning loads) results in much greater available water heating capacity. This would contribute to higher operating efficiency since electric backup heating is not necessary in most residential applications.

Technical Basis for Software Change

Although there is an existing AWHP modeling methodology in the 2019 CBECC-Res compliance software, the current approach utilizes air source heat pump algorithms and does not fully account for the performance characteristics of the AWHP technology. In addition, by using the static capacity and efficiency inputs of 17℉ and 47℉ COP and EER, the current algorithm does not distinguish whether the AWHP equipment has a variable speed compressor.[9]

An analysis of AWHP performance using the current 2019 CBECC-Res software was completed to demonstrate the technology's current compliance situation. Two AWHPs listed on the MAEDbS were modeled utilizing fan coil delivery (California Energy Commission 2020). [10] The fixed speed unit was modeled with 17 and 47°F COPs of 2.1 and 3.7, respectively, and an EER of 10.4. The variable speed unit was modeled with 17 and 47°F COPs of 2.0 and 2.8, respectively, and an EER of 11.0. Runs were completed for both the 2,100 and 2,700 ft^2 Energy Commission prototype homes with results weighted 55 percent for the larger prototype and 45 percent for the smaller

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[9] The existing AWHP implementation is recognized by the CBECC-Res software team as an interim modeling approach, with a goal of getting the technology recognized in the compliance software without a significant investment of software development time

[10] To find listed residential AWHPs, select the Central Heat Pump category, Heat Pump Water Heating Packages, and filter for single phase electrical service.

prototype. Figure 1 shows the 55/45 weighted compliance impact relative to the standard prescriptive air source heat pump case by climate zone. The graph Y-axis represents the compliance budget impact as a percentage of the total standard design compliance budget. Figure 2 shows results for the same two AWHPs but modeled with ducts in conditioned space delivery option[11].

Of most interest in Figure 1 is the overall poor projected performance in almost all climate zones, especially for the variable speed equipment which never meets the standard budget performance level in any of the climate zones. As expected, Figure 2 shows improved performance as the “ducts located entirely in conditioned space” credit provides a sizable performance boost. The fixed speed AWHP now complies in all but one climate zone. The variable speed case also shows improvement, but in only three climate zones does the variable speed unit perform better than the standard case. These results suggest that improvement in the AWHP model is critically needed to remedy the existing performance penalties.

AWHP field research has been underway at one of four CVRH lab test houses in Stockton, CA over the past four years. The lab house has tested AWHPs coupled with radiant ceiling panels for delivering thermal energy to the conditioned space. [12] During operation, water is circulated from the AWHP, and the radiant panel surface is maintained at uniform temperatures resulting in an improved radiant thermal environment within the house. The concept of mean radiant temperature as a comfort metric has been around for many years and reflects the thermal benefit of warmed surfaces during heating season (and cooled surfaces during cooling season) as a positive contributor to overall occupant comfort. To maintain conservative estimates, any benefit of improved mean radiant temperature is not recognized in this evaluation.

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[11] There are two options for modeling ducts in conditioned space within CBECC-Res. “Ducts located entirely in conditioned space” and “Verified low-leakage ducts entirely in conditioned space”. The former is the simpler to achieve in the field and was the case modeled here. It provides for a more conservative compliance credit than the latter technique.

[12] The design heating and cooling loads and the rated output of the radiant panels would dictate the required panel area in each room. Typically, about 70-80% of the ceiling area of a room is needed to meet the loads in an energy efficient home.

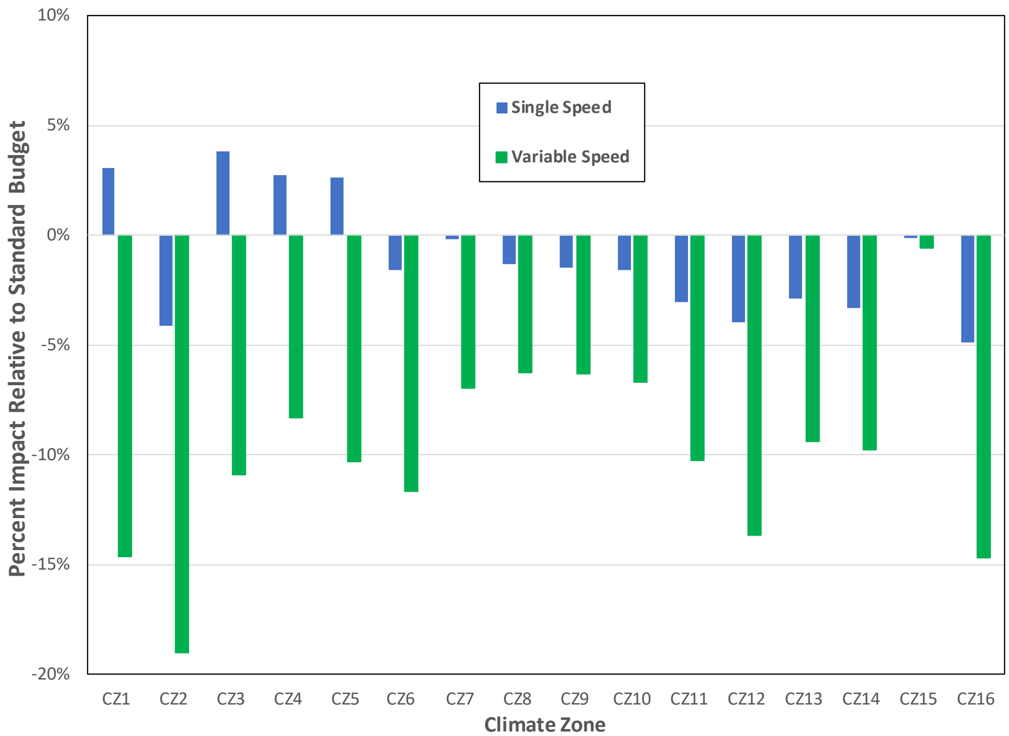

Figure 1: Single and variable speed AWHP compliance impacts (2019)

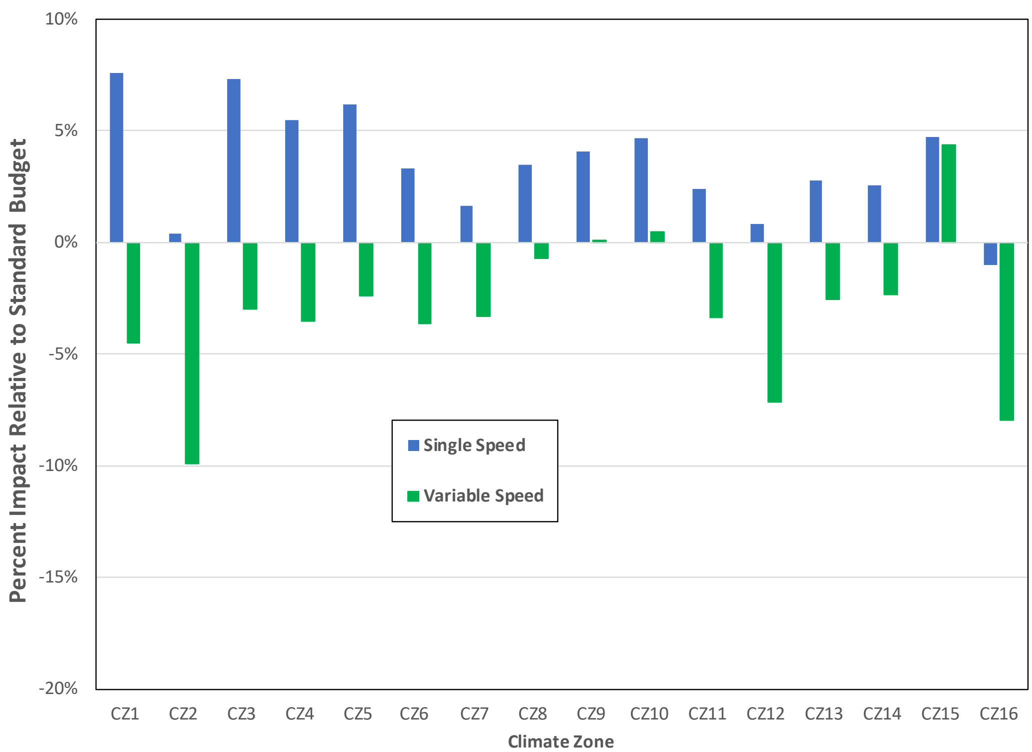

Figure 2: Single and variable speed AWHP impacts (2019, Ducts in Conditioned Space)

Two CVRH AWHP technical reports can be found at the Emerging Technology Coordinating Council website (Frontier Energy 2018) (Frontier Energy 2019). The reports document findings from the four AWHPs tested over the first two and a half years of field work. Throughout the field monitoring, installed high performance “reference” forced air HVAC systems have served as the baseline comparison system for the AWHPs. These reference systems alternated space conditioning operation with the installed AWHP plus radiant panel system, typically on three-day alternating cycles. The intent of this approach was to allow for data collection during similar weather conditions. The collected performance data forms the basis for the development of the AWHP modeling changes proposed for 2022. The October 10, 2019 Single Family AWHP HVAC Stakeholder Presentation included plots of monitored daily heating and cooling system energy use as a function of daily average outdoor temperature for the variable speed AWHP and the high efficiency air source heat pump (ASHP) (Statewide Codes and Standards Team 2019).[13] Figure 3 and Figure 4 present the heating and cooling energy usage data results (daily kWh consumed plotted against average daily outdoor temperature) for the high efficiency reference heat pump and the variable speed AWHP.

[13] It is important to highlight that the reference ASHP was not only high efficiency equipment (16 SEER, 12.5 EER, 9.5 HSPF), but carefully configured and commissioned for optimal operation (542 cfm per ton airflow, 0.15 Watts of fan power/cfm, resistance heat disabled, ducts fully in conditioned space, and optimized air distribution).

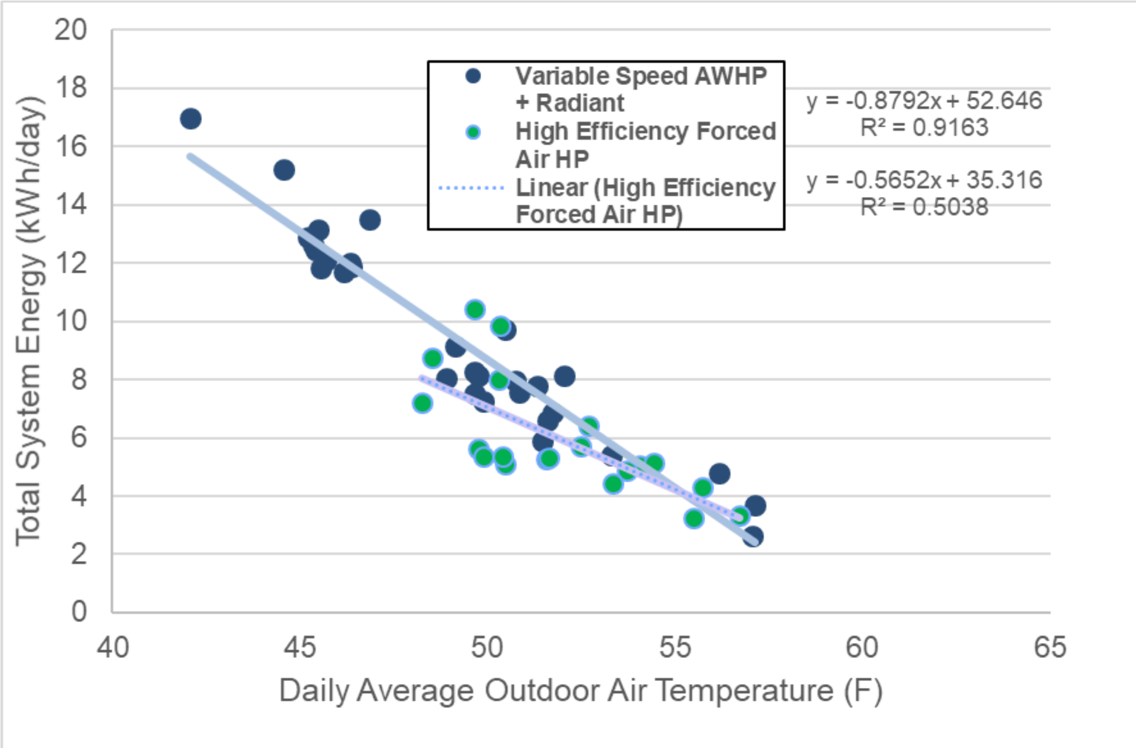

Figure 3: Daily heating energy use as a function of average outdoor air temperature

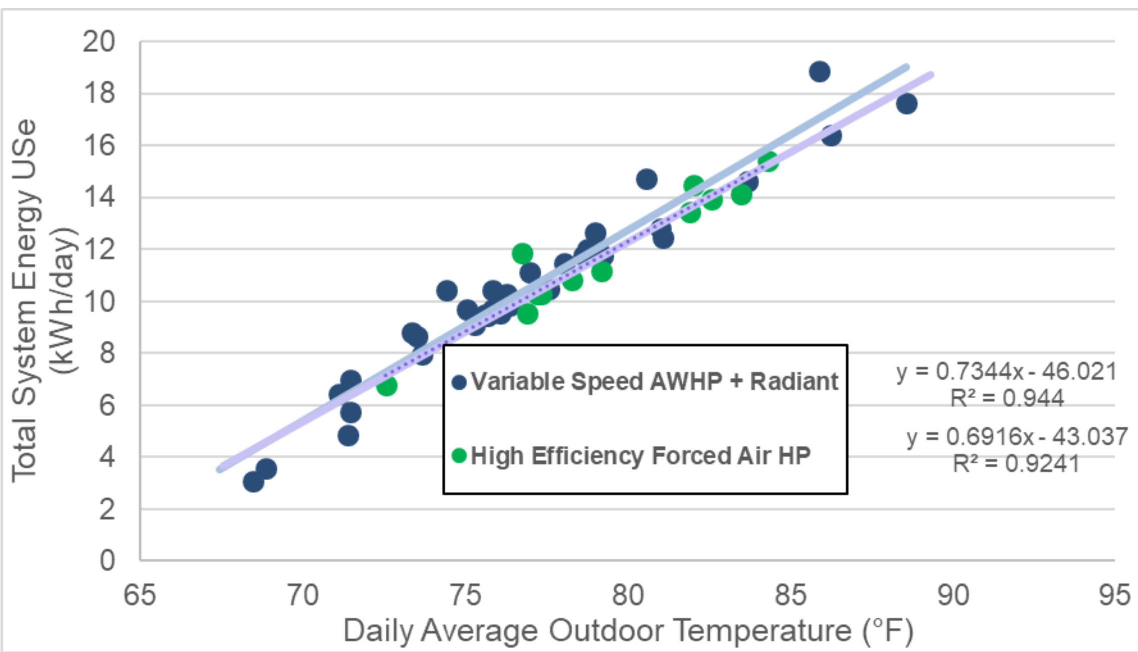

Figure 4: Daily cooling energy use as a function of average outdoor air temperature

Since the installed CVRH reference heat pump significantly exceeded the assumed performance level of a prescriptive standard ASHP (defined as 14 SEER, 8.2 HSPF, 350 cfm/ton airflow, 0.58 W/cfm fan energy), the monitored reference data needed to be recalibrated to a performance level consistent with a prescriptive standard base case ASHP. CBECC-Res simulations were completed in Climate Zone 12 for the two single family residential prototypes (2,100 ft^2 single story and 2,700 ft^2 two-story) to evaluate the expected energy impact of the prescriptive standard ASHP relative to the installed high efficiency heat pump. [14] By applying model-based corrections for both equipment efficiency and any deviations in indoor temperatures maintained (between reference system and AWHP system tests), an "adjusted" prescriptive standard base case could be defined and the performance deviation for the installed variable speed AWHP could then be determined relative to that prescriptive standard performance level.

Process to Develop New AWHP Modeling Approach

A brief overview of the methodology used to develop AWHP heating and cooling energy savings factors is outlined below.

1. Develop field-monitored HVAC energy use versus daily average outdoor temperature plots for variable speed AWHP and high efficiency reference HVAC systems. Develop linear regression relationships.
2. Complete CBECC-Res simulations (results from the two prototypes, weighted 55/45 to represent 2,430 ft^2 typical case) in Climate Zone 12 to generate daily heating and cooling energy usage. Aggregate hourly CBECC-Res output data in 2°F average daily outdoor temperature bins and develop linear regression relationships for both modeled standard minimum efficiency equipment with prescriptive attic duct requirements and field-installed high efficiency cases (with higher airflow, lower fan Watts per cfm).
3. Utilize regression relationships in Step 2 to define efficiency adjustment factors for each 2℉ outdoor temperature bin. Apply adjustment factors to the CVRH monitored reference system regression relationship (apply specified percentage adjustment to each 2℉ bin).
4. Review heating and cooling monitoring data to determine if differences in average maintained indoor temperature exists.[15] If so, complete simulations

[14] Both prototypes were modeled. Composite results were generated based on a 55 percent weighting of the 2,700 prototype and a 45 percent weighting of the 2,100 prototype.

[15] Although identical indoor temperatures were used in the CVRH field monitoring effort for reference and AWHP systems, differences in the controls deadband and variability in the cycling operation and HVAC air distribution impacted the average house indoor temperature to some extent.

(Step 2) with the adjusted heating and/or cooling setpoints to generate final monitored regression relationships (as in Step 3).

5. Apply the final reference equipment heating and cooling regression relationships to the CBECC-Res projected distribution of heating and cooling space conditioning energy use (percentage of annual usage in each 2°F bin) for the Climate Zone 12 2,430 ft^2 prototype, calculated the weighted annual heating and cooling energy use for the reference system.
6. Using the final reference regression and the monitored variable speed AWHP regression, apply the heating (and cooling) annual energy use bin percentages in Step 5 to build up the annual AWHP savings impact.

In addition to the installed high efficiency ASHP, the CVRH lab test house also have a split system air conditioner (16 SEER, 13 EER) also with ducts installed in conditioned space. Although the ASHP was predominantly operated as the reference system in heating, the air conditioner was operated more frequently as the cooling reference system. Since its monitored energy performance of the air conditioner was found to be slightly better than the reference heat pump, it was included in the reference system performance characterization by averaging with the ASHP case. Figure 5 plots the reference split system air conditioner data (yellow datapoints) and the ASHP (green datapoints). Averaging the linear regression lines for the two systems results in the blue (average) 16 SEER monitored regression line.

CBECC-Res hourly output data (for the 2,430 ft^2 weighted prototype) was aggregated for each day of the year to develop daily average outdoor temperature and heating and cooling energy usage. CBECC-Res projected daily average heating and cooling energy usage was then binned in 2℉ outdoor temperature bins for both the prescriptive and high performance ASHP cases. The binned data were plotted to calculate an adjustment factor ratio for each 2°F bin, defined as “prescriptive ASHP kWh/high performance ASHP kWh”. This bin adjustment factor was applied bin by bin to define a new normalized regression relationship that represents the minimum prescriptive performance level. For example, if the prescriptive 14 SEER, 8.2 HSPF predicted cooling energy usage was 14 percent higher than the high efficiency ASHP for the 72-74℉ temperature bin, the datapoint for the 72-74℉ bin would be adjusted upward 14 percent. This adjusted data for all bins were then used to define a new regression relationship. Figure 5 shows the resulting impact of this adjustment as the energy use regression shown in blue is adjusted to the red line.

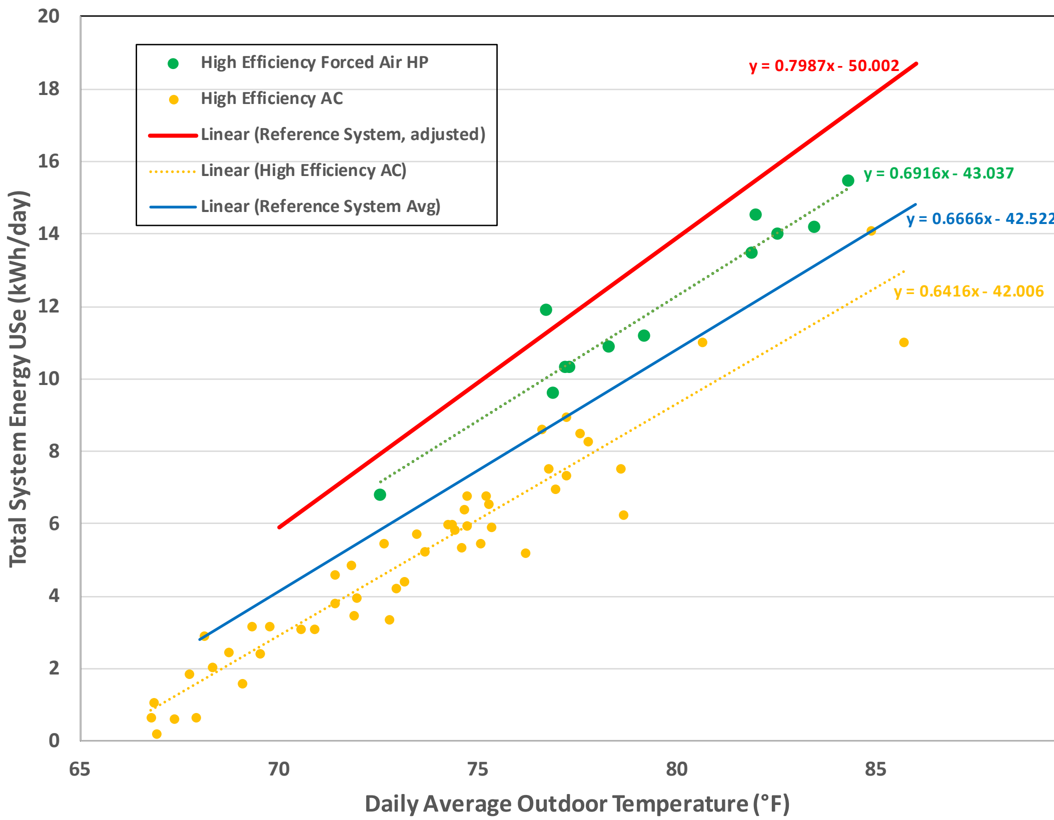

Figure 5. Comparison of monitored and model adjusted references cooling energy use as a function of daily average outdoor air temperature

Figure 6 plots the final cooling relationship comparing reference system and variable speed AWHP performance. The variable speed AWHP monitored energy use is shown in comparison to the model “adjusted” reference ASHP, now demonstrating equivalence with a prescriptive minimum ASHP efficiency unit. A similar process was completed for the heating data, resulting in an adjusted reference system regression relationship for heating, as shown in Figure 7.

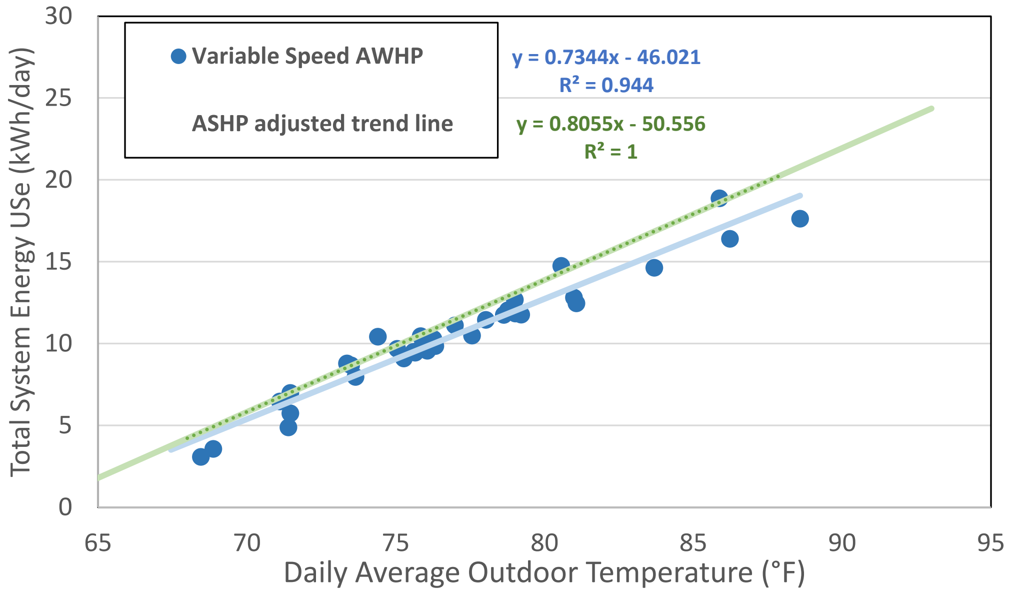

Figure 6: Comparison of monitored variable speed AWHP and model adjusted prescriptive ASHP cooling energy use as a function of daily average outdoor air temperature

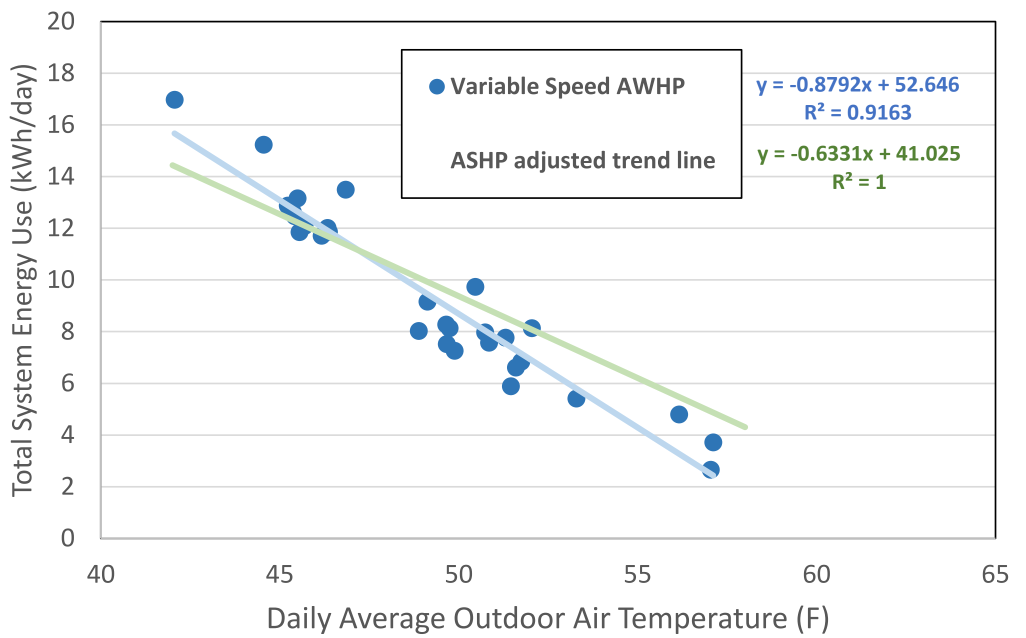

Figure 7: Comparison of monitored variable speed AWHP and model adjusted prescriptive ASHP heating energy use as a function of daily average outdoor air

With the final regression relationships defined, the final step is to develop energy use estimates. The heating and cooling regression relationships were used in conjunction with the binned 2,430 ft^2 prototype CBECC-Res results showing the percentage of heating and cooling energy usage occurring in each 2°F temperature bin. By weighting the regression relationship daily energy use by the fraction of the annual load that occurs in that bin, one can determine a load-weighted average annual energy usage for the two cases, with the percentage difference resulting in the savings factor. Table 11 shows the bin load factors for both heating and cooling. Combining this with the regression relationships shown in Figure 6 and Figure 7, results in a two percent heating savings factor and eight percent cooling savings factor. Although these results were derived using Climate Zone 12 weather data, the Statewide CASE Team feels that it is reasonable to use this climate zone as the basis since the weather includes a range of conditions spanning typical summer and winter conditions for most of state's population. This statewide approach is consistent with the recently adopted variable capacity heat pump modeling approach where statewide heating and cooling factors are being applied.

Fixed speed AWHP equipment was not found to perform as well as the variable speed equipment in the CVRH field monitoring studies. However, given the AWHP technology is new to the market and the current 2019 CBECC-Res software sends a mixed AWHP performance signal to the market, the Statewide CASE Team proposes that fixed speed AWHP equipment be treated in a neutral manner relative to the prescriptive standard ASHP. This would result in equivalence in all climate zones with the prescriptive standard ASHP (zero percent heating and zero percent cooling savings factors).

Table 11: Climate Zone 12 2,430 ft^2 Prototype HVAC Energy Use by Outdoor Temperature

Average Daily Outdoor Temperature (°F)	Percentage of Annual Heating Energy Use in Outdoor Bin	Percentage of Annual Cooling Energy Use in Outdoor Bin
Heating		
38	3.1%	N/A
40	5.0%	N/A
42	8.3%	N/A
44	5.4%	N/A
46	11.9%	N/A
48	14.1%	N/A
50	22.8%	N/A
52	10.5%	N/A
54	10.0%	N/A
56	5.5%	N/A
58	2.3%	N/A
60	0.4%	N/A
62	0.6%	N/A
Cooling		
72	N/A	4.4%
74	N/A	3.8%
76	N/A	17.9%
78	N/A	22.8%
80	N/A	15.8%
82	N/A	21.3%
84	N/A	6.0%
86	N/A	7.8%

Description of Software Change

Background Information for Software Change

The proposed software modification would be applicable to single family and low-rise multifamily buildings in all 16 climate zones. The current available AWHP equipment offerings listed in the MAEDbS are best suited for single family applications due primarily to the heating and cooling capacities of the equipment, but there may be opportunities where the technology makes sense in multifamily building types.

The proposed software implementation would rely on heating and cooling energy use adjustment factors,[16] analogous to what the Energy Commission adopted for variable capacity heat pumps in November 2019. This proposed approach has several advantages, with the primary advantage being ease of software implementation relative to the challenges in developing, testing, and debugging of more complicated first principal algorithms. Since AWHPs at this time are not a product with significant market share in the California residential market, it is prudent to move incrementally (in terms of software development resources expended) to accommodate the technology within the compliance software. Another reason this approach is proposed is that there are only a small number of products listed on the MAEDBS (California Energy Commission 2020). With new products anticipated in the coming years as the AWHP technology gains market share, it is the Statewide CASE Team's judgment that generic modeling is the most appropriate solution at this time.

In addition to modifying the space conditioning modeling of AWHPs, the Statewide CASE Team proposes that radiant ceiling panels be included as a delivery option for AWHPs. Radiant ceiling panels are another niche product in the California residential sector at this time but increasing interest in radiant delivery for both residential and nonresidential applications suggest that in the coming years the radiant delivery approach may achieve greater market penetrations.

No changes are proposed for the standard design model.

Existing CBECC-Res Modeling Capabilities

The current CBECC-Res AWHP implementation utilizes the standard rating inputs (47℉ and 17℉ heating capacity and COP values and the rated EER for cooling). These inputs are currently used by CBECC-Res in the air source heat pump model. Since air source heat pumps (ASHPs) and AWHPs utilize different rating test standards, direct comparison of the ratings is not appropriate. For example, the AHRI 210/240 Test Standard (Performance Rating of Unitary Air-Conditioning and Air-Source Heat Pump Equipment) specifies indoor, outdoor, and return air test conditions, as well as airflow rates and assumed fan energy, while the AWHP ratings are derived from the ANSI/AHRI Standard 550/590 test procedures which specify leaving water temperatures, outdoor conditions, and water flow rate.

The ASHP 550/590 test procedure provides for recognizing the performance benefit of variable speed operation which is specifically recognized in the HSPF and SEER ratings. Although AWHP part load performance is recognized in the Integrated Part-

[16] These heating and cooling adjustment factors would be used to adjust performance of a minimum efficiency air source heat pump, identical to the process applied to variable capacity heat pumps.

Load Value (listed in the MAEDbS), the impact of variable speed performance benefits are not recognized in the current CBECC-Res model, leading to the performance anomalies shown in Figure 1.

The screenshot in Figure 8 below shows the current input screen for AWHPs. The EER input value has no impact on performance, as the CBECC-Res algorithm uses a fixed 11.7 EER in all cases. Similarly, the zonal control check box has no impact.

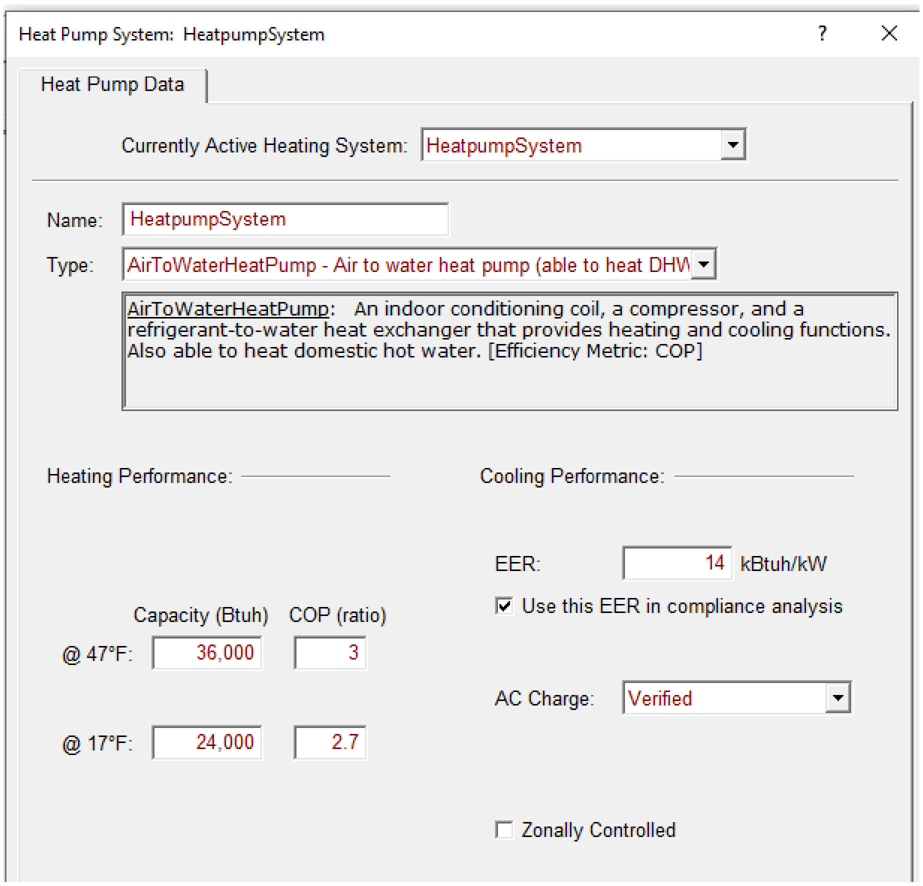

Figure 8: Existing CBECC-Res AWHP input screen

Summary of Proposed Revisions to CBECC-Res

Two modeling changes are proposed for this measure.

1. Modification of AWHP modeling for 2022

   This software modification proposes that the current AWHP "type" be split into two distinct types: fixed speed AWHP and variable speed AWHP. The Statewide CASE Team's proposal would specify different heating and cooling energy savings factors for the two distinct AWHP types. These heating and cooling savings factors would be applied to the calculated heating and cooling energy usage of a minimum efficiency prescriptive ASHP (as per current CBECC-Res

ASHP modeling) for each hour of the year. For variable speed AWHP equipment, the proposed factors would be two percent for heating and eight percent for cooling. For fixed speed AWHP equipment, the proposed factors would be zero percent for both heating and cooling.

2. Radiant Ceiling Panels

   Radiant ceiling panels are not currently recognized in the ACM Reference Manual. The Statewide CASE Team proposes to include this distribution system type with two variations. If radiant ceiling panels are installed according to all eligibility criteria proposed in the newly proposed RA3.4.5 (see Section 7.3), then the distribution system type is modeled as "Ducts Located Entirely in Conditioned Space". This would mean that duct conduction losses are eliminated, but the assumed duct leakage term would be modeled as leakage to outside the conditioned space. The duct leakage term would approximate the magnitude of radiant panel thermal losses to the attic, since prescriptive insulation levels would be required, as well as all hydronic piping feeding the panels be in conditioned space, and QII inspections be completed to verify insulation installation quality. If all the RA3.4.5 eligibility criteria are not fully met, modeling of distribution losses would default to the high-performance attic prescriptive requirement for that climate zone.

Proposed Revisions to CBECC-Res Graphical User Interface

The current Heat Pump Data screen in CBECC-Res (shown in Figure 9) would be modified to accommodate the following four AWHP types:

AirToWaterHeatPump – Fixed Speed

AirToWaterHeatPump – Fixed Speed (able to provide domestic hot water)

AirToWaterHeatPump – Variable Speed

AirToWaterHeatPump – Variable Speed (able to provide domestic hot water)

The fixed or variable speed designation would define the heating and cooling savings factors to be used by the compliance software, and selection of an AWHP type with the ability to provide DHW would engage the existing three function heat pump water heating algorithm in the 2019 CBECC-Res software.

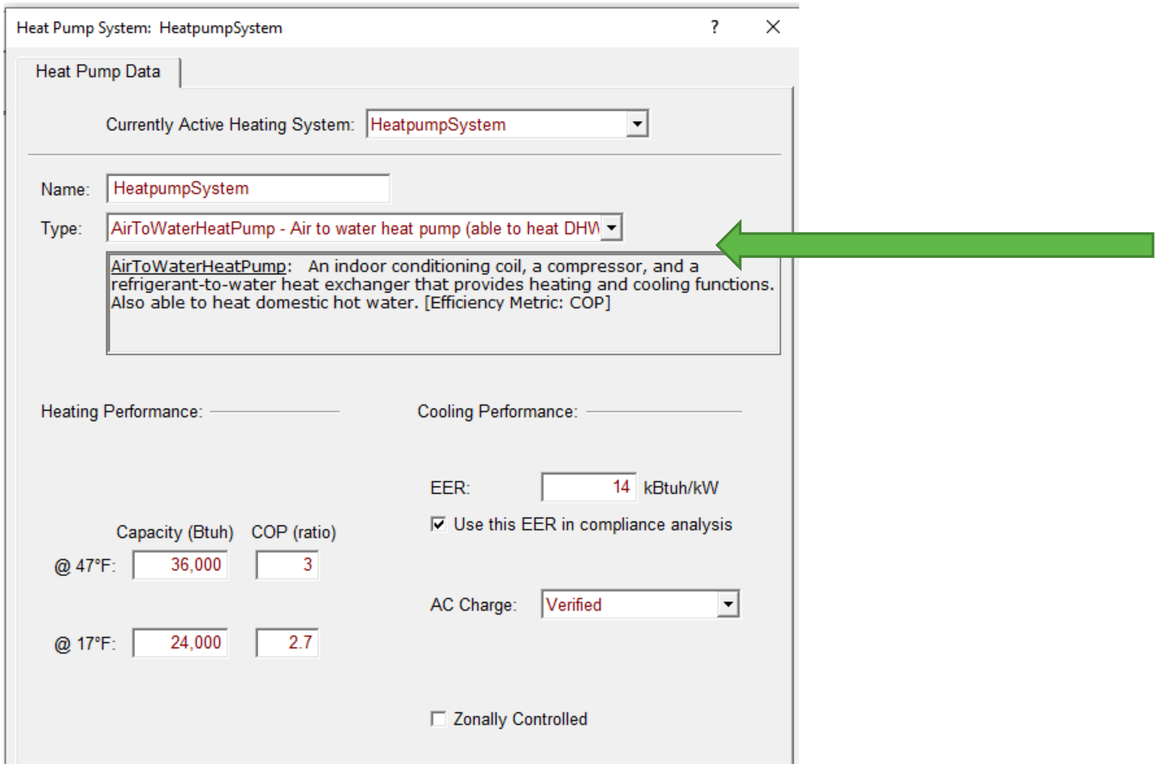

Figure 9: AWHP input screen

A second proposed software input change would add a new “distribution” system type (shown in Figure 10) to the options. The new option to be added would be “Radiant Ceiling Panel Delivery”, with applicability only to an AWHP system type. This delivery option would trigger modeling of HVAC thermal distribution (as described above) and require modifications to compliance forms and new HERS field verification requirements.

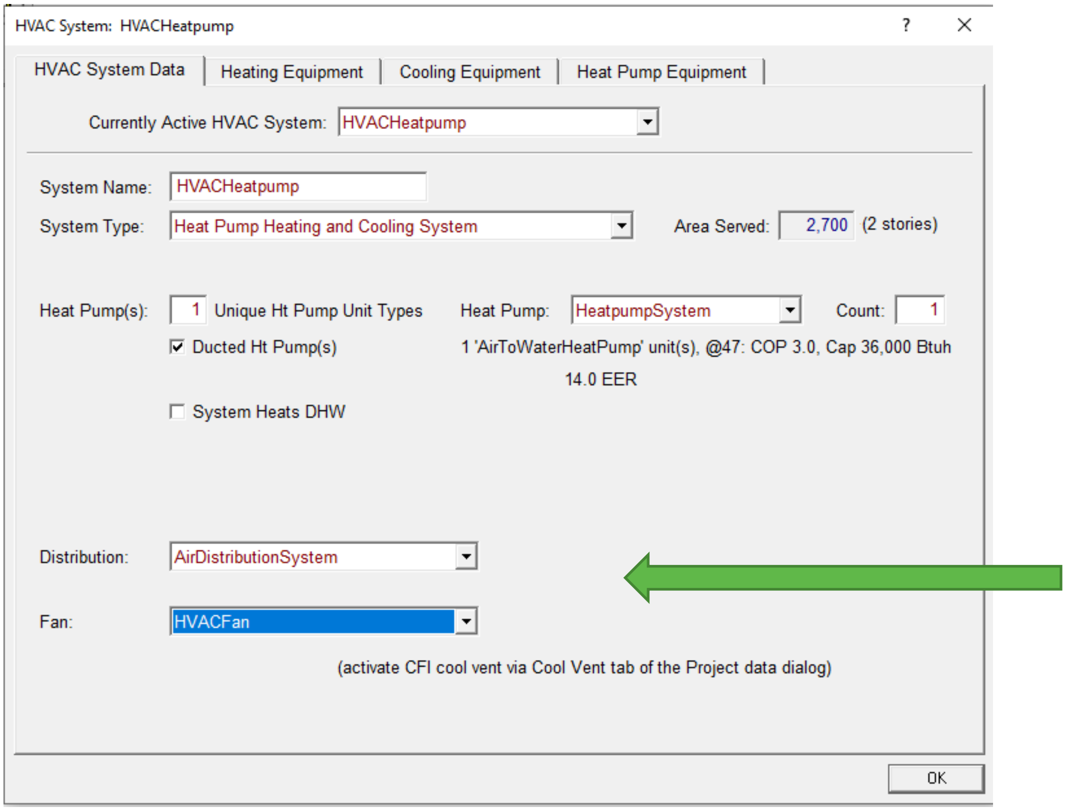

Figure 10: Heat pump distribution input screen

This Radiant Panel Delivery option would require a Distribution System input screen be developed (Figure 11)The "type" should include a pull-down option with two selectable options:

- "Hydronic delivery not fully in conditioned space", and
- "Hydronic delivery in conditioned space"

Selection of the latter should provide pop up notes indicating that "(QII and prescriptive ceiling insulation levels required)".

Additional new input fields on the Radiant Panel Delivery screen should include:

1. Manual J design heating load (Btu/hr)
2. Manual J design cooling load (Btu/hr)
3. Manufacturer rated panel heating capacity (Btu/hr-ft^2)
4. Manufacturer rated panel cooling capacity (Btu/hr-ft^2)

   When the above entries are populated as shown in Figure 11, the input screen should display box labeled "Required minimum panel area (ft^2)"

This minimum panel area box should be calculated as the maximum value of the following two items:

1. Manual J design heating load/Manufacturer rated panel heating capacity
2. Manual J design cooling load/Manufacturer rated panel cooling capacity

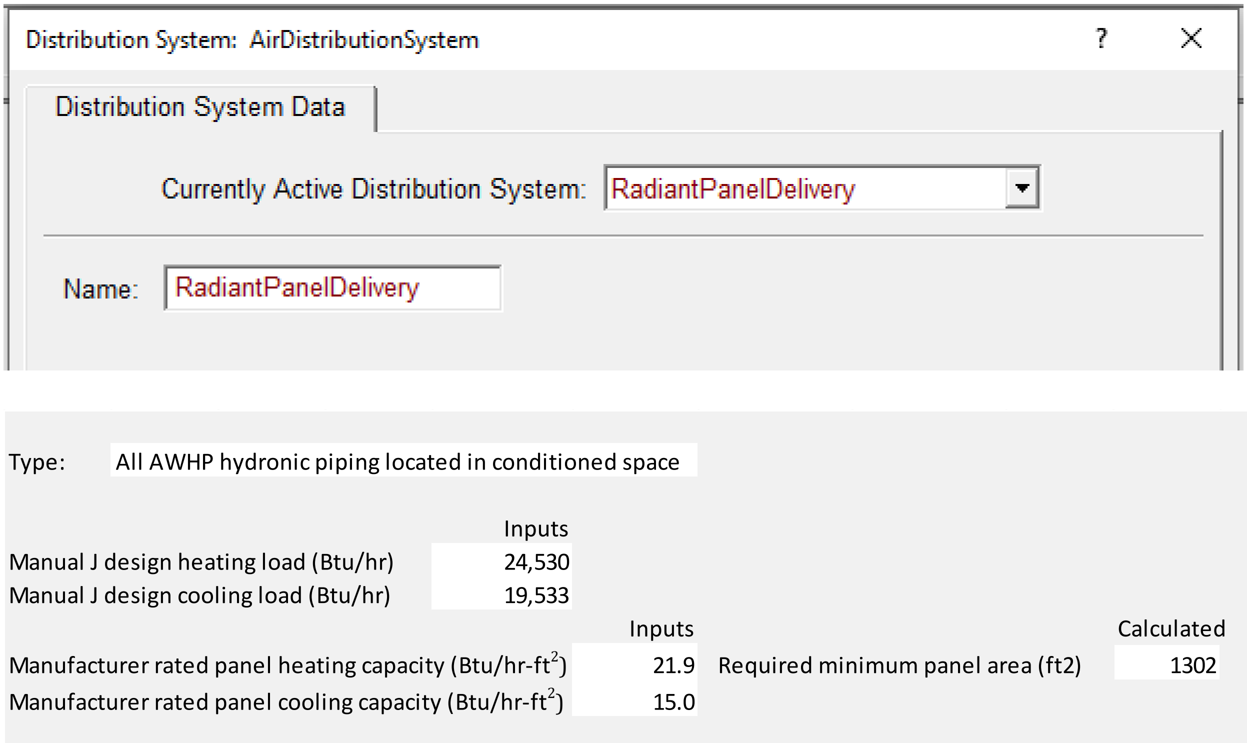

Figure 11: Radiant panel delivery input screen

Testing and Confirming CBECC-Res Modeling

The testing of a revised CBECC-Res AWHP algorithm is anticipated to be straightforward. Since the proposed heating and cooling savings factors for variable speed AWHPs are fixed values, impacts of the measure can be easily determined by comparing standard and proposed hourly energy use (found in the .csv output file) and verifying that the difference between the two is consistent with the multipliers.

The initial release of the 2022 compliance software (December 2019) occurred just prior to the completion of the Draft CASE Report. Table 12 presents variable speed AWHP impacts based on this initial 2022 software release relative to the standard prescriptive budget for an ASHP in the weighted 2,430 ft^2 prototype. Heating energy savings shown are two percent of the standard ASHP heating energy use and cooling energy savings are eight percent of the ASHP cooling energy use. Results may change slightly with future 2022 software updates and revised TDV values as software clean-up activities proceed and other modeling changes impacting space conditioning loads occur.

Table 12: Projected Variable Speed AWHP Impacts (2022 CBECC-Res for 2,430 ft^2 Prototype)

Climate Zone	Heating Energy Savings (kWh/year)	Cooling Energy Savings (kWh/year)	Percent Impact on Heating + Cooling Compliance Budget	Percent Impact on Total Compliance Budget
1	81	0	2.0%	1.5%
2	46	5	3.5%	2.3%
3	24	0	2.2%	1.0%
4	22	17	4.6%	2.9%
5	24	0	2.0%	1.0%
6	9	7	5.2%	2.4%
7	5	8	5.2%	1.7%
8	5	57	7.1%	4.4%
9	9	55	6.6%	4.2%
10	15	80	6.3%	4.5%
11	40	121	5.5%	4.4%
12	36	38	4.7%	3.4%
13	27	163	6.2%	5.0%
14	41	108	5.1%	3.9%
15	2	380	7.9%	7.0%
16	90	17	2.2%	1.7%

Appendix E: Impacts of Compliance Process on Market Actors

This appendix discusses how the recommended compliance process, which is described in Section 2.5, could impact various market actors. Table 13 identifies the market actors who would play a role in complying with the proposed change, the tasks for which they would be responsible, their objectives in completing the tasks, how the proposed code change could impact their existing work flow, and ways negative impacts could be mitigated. The information contained in Table 13 is a summary of key feedback the Statewide CASE Team received when speaking to market actors about the compliance implications of the proposed code changes.

Table 13: Roles of Market Actors in the Proposed Compliance Process

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Workflow	Opportunities to Make this Measure Successful
Designer/ Responsible Person	• Ensure that all required details and specifications are adequately shown and communicated on the plans. • Coordinate with Energy Consultant that intended design meets requirements	Clearly communicate requirements on plans to ensure builder and construction team are aware and there are no surprises	Initial learning curve in gaining familiarity with technology and Title 24, Part 6 requirements	Clearly identify design details and HERS requirements (e.g. QII inspection for radiant panels)
Builder/ Installer	• Coordinate with energy consultant and designer to clearly understand the elements and details needed to certify building. • Ensure construction managers/superintendents know all the requirements • Coordinate with all subs to ensure everyone understands requirements and installation quality is met • Coordinate with HERS Rater to schedule inspections	• Meet project budgets and schedules • Minimize/eliminate inspection failures and callbacks • Ensure inspections do not cause schedule delays • Minimize paperwork required • Avoid warranty issues	• Would require more builders to be aware of AWHP/Radiant HERS requirements and steps needed to comply • For radiant panel designs, would need to verify that insulation levels specified meet prescriptive minimums and include QII; awareness of HERS inspection requirements • Would require builders to make sure QII requirements are being met in the field	• Clearly articulate goals and expectations to contractors • Ensure job superintendent understands expectations and knows when a job is ready for HERS Rater
Energy Consultant	• Coordinate AWHP design with other team members	• Clearly communicate requirements and ensure	Would need to understand and convey timing of	Ensure that any requirements are

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Workflow	Opportunities to Make this Measure Successful
	on the requirements and HERS inspections needed • Complete required calculations to confirm compliance; provide compliance documents for permit application. • Coordinate with design team to ensure that all required measures are included in the design documents	that builder/construction team are aware of requirements and there are no surprises • Demonstrate compliance and energy performance goals are met	additional potential HERS inspections (radiant panel verifications, pipe insulation inspections) to builder/construction team	clearly articulated in specifications and plans and that design team and builder are aware of any construction impacts
Suppliers / Manufacturers	• Provide AWHP equipment, radiant panels, and related components and controls • Provide technical support to designers and installers	Ensure installers are following manufacturer requirements and best practices	Would need to make sure contractors using their products are installing them properly	Actively engage with contractors to ensure that they understand how to properly design and install AWHP/radiant equipment
Plans Examiner	• Verify Title 24, Part 6 documentation matches plans	• Minimize amount of paperwork needed to review • Quickly and easily determine if plans/ specs match CF1R	For radiant panels, verify that installed panel area meets the Manual J loads based on manufacturer reported panel capacity data	Understand new AWHP/radiant requirements
HERS Rater	• Review design documents used on site • Makes sure all parties are aware of responsibilities, expectations, and	• Coordinate w/ builder on scheduling necessary inspections including potentially QII inspection for attic and pipe	• Verify whether AWHP is fixed or variable speed equipment • Timing of inspections needs to be accounted for	• Work with builder to ensure that goals and expectations are set by team to achieve compliance

Market Actor	Task(s) In Compliance Process	Objective(s) in Completing Compliance Tasks	How Proposed Code Change Could Impact Workflow	Opportunities to Make this Measure Successful
	schedule of inspections	insulation, radiant ceiling panel sizing, • Maintain positive working relationships with builder and construction team without impacting construction schedule	• Verify AWHP HERS requirements are being met • If project does not pass, communicate issues with responsible parties and complete re-inspection • Complete and submit required forms for permit	• Provide as-needed pre-installation training and coordination with construction team prior to installation inspections • Gain familiarity with AWHP technology and available listed equipment at Energy Commission website
Building Inspector	• Verify that all required HERS inspections listed on plans have been completed and signed by HERS Rater • Sign off on permit	Minimize amount of time and paperwork needed to approve installation	Minimal impact. Assess basic electrical and plumbing are properly completed.	Gain familiarity with AWHP technology and available listed equipment at Energy Commission website
Energy Commission	• Develop procedures and verification requirements • Educate builders, installers, building officials, and HERS Raters.	Ensure compliance is being achieved	Need to update forms (CF2R and CF3R), Reference Appendices, ACM, and RCM manuals	Integrate AWHP/radiant changes in Title 24, Part 6 training and educational information

Appendix F: Summary of Stakeholder Engagement

As a compliance option software enhancement, Appendix F is not required.

Appendix G: Synopsis of CVRH Radiant Ceiling Panel Condensation Research

During prior research completed at the CVRH test house, several different scenarios were tested to assess radiant panel performance, specifically as it relates to condensation potential at the panel surfaces. This appendix provides a high-level synopsis of the results to convey the key findings. Interested reviewers looking for more detail should refer to the two published Emerging Technology Coordinating Council reports (Frontier Energy 2018, Frontier Energy 2019).

The factors that impact panel condensation potential include the indoor space air temperature and relative humidity (RH), and the panel surface temperature which is dependent upon the temperature of the chilled water delivered to the panels and the relative thermal effectiveness of the panels (i.e. how much temperature difference there is between the water supplied to the panels and the panel surface temperature). Two different types of panels were installed in the house: a lower cost, less thermally efficient product (Panel 1) and a higher quality, more expensive product (Panel 2).

In the extensively monitored CVRH test house indoor air temperature was monitored in most rooms and RH was measured on the first and second floor of the two-story house. Radiant panel surface temperatures were measured in most rooms using infrared temperature transmitters oriented towards the panels. The air temperatures in each room were paired with the RH measurement closest to them, to determine room dewpoint temperature on a minute-by-minute basis. The differences between the measured panel surface temperatures and calculated room dewpoints were determined to evaluate the risk of condensation occurring on the panel surface. These differences are referred to as "surface and dewpoint deltas" (SADD). Condensation on the panel surface would be expected if panel surface temperature were less than or equal to dewpoint (SADD ≤ zero).

Simulated latent gains were introduced to the test house via a humidifier and amounted to approximately 1.6 gallons/day. This amount is consistent with latent gain assumptions in the Title 24, Part 6 Alternative Calculation Method (ACM) manual. The house also included continuous fresh air mechanical ventilation consistent with the 2013 Title 24, Part 6 residential ventilation requirements. The bath exhaust fan was measured to exhaust 57 cfm[17]. In most of California, the dry summer climate will result in ventilation air leading to reduced indoor air RH. Higher ventilation rates associated with the 2019 standards will therefore further reduce indoor RH relative to the monitored

[17] Note that for 2019 standards update, residential mechanical ventilation airflow rates were increased for single family homes.

data. A second factor that makes the CVRH test results conservative is that the test house did not have realistic internal mass (furnishings, books, etc.) representative of an occupied home. These items would normally serve as a capacitor, absorbing and releasing moisture over time as indoor conditions change.

CVRH testing explored varying panel supply water temperatures and configurations. Initially a higher supply water temperature (55 °F) was tested without any supplemental dehumidification. At this operating condition there was some relaxation of comfort standards on the hottest days as the cooling setpoint of 76°F was exceeded during the peak load period of the day. Subsequently a lower supply water temperature of 48 °F was tested with a free-standing dehumidifier. Finally, a third test was completed using 52 °F supply water temperature[18] with an integrated hydronic fan coil to provide supplemental dehumidification. In this mode during dehumidification calls, the hydronic fan coil was supplied with chilled water from the AWHP. The fan coil operated at a very low fan speed (consuming ~10 Watts) to maximize dehumidification potential, while still providing some sensible cooling. This configuration allowed colder water to be first sent to the fan coil where it could slightly dry the air, before sending the warmed water to the radiant panels where panel surface temperatures would be slightly elevated due to the heat addition from the fan coil.

Table 14 shows the smallest SADD for each dehumidification method and supply water temperature. The reported SADD value is the difference between the corresponding surface temperature (always associated with Panel 2, which consistently operated at lower surface temperatures than Panel 1) and the corresponding dew point temperature.

[18] The 52°F setpoint was found to provide optimal balance of comfort, efficiency, and condensation avoidance.

Table 14: Summary of Radiant Ceiling Panel Condensation Risk Results

Dehumidification Method	Panel Supply Water Temperature (°F)	Smallest SADD (°F)	Corresponding Surface Temperature (°F)	Corresponding Dewpoint Temperature (°F)
None	55	4.5	68.2	63.7
Free-standing dehumidifier	48	12.7	62.4	49.7
Fan Coil	52	7.7	65.3	57.6

The minimum SADD observed without dehumidification was small (4.5°F), but not critical. However, at the lower panel supply water temperature of 48°F, assuming the same dewpoints, the panel surface temperature would have gone below the dewpoint under the absolute worst case condition observed.[19] The minimum SADD seen with the free-standing dehumidifier was substantially larger than necessary due to the dehumidifiers excessive overdrying of the indoor air. Typical indoor RH in this mode was between 35% and 40% most of the time, which is too dry.[20] The minimum SADD seen with the hydronic fan coil is smaller, but still provides a comfortable buffer between the panel surface temperature and dewpoint. In the fan coil mode of operation, a total of 0.1 gallons per day of condensate were removed at the expense of 10 Watt-hrs/day of summer fan coil energy. Indoor RH with the fan coil was between 45% and 55%, a much more reasonable level.

A comparison of indoor RH during all the CVRH summer testing reported to date is shown in Table 15. The table provides characterization of the system type, whether the standard latent gain generation was active during the test period, whether supplemental dehumidification was being operated and the resulting average indoor RH levels during the monitored time period (all with nominal 76°F cooling setpoint). Cases with no moisture generation indicate average indoor RH levels in the low to mid-40% range. Introduction of moisture generation raises the average indoor RH to a range from 48% to 55% (excluding 1b with the free-standing dehumidifier). Configuration 2 (with the hydronic coil) was found to operate at an RH level roughly halfway between the split

[19] As seen in Table 14, lowering the supply water temperature by 7 °F (from 55 to 48°F) resulted in a 5.8 °F lower surface temperature. This is greater than the 4.5 ∆°F SADD at the higher water supply temperature. Because the same latent gains schedule was used, it is reasonable to assume that the dewpoint without dehumidification would have been similar.

[20] RH < 30% can result in health problems. Optimum summer RH is 40% to 60% according to ASHRAE 55.

system air conditioner and the AWHP System 1a. All of the reported cases fall well within ASHRAE 55's optimal summer range of 40% to 60% (ASHRAE 2010).

These results suggest that under typical operational cases supplemental dehumidification is not needed, especially given the lack of house furnishings and the lower than currently prescribed mechanical ventilation at the house. It is however important for designers evaluating radiant ceiling panels to assess the need for supplemental dehumidification for the project and the climate. In some applications, dehumidification could be warranted but it is the Statewide CASE Team's perspective that under typical assumed operating conditions (i.e. the basis of the ACM modeling rules), any incremental energy usage associated with an installed dehumidification system operation would be minimal.

Table 15: Summary of Reported Summer Indoor RH During Various CVRH Tests

System Type	Configuration Tested	Latent Gains Applied	Supplemental Dehumidification	Average Indoor Relative Humidity
Reference	Split System Heat Pump	No	No	42.2%
Reference	Split System Air Conditioner	Yes	No	48.3%
AWHP	System 1a	Yes	No	55.3%
AWHP	System 1b	Yes	Yes (free-standing dehumidifier)	41.5%
AWHP	System 2	Yes	Yes (hydronic fan coil)	52.7%
AWHP	System 3	No	No	45.7%