**Codes and Standards Enhancement (CASE) Initiative**

2019 California Building Energy Efficiency Standards

# Residential Quality HVAC Measures – Final Report

Measure Number: 2019-RES-HVAC1-F

Residential Mechanical

Revised December 2017

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## Introduction

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (Energy Commission) efforts to update California's Building Energy Efficiency Standards (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. The four California IOUs – Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison, and SoCalGas® – and two Publicly Owned Utilities (POUs) – Los Angeles Department of Water and Power and Sacramento Municipal Utility District – 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 is 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 2019 Title 24 website for information about the rulemaking schedule and how to participate in the process: http://www.energy.ca.gov/title24/2019standards/.

## Measure Description

This code change proposal includes one mandatory requirement, one compliance option, and one alternative verification method. The measures affect single family and multifamily building types and apply to all climate zones. The proposed measures will:

- **Mandatory fan efficacy requirement:** Reduce the maximum air handling unit fan efficacy currently required under Title 24 Part 6, 150.0(m)13 from 0.58 watts per cubic feet per minute (W/cfm) to 0.45 W/cfm.
- **Compliance option for fault detection and diagnosis (FDD) devices:** Allow compliance credit for FDD devices that will support both the long-term, as well as initial, performance of cooling systems.
- **Alternative verification method (temperature split):** Provide an alternate method to refrigerant charge verification that measures system performance and that can identify multiple system faults while reducing verification time.

The United States (U.S.) Department of Energy (DOE) adopted a new fan efficacy standard for residential furnaces and certain other air handling equipment. The standard, which takes effect July 2019, will require maximum efficacies that will induce manufacturers to use fan motors that have efficiencies consistent with brushless permanent magnet (BPM) motor types, enabling a reduction in the current 0.58 W/cfm Title 24, Part 6 maximum efficacy to 0.45 W/cfm. Though the DOE standard does not extend to heat pump or combined hydronic air handlers, the same Title 24, Part 6 limit is proposed for furnaces, heat pumps, and hydronic air. Tables 150.0-2B and 150.0-2C will continue to provide an alternative method of compliance to airflow-watt draw verification.

To date, the Title 24, Part 6 Standards for residential buildings have only been concerned with the efficiency of heating, ventilation, and air conditioning (HVAC) systems when they are installed. Performance can degrade substantially over time owing to things like lack of filter replacement, fouled coils, and more serious defects. Service contractors have difficulty retaining technicians that have the skills to identify, diagnose, and remediate faults. Fault indicator displays (FIDs) have been provided for in the Title 24, Part 6 Standards since 2008 as a substitute for refrigerant charge verification, but no manufacturers have taken the initiative to meet the detailed specifications listed in Joint Appendix 6 (JA6) or to submit products for Energy Commission approval. To create an incentive for devices that can provide long-term fault detection and diagnosis, a credit for both FID and simpler and lower cost fault detection and diagnosis (FDD) devices is proposed. The credit will introduce two new multipliers that modify the energy efficiency ratio (EER) in the compliance models, adding to the current multiplier of 0.96 that is prescriptively applied for Climate Zones 2 and 8 through 15. Without refrigerant charge verification, the multiplier will be 0.94. If either an FID is installed, or an FDD is installed in combination with refrigerant charge verification, then the multiplier will increase to 0.98.

As noted above, refrigerant charge verification is an existing prescriptive requirement in the warmer climate zones, and FIDs and weigh-in methods can be substituted under certain circumstances. According to statewide Home Energy Rating System (HERS) Registry data provided by CalCERTS, the largest HERS certification provider, 73 percent of new single family installations and 81 percent of multifamily installations over a sixteen-month period were completed without refrigerant charge verification. For replacements, the estimated number of installations that are not permitted ranges from 71 percent to 92 percent. Without a permit, it can be assumed that no HERS Rater verification of refrigerant charge and system airflow has been completed. An alternate verification method is proposed making the verification process easier and less time consuming, contributing to an increase in the level of HERS verification. In past versions of Title 24, Part 6 measurement of temperature split has been used by to estimate system airflow. With improvements to previously used methods, the Statewide CASE Team sees temperature split measurement as a way to improve verification percentages and to identify multiple conditions that can lead to poor HVAC performance.

Relative to additions and alterations, measures described in this report will only apply to full equipment replacements (furnace, evaporator coil, and ducting).

***NOTE:*** *At the time of writing, the Energy Commission has indicated they will only consider the mandatory fan efficacy measure for the 2019 Title 24, Part 6 Standards. The FDD and temperature split measures are documented for potential use in future proceedings.*

# Scope of Code Change Proposal

Table 1 summarizes the scope of the proposed changes and which sections of the Standards, References Appendices, and compliance documents will be modified as a result of the proposed changes.

**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 | Will Compliance Software Be Modified | Modified Compliance Document(s) |
|---|---|---|---|---|---|
| Fan Efficacy Improvement | Mandatory | 150.0(m)13B, 150.0(m)13C, 150.1(c)10 | No change | Yes | CF1R-NCB-01-E, CF2R-MCH-22-H, CF3R-MCH-22H<br><br>(Substitute 0.45 for 0.58) |
| FID/FDD | Performance | 150.1(b)4(B) | JA1, JA6, RA2, RA3 | Yes | CF1R-NCB-01-E, CF2R-MCH-22-H, CF3R-MCH-22H |
| Temperature Split | Optional verification protocol | 150.1(c)7A | JA6, RA3 | No | CF1R-NCB-01-E, CF2R-MCH-22-H, CF3R-MCH-22H (possible new forms added) |

# Market Analysis and Regulatory Impact Assessment

Overall this proposal, in combination with others, increases the wealth of the State of California. California consumers and businesses save more money on energy than they do for financing the efficiency measure.

The proposed changes to Title 24, Part 6 Standards have a negligible impact on the complexity of the standards or the cost of enforcement. When developing this code change proposal, the Statewide CASE Team interviewed building officials, Title 24 energy analysts, and others involved in the code compliance process to simplify and streamline the compliance and enforcement of this proposal.

Changing DOE standards will make furnaces and air handlers that incorporate ECMs the exclusive choice for residential systems. This highly cost-effective measure will have no impact on current installation practices or distribution channels.

FID and FDD devices are currently available in the market, though none comply with existing specifications in JA6. The proposed code changes will encourage manufacturer participation in further development and market deployment of these devices. It will also create opportunities for HVAC service companies.

The proposed temperature split air conditioner verification alternative will have no impact on marketed products, but may also create increased demand for employment in the HVAC service sector.

# Cost-Effectiveness

The proposed fan efficacy code change was found to be cost-effective in all climate zones. The benefit-to-cost (B/C) ratio compares the lifecycle benefits (cost savings) to the lifecycle costs. Measures that have a B/C ratio of 1.0 or greater are cost-effective. The larger the B/C ratio, the faster the measure pays for itself from energy savings. The B/C ratio for this measure ranges from 1.37 to 43.25. See Section 5 for a detailed description of the cost-effectiveness analysis.

# Statewide Energy Impacts

Table 2 shows the estimated energy savings over the first twelve months of implementation of the proposed code change. Additions and alterations impacts are relatively small in comparison to new construction projection based on the Statewide CASE Teams assessment that only a small fraction of replacement systems include a full duct system replacement (the trigger for the fan efficacy measure). See Section 6 for more details.

**Table 2: Estimated Statewide First-Year[a] Energy and Water Savings**

| Measure | First-Year Electricity Savings (GWh/yr) | First-Year Peak Electrical Demand Reduction (MW) | First-Year Water Savings (million gallons/yr) | First-Year Natural Gas Savings (million therms/yr) |
|---|---|---|---|---|
| New Construction | 8.3 | 9.2 | 0.0 | -0.2 |
| Additions | 0.2 | 0.2 | 0.0 | 0.0 |
| Alterations | 0.2 | 0.2 | 0.0 | 0.0 |
| **TOTAL** | **8.7** | **9.6** | **0.0** | **-0.2** |

a. First-year savings from all buildings completed statewide in 2020.

# Compliance and Enforcement

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

- Failure to obtain a permit for installation of a new duct system in an existing dwelling that triggers the air handler W/cfm test.
- Lack of approved products and incentives to encourage marketing and installation of FDD and FID devices.
- Low use of prescriptive refrigerant charge verification in new installations, and low permitting of replacement systems.

Although a needs analysis has been conducted with the affected market actors while developing the code change proposal, the code requirements may change between the time the final CASE Report is submitted and the time the 2019 Standards are adopted. The recommended compliance process and compliance documentation may also evolve with the code language. To effectively implement the adopted code requirements, a plan should be developed that identifies potential barriers to compliance when rolling-out the code change and approaches that should be deployed to minimize the barriers.

# 1. INTRODUCTION

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (Energy Commission) efforts to update California's Building Energy Efficiency Standards (Title 24, Part 6) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric, Southern California Edison (SCE), and SoCalGas® – and two Publicly Owned Utilities (POUs) – Los Angeles Department of Water and Power and Sacramento Municipal Utility District sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to energy efficiency in buildings. This report and the code change proposal presented herein is 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 2019 Title 24 website for information about the rulemaking schedule and how to participate in the process: http://www.energy.ca.gov/title24/2019standards/.

The overall goal of this CASE Report is to propose a code change proposal for residential heating, ventilation, and air conditioning (HVAC) measures. 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 building officials, manufacturers, builders, utility incentive program managers, Title 24 energy analysts, and others involved in the code compliance process. The proposal incorporates feedback received during two public stakeholder workshops that the Statewide CASE Team held on September 27, 2016 and March 16, 2017.

Section 2 of this CASE Report provides a description of the measure and its background. This section also presents a detailed description of how this change is accomplished in the various sections and documents that make up the Title 24, Part 6 Standards.

Section 3 presents the market analysis, including 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 presents the per-unit energy, demand, and energy cost savings associated with the proposed code change. This section also describes the methodology that the Statewide CASE Team used to estimate energy, demand, and energy cost savings.

Section 5 presents the lifecycle cost and cost-effectiveness analysis. This includes a discussion of additional materials and labor required to implement the measure and a quantification of the incremental cost. It also includes estimates of incremental maintenance costs. That is, equipment lifetime and various periodic costs associated with replacement and maintenance during the period of analysis.

Section 6 presents the statewide energy savings and environmental impacts of the proposed code change for the first year after the 2019 Standards take effect. This includes the amount of energy that will 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. Statewide water consumption impacts are also considered.

Section 7 concludes the report with specific recommendations with ~~strikeout~~ (deletions) and underlined (additions) language for the Standards, Reference Appendices, Alternate Calculation Manual (ACM) Reference Manual, Compliance Manual, and compliance documents.

# 2. MEASURE DESCRIPTION

## 2.1 Measure Overview

This code change proposal includes one mandatory requirement, one compliance option, and one alternative verification method. The measures affect single family and multifamily building types and apply to all climate zones. The impact of the proposed measures will be to:

- **Mandatory fan efficacy requirement:** Reduce the maximum air handling unit fan efficacy currently required under Title 24 Part 6, 150.0(m)13 from 0.58 watts per cubic feet per minute (W/cfm) to 0.45 W/cfm. As proposed, the requirement would apply to furnaces and heat pump air handlers.
- **Compliance option for fault detection and diagnosis (FDD) devices:** Allow compliance credit for FDD devices that will support both the long-term, as well as initial, performance of cooling systems.
- **Alternative verification method (temperature split):** Provide an alternate method to refrigerant charge verification that measures system performance and that can identify multiple system faults while reducing verification time.

These three code changes are being proposed for the following reasons:

- Lowering the fan efficacy will ensure continued quality design and installation practice while accounting for improved fan motor efficiency resulting from new DOE fan efficacy standards.
- Encouraging use of FDDs and FIDs will result in improved accuracy of verification, ensure persistence of energy savings and comfort, and improve the efficiency and quality of HVAC system service.
- The proposed temperature split method will speed diagnosis and will identify system faults that are not captured by refrigerant charge verification while requiring minimal training and equipment.

These code changes will modify existing code language as well as create new sections of code. Minor revisions to the CBECC-Res (California Building Energy Code Compliance for Residential buildings software) modeling algorithms will be necessary. The changes will apply to new construction and to additions and alterations where complete systems are being installed and/or replaced (furnace or air handler, evaporator coil, ducts, registers, and grilles).

***NOTE:*** *At the time of writing, the Energy Commission has indicated they will only consider the mandatory fan efficacy measure for the 2019 Title 24, Part 6 Standards. The FDD and temperature split measures are documented for potential use in future proceedings.*

## 2.2 Measure History and Background

### *2.2.1 Fan Efficacy*

Over a decade ago Sachs et al. (Sachs 2002) pointed out that improving motors and fans in residential furnaces and heat pumps could save more energy than a typical refrigerator uses. To curb the use of fan energy, the 2008 Title 24, Part 6 Standards adopted a prescriptive limit of 0.58 W/cfm, which was based on a field study completed in 2006 that identified a median fan watt draw for the houses surveyed of 0.51 W/cfm (Proctor, Efficiency Characteristics and Opportunities for New California Homes 2011). The mandatory 0.58 W/cfm efficacy limit was adopted for the 2013 Title 24, Part 6 Standards.

Two types of fan motors have been used in residential furnaces and air handlers, permanent split capacitor (PSC) motors, and brushless permanent magnet (BPM) motors. There are two types of motors (or motor programming) in the latter category, constant airflow and constant torque. Both BPM motor types are electronically commutated and referred to as ECMs[1], though this label is more frequently applied to the constant airflow type.

Figure 1 illustrates how airflow and power (watts per cubic feet per minute) can vary with static pressure for a typical furnace (Michael 2009). The Regal Beloit X13 is a constant torque motor and the ECM2.3 is a constant cfm motor. Fans with PSC motors respond to increasing static pressure with reduced airflow and a slight increase in power. Fans with regulated torque motors are less susceptible to increases in static pressure than PSC motors, but their power increases with increasing static pressure. Constant airflow motors maintain relatively constant airflow over a range of static pressures, and their power also increases as static pressure rises. The advantage of BPM motor types is that they use much less power than PSC motors of similar horsepower, as shown by the right-hand plot. Both types are in widespread use by furnace and heat pump manufacturers.

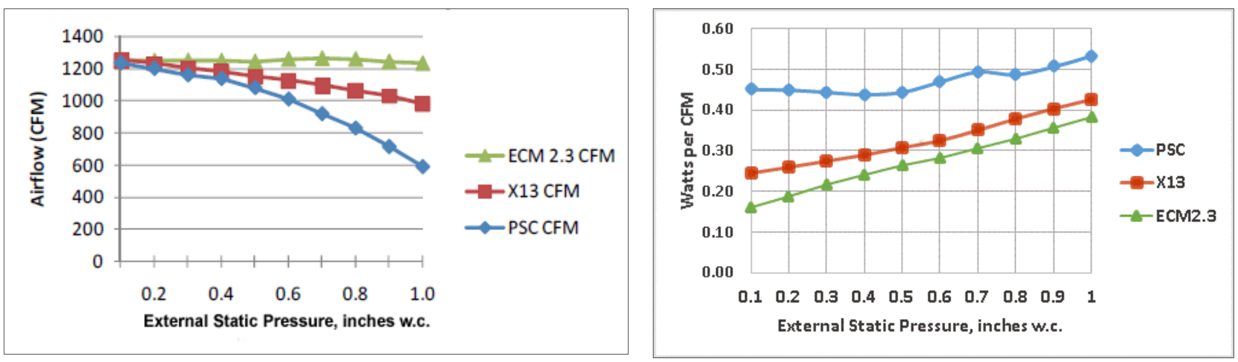


**Figure 1: Typical airflow and power responses to static pressure for three fan motor types**

Responding to the energy savings opportunity created by this technology, the United States (U.S.) Department of Energy (DOE) adopted a new fan efficacy standard for certain residential air delivery equipment. The standard requires a maximum fan efficacy (W/cfm), which varies by equipment type and maximum air volume. Products that are covered by the DOE rulemaking include:

- Furnace fans used in weatherized and non-weatherized gas furnaces
- Oil furnaces
- Electric furnaces
- Modular blowers

[1] ECM was coined by General Electric and stands for “electronically commutated motor”.

Products not addressed in the rulemaking include:

- Furnace fans used in other products
- Heat pump air handlers
- Through-the-wall air handlers
- Small-duct, high-velocity air handlers
- Energy recovery ventilators (ERVs) and heat recovery ventilators (HRVs)
- Draft inducer fans
- Exhaust fans
- Hydronic air handlers

The DOE standard, which was adopted September 2, 2014 and takes effect July 3, 2019, will require maximum efficacies ranging from about 0.2 to 0.28 W/cfm (U.S. Department of Energy 2014). The test procedure that manufacturers must apply to obtain FER ratings (Code of Federal Regulations 10 CFR Part 430, Subpart B, Appendix AA (2016)) references ASHRAE Standard 103-2007 (Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers). The test parameters described in the DOE standard are not analogous to those used for Title 24 verification. For example, the DOE procedure considers heating, cooling, and recirculating functions of fans while the Title 24 verification procedure only tests fans at the speed used for air conditioning. The DOE standard also applies fixed external pressure drop values while Title 24 field verification accounts for the friction loss of the installed ducts, filter, and coil, which can vary widely.

The DOE standard uses the following equation to calculate the fan efficacy rating, or "FER":

$$FER = \frac{(CH \times E_{Max}) + (HH \times E_{Heat}) + (CCH \times E_{Circ})}{(CH + 830 + CCH) \times Q_{Max}} \times 1000$$

Where: CH = Cooling operating hours (640)

HH = Heating operating hours (830)

CCH = Constant circulation operating hours (400)

EMax = Furnace fan energy at maximum speed (watts)

EHeat = Furnace fan energy at the default heating speed (watts)

ECirc = Furnace fan energy at the default constant circulation speed (watts)

QMax = Airflow at maximum fan speed (cfm)

DOE testing is conducted using an external static pressure (ESP) of 0.65 inch water column (inch w.c.) for units designed to be paired with an evaporator coil (e.g., furnaces) and 0.50 inch w.c. for units with an internal evaporator coil. Individual airflow settings are specified, depending on which operating mode is being tested (heating, cooling, or circulation). Operating hours used in the equation are listed above. Thus, the FER is weighted 44 percent at heating speed, 34 percent at cooling speed, and 21 percent at constant circulation speed. This approach results in much lower FERs than would be calculated at cooling speed only, which is how fan efficacy is field tested under Title 24. Also, the external static pressure in installed systems may be as high as 1 inch w.c., compared to the 0.65 inch w.c. value used in DOE tests. FER ratings in watts per 1000 cfm[2] are listed in Figure 2, which is duplicated from the DOE standard.

[2] The heading in the table is incorrectly labeled W/cfm when it should be W/1000 cfm.

**Table I.1. Energy Conservation Standards for Covered Residential Furnace Fans**

| Product Class | FER* (Watts/cfm) | Percent Increase Over Baseline |
|---|---|---|
| Non-Weatherized, Non-Condensing Gas Furnace Fan (NWG-NC) | FER = 0.044 x $Q_{Max}$ + 182 | 46% |
| Non-Weatherized, Condensing Gas Furnace Fan (NWG-C) | FER = 0.044 x $Q_{Max}$ + 195 | 46% |
| Weatherized Non-Condensing Gas Furnace Fan (WG-NC) | FER = 0.044 x $Q_{Max}$ + 199 | 46% |
| Non-Weatherized, Non-Condensing Oil Furnace Fan (NWO-NC) | FER = 0.071 x $Q_{Max}$ + 382 | 12% |
| Non-Weatherized Electric Furnace / Modular Blower Fan (NWEF/NWMB) | FER = 0.044 x $Q_{Max}$ + 165 | 46% |
| Mobile Home Non-Weatherized, Non-Condensing Gas Furnace Fan (MH-NWG-NC) | FER = 0.071 x $Q_{Max}$ + 222 | 12% |
| Mobile Home Non-Weatherized, Condensing Gas Furnace Fan (MH-NWG-C) | FER = 0.071 x $Q_{Max}$ + 240 | 12% |
| Mobile Home Electric Furnace / Modular Blower Fan (MH-EF/MB) | FER = 0.044 x $Q_{Max}$ + 101 | 46% |
| Mobile Home Non-Weatherized Oil Furnace Fan (MH-NWO) | Reserved | |
| Mobile Home Weatherized Gas Furnace Fan (MH-WG) | Reserved | |

* $Q_{Max}$ is the airflow, in cfm, at the maximum airflow-control setting measured using the final DOE test procedure at 10 CFR part 430, subpart B, appendix AA.

**Figure 2: Fan Efficacy Ratings from 10 CFR Part 430 Subpart B Appendix AA**

Under the federal standard, maximum FERs for product classes that include condensing and non-condensing non-weatherized furnaces range from about 0.20 to 0.28 W/cfm.

Brushless permanent magnet (BPM) motors were identified by the DOE as the key technology that manufacturers can use to achieve the prescribed efficacy levels (DOE 2013). Thus, after the DOE standard takes effect it will facilitate a lowering of the Title 24 0.58 W/cfm efficacy to 0.45 W/cfm without requiring other measures to be taken to achieve the lower value. Though the DOE standard does not extend to heat pump air or hydronic air handlers, the same efficacy limit is proposed for those system types, which can comply either by meeting the revised fan efficacy of 0.45 W/cfm or by demonstrating compliance with Table 150.0-B or 150.0-C. Heat pump manufacturers are incentivized to utilize BPM fan motors as a way to reach the 14 SEER and 8.2 HSPF performance levels required by the 2017 DOE appliance efficiency standards.

The proposed efficacy limit of 0.45 W/cfm was initially derived by reviewing data from a Building America study of filter pressure drop (D. Springer 2009). This laboratory study used an air handler that was alternately equipped with PSC and BPM motors. Static pressures typical of a residential duct system with cooling coil were imposed, and the pressure drop across the fan and fan power were measured for filters having a variety of minimum efficiency reporting value (MERV) ratings, and at a range of airflows. For the high efficiency (MERV 11-13) filters tested, the data showed that the BPM powered fan would use less than 0.40 W/cfm at a total external static pressure in the range of 0.6 to 0.7 inch w.c.

Recently Proctor Engineering Group tested two BPM equipped furnaces that were maintained at realistic external static pressures, and efficacies of 0.30 and 0.38 W/cfm were measured (B. e. Wilcox 2008). For further evidence, the Statewide CASE Team obtained and tested two BPM-equipped furnaces, a constant CFM (Goodman) rated at 1600 cfm, and a constant torque (Bryant) rated at 1000 cfm.

Each was tested at two speeds using varying DIP switch settings, and a damper was used to adjust the total external static pressure (ESP) to 0.5, 0.6, and 0.7 inch w.c. at each speed setting. The highest setting (0.7 inch w.c.) is a recommended value by ACCA (Air Conditioning Contractors of America) Manual D when BPM powered furnaces or heat pumps are used. As results shown in Figure 3 indicate, at an external static pressure of 0.7 inch w.c., an efficacy less than 0.45 W/cfm should be easily obtained with proper filter sizing and duct design.[3]

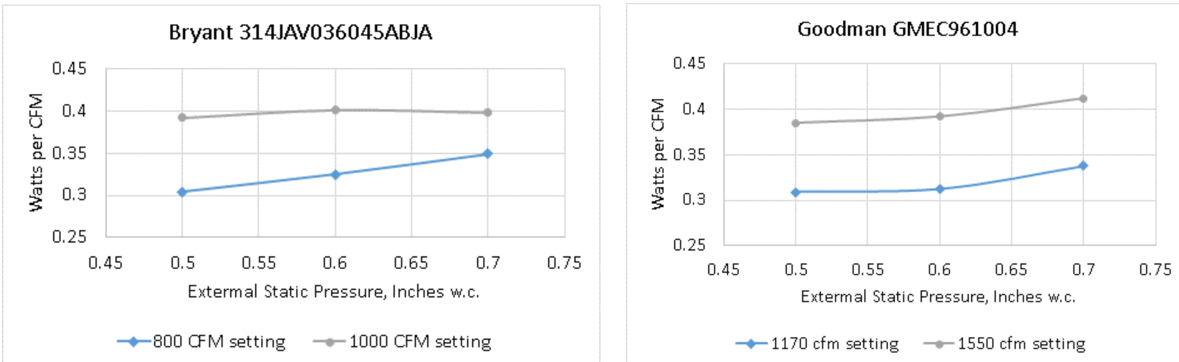


**Figure 3: Results of fan efficacy tests for two furnaces with BPM fans**

A furnace model database compiled by LBNL in 2004 from manufacturer expanded ratings (Lutz 2004) also shows the efficacy increasing to 0.4 W/cfm as the static pressure increases to 0.7 inch w.c. (see Figure 4).

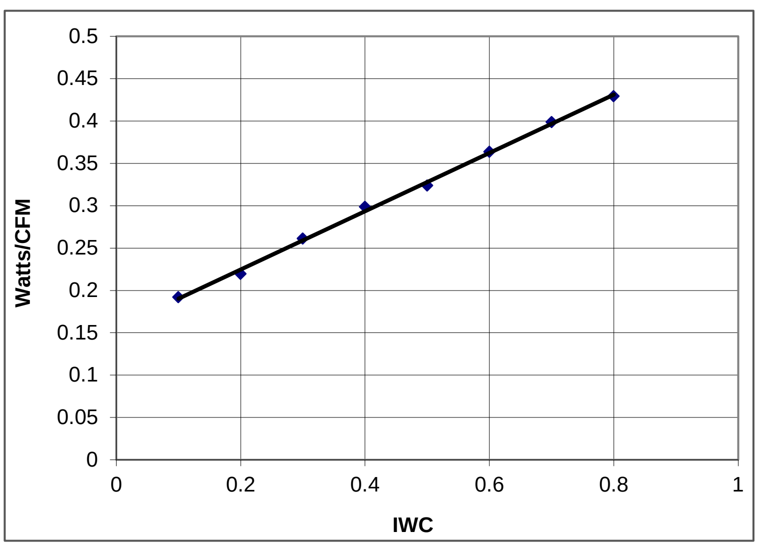


**Figure 4: ECM furnace average W/cfm from manufacturer published performance data**

These data provide compelling evidence that the proposed decrease of fan efficacy from 0.58 to 0.45 W/cfm will be easily attained when systems are properly designed and furnaces with BPM fan motors are installed. However, at the request of Energy Commission staff, additional testing was completed on both furnaces and heat pumps that supports this measure, as described in Appendix D.

[3] Title 24, Part 11 requires that residential HVAC systems be designed in accordance with ACCA Manuals J and D.

It should be noted that adoption of the 0.45 W/cfm efficacy limit was not determined by translating the federal furnace fan rule. It was based on an understanding from a review of the federal register (U.S. Department of Energy 2014) that it will be necessary for furnaces to incorporate BPM motors to comply with the federal ruling. Testing demonstrated furnaces that are so equipped can easily meet the new efficacy requirement when air distribution systems are designed in accordance with industry standards. The purpose of the current 0.58 W/cfm requirement is to ensure that duct systems are properly sized. The intention of this fan efficacy measure is to maintain current Title 24, Part 6 standards for duct design as furnace fan efficiency improves.

The residential indoor air quality CASE Report proposes to require MERV 13 filtration in thermal conditioning systems. If the designer is attentive to filter pressure drop, they will size the filter so that pressure drop is not excessive. For example, a system will have the same efficacy whether it uses a MERV 6 or MERV 13 filter if both filters are sized for a pressure drop of 0.15 inch w.c.

Systems using furnaces to supply air for heating and cooling must overcome pressure drops through the furnace heat exchangers and cooling coils, as well as external ductwork. Though heat pump air handler fans are not bound by the DOE ruling, they need only overcome the static pressure of the heating/cooling coil, so they should more easily be able to meet the proposed 0.45 W/cfm standard.

### *2.2.2 Fault Detection and Diagnosis (FDD) Devices*

This report refers to two classes of fault detection devices, fault detection and diagnosis devices (FDDs), which may or may not include a display visible to the homeowner, and fault indicator displays (FIDs), which display faults to the homeowner and meet the specification provided in Joint Appendix 6 (JA6) to the Title 24, Part 6 Standards. Both may be included in the general category of FDDs. As implemented in the 2016 Title 24 Part 6 Standards, FIDs are only used as an alternative to refrigerant charge verification.

The 2016 Title 24 Part 6 Standards provide two paths for residential air conditioner performance verification: refrigerant charge verification, or a “fault indicator display” (Section 150.1(c)7A and Table 150.1-A). As mentioned, the specifications for FIDs are provided in JA6 and describe a device that continually monitors operation and displays faults to the home occupant. An FID would therefore provide long-term validation of system performance, but the Title 24, Part 6 compliance software does not provide a performance credit for this highly beneficial feature. FIDs (formerly CIDs or “charge indicator displays) were introduced in the 2008 Title 24, Part 6 Standards, but since then no manufacturers have introduced products that meet the FID specification provided in JA6, nor have any applied for their products to be approved by the Energy Commission, as also provided for in JA6.

Title 24, Part 6 Section 120(i) requires FDD devices for commercial package systems with economizers, but there are currently no residential compliance options that credit FDD devices that are capable of ensuring long-term performance of residential air conditioning systems.

FDDs for the residential market are currently available and take many forms. Some are simple and very low cost and record faults to alert service technicians that a problem has occurred, but they do not provide the instantaneous verification of performance required for an FID. Some FDDs serve dual purposes, for example Emerson’s CoreSense (see Figure 5) can be installed as a replacement compressor contactor, and the Lennox iComfort system provides both thermostatic control and fault detection. They also provide information that can be used by technicians with relatively low skills to diagnose problems.


**Figure 5: Emerson CoreSense FDD**

Other FDDs, such as the Truveon, have extensive measurement and diagnostic capability, provide instantaneous performance information, and though they do not meet the exact requirements of the JA6 specification could be used as alternative to refrigerant charge verification. As provided for in JA6, FIDs that do not meet the specification may be given approval by filing a request with the Commission.

There are no existing compliance credits for either FIDs or FDDs. Although no large-scale field studies have been completed, the probability of energy savings has been evaluated. As a benchmark, where a technician is without the aid of an automated FDD device, Yuill and Braun predict that the probability of the technician correctly diagnosing a fault that results in a 25 percent loss of capacity is 50 percent (Yuill and Braun 2016). The same authors in a different article discuss issues surrounding the problem of false alarms from FDDs and propose a "figure of merit" for assessing their value that could be used for certification purposes (Yuill and Braun 2017). One FDD manufacturer cited a reduction in the warranty rate of 48 percent for systems using their low cost FDD device (Pham 2017). Resulting cost savings can translate to lower warranty margins and reduced costs to contractors.

A credit that accounts for the persistence of efficient system operation provided by FDDs could implement the same method as the ACM rules use for refrigerant charge verification, which is as an adjustment to cooling system EER. This code change proposal adds two new scenarios as demonstrated in Table 3. Currently, a 90 percent multiplier is used to degrade EER if there is no refrigerant charge verification, and a 96 percent multiplier is used if refrigerant charge is verified by testing or weigh-in. As proposed, a 94 percent multiplier would be used if an FDD is installed in the cooler climate zones. If any of the approved verification methods is used and an FDD or FID device is installed, the multiplier would increase to 98 percent.

**Table 3: Summary of Refrigerant Charge and Fault Detection Modeling Approach**

| Case | Climate Zone | EER Multiplier |
|---|---|---|
| No refrigerant charge or FDD, all climate zones [a] | All | 90% |
| No refrigerant charge, FDD installed [b] | 1, 3 - 7, 16 | 94% |
| Refrigerant charge, <u>OR</u><br>Temperature split, <u>OR</u><br>Weigh-in method (no FDD) [a] | 2, 8 - 15 | 96% |
| FID <u>OR</u><br>FDD & refrigerant charge [b] | All | 98% |

a. Multipliers are included in the 2016 ACM Reference Manual and compliance software; included for reference, but not recommending a revision.

b. Multipliers are not included in the 2016 ACM Reference Manual and compliance software; Statewide CASE Team is proposing the multiplier listed in the table.

A self-certification system like that used for commercial economizer FDDs could be used for qualifying residential FID and FDD devices. Inspection of both FDD and FID devices by a HERS Rater will be required and may consist of verification that a device is present, is listed by the Energy Commission as an approved device, and operational.

### *2.2.3 Performance Verification Using Temperature Split*

Refrigerant charge verification, which is a prescriptive requirement in Climate Zones 2 and 8-15, has undoubtedly improved air conditioner performance since it was introduced to the Title 24, Part 6 Standards in 2001. However, there are other faults that can impact performance that are difficult to detect using the RA3.2 testing and verification protocol, such as an improperly attached thermostatic expansion valve (TXV) bulb, a restriction in the liquid line, or contaminated refrigerant. As Figure 6 illustrates, individual defects can interact and have a compounding impact on system performance (Li 2004). In addition to devices that can monitor systems over an extended period of time, there is a need for simple but effective performance-based tests that can identify hidden faults at the time of installation.

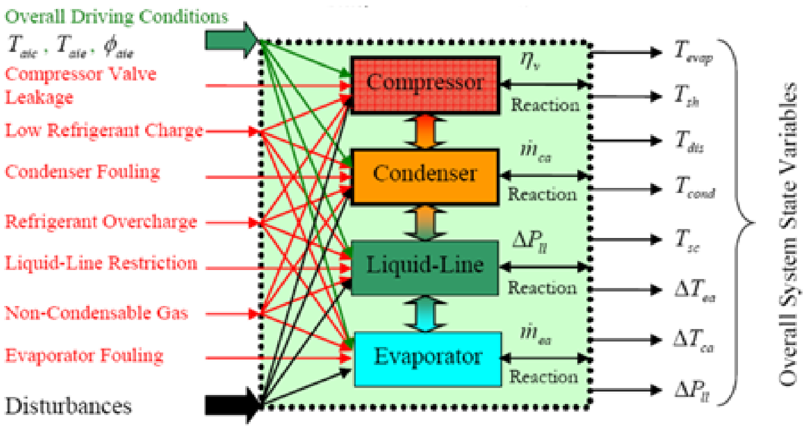


**Figure 6: Complex interactions and the impact of various system faults**

Measurement of temperature split, or the difference between return and supply temperature, has potential merit as a means of assessing overall air conditioner performance and has been used in maintenance programs as well as Title 24, Part 6 (Proctor Engineering n.d.). Temperature split and airflow measurement (or "TSA") provides an easy-to-implement alternative to refrigerant charge verification that captures a multitude of faults including liquid line restrictions, defective or improperly installed thermostatic expansion valves (TXVs), contaminated refrigerant, blocked coils, and defective compressors, as well as incorrect charge. Essentially, the method involves comparing the measured temperature difference to values in a table, and if the variance between the two values is within certain tolerances, the system is judged to have adequate performance.

Temperature split measurement was allowed in the 2005 and 2008 Title 24, Part 6 Standards as a means of estimating airflow. As implemented, the method was lacking in accuracy and was replaced in the 2013 Standards with the direct measurement methods described in RA3.3. A temperature split table is still a component of the FID specification listed in JA6.1 of the 2016 Standards. As pointed out by Temple (Temple 2011), using only one temperature split table fails to address outdoor temperature dependence. Figure 7, created from test data provided by Southern California Edison (SCE 2012), shows that measured EER is highly dependent on outside air temperature. EER is much less sensitive to entering wet bulb temperature, which affects the sensible heat ratio. When tables are used that align with the outdoor temperature at the time the temperature split is measured, it vastly improves the reliability of the measurement.

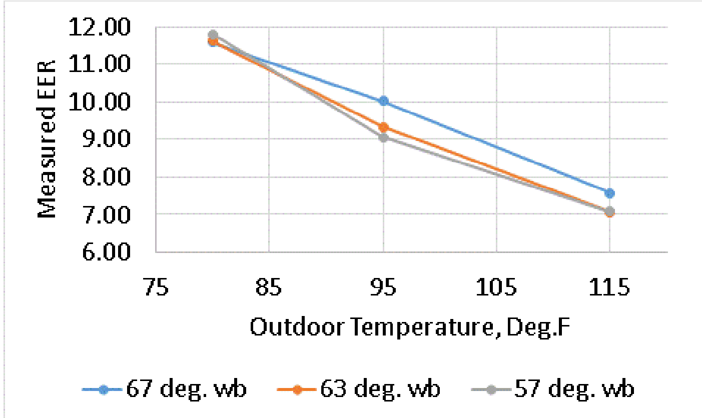


**Figure 7: Impact of outdoor temperature and entering wet bulb temperature on EER**

In the laboratory, sensible capacity of a system is measured using the airflow and temperature difference across the furnace or air handler and cooling coil using:

$$Q_{sens} = \dot{m}\, C_p(T_r - T_s)$$

Where:

$\dot{m}$ is the mass flowrate of the air;

$C_p$ is the specific heat of the air; and

$T_r$ and $T_s$ are the return and supply temperatures, respectively.

For a nominal one ton (12,000 Btu/hr total capacity with 80 percent sensible capacity) system delivering 400 cfm of supply airflow, the temperature difference (or split) will be 22.2°F (neglecting heat gains from the fain motor)[4] In this example, if the ratio of airflow to equipment size (cfm/ton) does not change, the temperature difference will be the same regardless of the size of the equipment. The temperature split is inversely proportional to the airflow, or cfm/ton. Accuracy of the temperature split method is improved by normalizing the measured airflow to 400 cfm/ton.

Temperature split tables, which list "target" values, account for the outdoor temperature and the dry and wet bulb temperatures of the air entering the cooling coil. At higher return air wet bulb temperatures, the temperature split is adjusted downward to account for the decrease in sensible capacity. At higher return air dry bulb temperatures, the temperature split is adjusted higher to account for the higher capacity resulting from the reduced amount of work required to cool the air. The tables also adjust for heat added by the fan motor. An example temperature split table for 95°F outdoor temperature is provided in Table 4 (Temple 2011). The left-hand column is the return air wet-bulb temperature and the top row is the return air dry-bulb temperature.

The proposed TSA method will involve the following steps:

1. Measure airflow using prescribed methods to verify it is ≥ 350 cfm/ton.
2. Measure outdoor temperature, return air dry bulb and wet bulb temperatures, and supply air temperature.

---

[4] Using an approximate volumetric heat capacity of 0.018 Btu/°F-cfm times 60 minutes per hour, the resulting temperature split calculation is equal to (12,000 Btu/hour x 0.8) / (400 cfm x 0.018 Btu/°F-ft$^3$ x 60 minutes per hour) = 22.2°F

3. Subtract the supply air temperature from the return air temperature and normalize this measured temperature split to 400 cfm/ton using: $TS_{normal} = TS_{measured}$ x (0.00264 x cfm/ton – 0.054).[5]
4. Look up the target temperature split in the table corresponding to the outdoor temperature (e.g., Table 4), and subtract the normalized measured value from the target value.
5. If the result is ≤ 5°F, then the system passes the test.

**Table 4: Temperature Split Table for 95°F Outdoor Temperature**

| | RETURN AIR DRY BULB | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **RA WB** | **65** | **66** | **67** | **68** | **69** | **70** | **71** | **72** | **73** | **74** | **75** | **76** | **77** | **78** | **79** | **80** | **81** | **82** | **83** | **84** |
| **46** | 21.0 | 21.3 | 21.6 | 21.9 | 22.2 | 22.5 | 22.8 | 23.1 | 23.4 | 23.7 | | | | | | | | | | |
| **47** | 21.0 | 21.3 | 21.6 | 21.9 | 22.2 | 22.5 | 22.8 | 23.1 | 23.4 | 23.7 | 24.1 | 24.4 | | | | | | | | |
| **48** | 21.0 | 21.3 | 21.6 | 21.9 | 22.2 | 22.5 | 22.8 | 23.1 | 23.4 | 23.7 | 24.1 | 24.4 | 24.7 | 25.0 | | | | | | |
| **49** | 21.0 | 21.3 | 21.6 | 21.9 | 22.2 | 22.5 | 22.8 | 23.1 | 23.4 | 23.7 | 24.1 | 24.4 | 24.7 | 25.0 | 25.3 | 25.6 | | | | |
| **50** | 21.0 | 21.3 | 21.6 | 21.9 | 22.2 | 22.5 | 22.8 | 23.1 | 23.4 | 23.7 | 24.1 | 24.4 | 24.7 | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | | |
| **51** | 21.0 | 21.3 | 21.6 | 21.9 | 22.2 | 22.5 | 22.8 | 23.1 | 23.4 | 23.7 | 24.1 | 24.4 | 24.7 | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | 26.5 | 26.8 |
| **52** | 20.2 | 21.0 | 21.6 | 21.9 | 22.2 | 22.5 | 22.8 | 23.1 | 23.4 | 23.7 | 24.1 | 24.4 | 24.7 | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | 26.5 | 26.8 |
| **53** | 19.4 | 20.2 | 21.0 | 21.7 | 22.2 | 22.5 | 22.8 | 23.1 | 23.4 | 23.7 | 24.1 | 24.4 | 24.7 | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | 26.5 | 26.8 |
| **54** | 18.6 | 19.4 | 20.2 | 20.9 | 21.7 | 22.5 | 22.8 | 23.1 | 23.4 | 23.7 | 24.1 | 24.4 | 24.7 | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | 26.5 | 26.8 |
| **55** | 17.8 | 18.6 | 19.4 | 20.1 | 20.9 | 21.7 | 22.5 | 23.1 | 23.4 | 23.7 | 24.1 | 24.4 | 24.7 | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | 26.5 | 26.8 |
| **56** | 17.0 | 17.8 | 18.6 | 19.3 | 20.1 | 20.9 | 21.7 | 22.5 | 23.2 | 23.7 | 24.1 | 24.4 | 24.7 | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | 26.5 | 26.8 |
| **57** | 16.2 | 17.0 | 17.8 | 18.5 | 19.3 | 20.1 | 20.9 | 21.7 | 22.4 | 23.2 | 24.0 | 24.4 | 24.7 | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | 26.5 | 26.8 |
| **58** | 15.4 | 16.2 | 17.0 | 17.7 | 18.5 | 19.3 | 20.1 | 20.9 | 21.6 | 22.4 | 23.2 | 24.0 | 24.7 | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | 26.5 | 26.8 |
| **59** | 14.6 | 15.4 | 16.2 | 16.9 | 17.7 | 18.5 | 19.3 | 20.1 | 20.8 | 21.6 | 22.4 | 23.2 | 24.0 | 24.7 | 25.3 | 25.6 | 25.9 | 26.2 | 26.5 | 26.8 |
| **60** | 13.8 | 14.6 | 15.4 | 16.1 | 16.9 | 17.7 | 18.5 | 19.3 | 20.0 | 20.8 | 21.6 | 22.4 | 23.2 | 23.9 | 24.7 | 25.5 | 25.9 | 26.2 | 26.5 | 26.8 |
| **61** | 13.0 | 13.8 | 14.6 | 15.3 | 16.1 | 16.9 | 17.7 | 18.5 | 19.2 | 20.0 | 20.8 | 21.6 | 22.4 | 23.1 | 23.9 | 24.7 | 25.5 | 26.2 | 26.5 | 26.8 |
| **62** | 12.2 | 13.0 | 13.8 | 14.5 | 15.3 | 16.1 | 16.9 | 17.7 | 18.4 | 19.2 | 20.0 | 20.8 | 21.6 | 22.3 | 23.1 | 23.9 | 24.7 | 25.5 | 26.2 | 26.8 |
| **63** | 11.4 | 12.2 | 13.0 | 13.7 | 14.5 | 15.3 | 16.1 | 16.9 | 17.6 | 18.4 | 19.2 | 20.0 | 20.8 | 21.5 | 22.3 | 23.1 | 23.9 | 24.7 | 25.4 | 26.2 |
| **64** | 10.6 | 11.4 | 12.2 | 12.9 | 13.7 | 14.5 | 15.3 | 16.1 | 16.8 | 17.6 | 18.4 | 19.2 | 20.0 | 20.7 | 21.5 | 22.3 | 23.1 | 23.9 | 24.6 | 25.4 |
| **65** | | 10.6 | 11.4 | 12.1 | 12.9 | 13.7 | 14.5 | 15.3 | 16.0 | 16.8 | 17.6 | 18.4 | 19.2 | 19.9 | 20.7 | 21.5 | 22.3 | 23.1 | 23.8 | 24.6 |
| **66** | | | 10.6 | 11.3 | 12.1 | 12.9 | 13.7 | 14.5 | 15.2 | 16.0 | 16.8 | 17.6 | 18.4 | 19.1 | 19.9 | 20.7 | 21.5 | 22.3 | 23.0 | 23.8 |
| **67** | | | | 10.5 | 11.3 | 12.1 | 12.9 | 13.7 | 14.4 | 15.2 | 16.0 | 16.8 | 17.6 | 18.3 | 19.1 | 19.9 | 20.7 | 21.5 | 22.2 | 23.0 |
| **68** | | | | | 10.5 | 11.3 | 12.1 | 12.9 | 13.6 | 14.4 | 15.2 | 16.0 | 16.8 | 17.5 | 18.3 | 19.1 | 19.9 | 20.7 | 21.4 | 22.2 |
| **69** | | | | | | 10.5 | 11.3 | 12.1 | 12.8 | 13.6 | 14.4 | 15.2 | 16.0 | 16.7 | 17.5 | 18.3 | 19.1 | 19.9 | 20.6 | 21.4 |
| **70** | | | | | | | 10.5 | 11.3 | 12.0 | 12.8 | 13.6 | 14.4 | 15.2 | 15.9 | 16.7 | 17.5 | 18.3 | 19.1 | 19.8 | 20.6 |
| **71** | | | | | | | | 10.5 | 11.2 | 12.0 | 12.8 | 13.6 | 14.4 | 15.1 | 15.9 | 16.7 | 17.5 | 18.3 | 19.0 | 19.8 |
| **72** | | | | | | | | | 10.4 | 11.2 | 12.0 | 12.8 | 13.6 | 14.3 | 15.1 | 15.9 | 16.7 | 17.5 | 18.2 | 19.0 |
| **73** | | | | | | | | | | 10.4 | 11.2 | 12.0 | 12.8 | 13.5 | 14.3 | 15.1 | 15.9 | 16.7 | 17.4 | 18.2 |
| **74** | | | | | | | | | | | 10.4 | 11.2 | 12.0 | 12.7 | 13.5 | 14.3 | 15.1 | 15.9 | 16.6 | 17.4 |
| **75** | | | | | | | | | | | | 10.4 | 11.2 | 11.9 | 12.7 | 13.5 | 14.3 | 15.1 | 15.8 | 16.6 |
| **76** | | | | | | | | | | | | | 10.4 | 11.1 | 11.9 | 12.7 | 13.5 | 14.3 | 15.0 | 15.8 |

All measurements can be made easily and accurately except for supply air temperature. The temperature of air leaving a cooling coil can vary greatly, affecting the temperature of air supplied to individual ducts. Supported by the information that follows, the recommended method for obtaining a representative supply air temperature is to measure and average temperatures taken at the three largest registers.

The example below was from an actual field test of a newly installed air conditioner:

Return dry bulb temperature = 79.1°F

Return web bulb temperature = 62.7°F

Supply air temperature = 56.2°F

Outdoor temperature = 95°F

[5] This equation was derived by varying airflow and calculating the air temperature drop (or split) from the heat capacity of the air and an assumed total cooling capacity, while accounting for heat added by the fan (based on efficacy) and the sensible heat ratio. A linear fit of the resulting temperature split variance from a nominal 400 cfm per ton was used to develop the constants for the equation.

Airflow = 1220 cfm / 3 tons = 407 cfm/ton

Measured temperature split = 79.1°F – 56.2°F = 22.9°F

Normalized temperature split = 22.9°F x (0.00264 x 407 – 0.054) = 23.3°F

Target temperature (from Table 4) = 22.3°F

Temperature split variance = 22.3 – 23.3 = -0.1°F

Several steps were taken to refine procedures and validate the method. Data obtained during an extensive project to gather data to support the Title 24, Part 6 standards process (Proctor, Efficiency Characteristics and Opportunities for New California Homes 2011) was evaluated to determine the extent to which temperature split varied based on supply temperature measurements taken at each register. The distribution of measurements from the 2008 vintage homes is displayed in Figure 8. The mean temperature split was 4.3 and the standard deviation was 2.9.

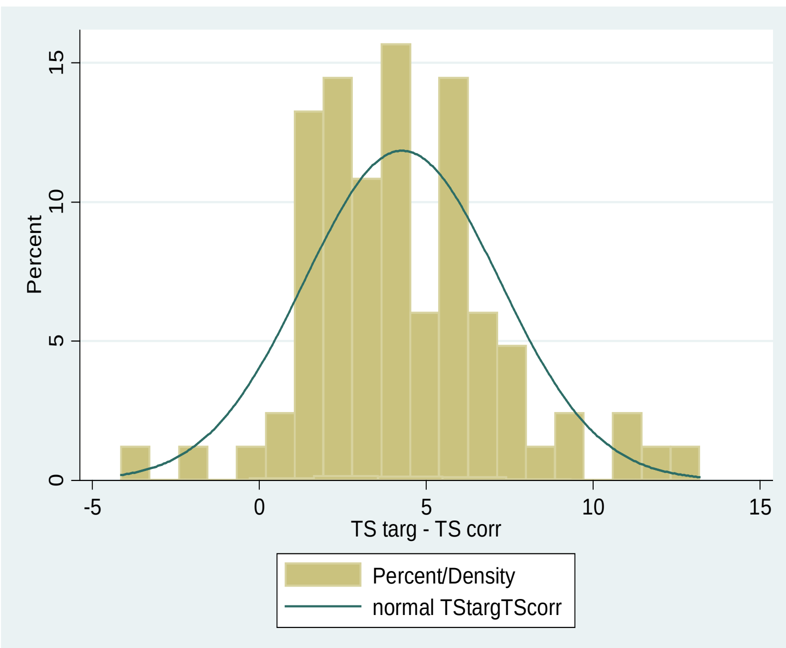


**Figure 8: Temperature split (TS) distribution for 83 vents from eight 2008 vintage homes**

Figure provided by Proctor Engineering

Additional data obtained from nine houses that participated in a "ducts in conditioned space" study (Hoeschele 2015) was used to identify optimal methods for measuring supply air temperature. Field measurements included the temperature at each collar that connected the main ducts to the supply plenum, and supply temperatures and airflows at each supply grille. The temperatures at each collar were weighted by the airflows and used to serve as an accurate reference mean supply air temperature. Temperatures splits were then determined using the reference supply temperatures and six different supply temperature measurement strategies, each of which were compared to the reference values. The objective was to find which strategy will yield the least deviation from the reference temperature split.

The six strategies include an airflow-weighted average of temperatures from every grille; the grille with the greatest airflow; an average of the two, three, and four grilles having the highest flow; and an airflow weighted average of the three grilles having the highest flow. Results for each of the nine houses are graphed in Figure 9. The houses labeled with an "A" had ducts in conditioned space or in a high-performance attic ("DCS"), and the "B" houses were standard construction with R-8 attic ducts and built to 2013 Standards.

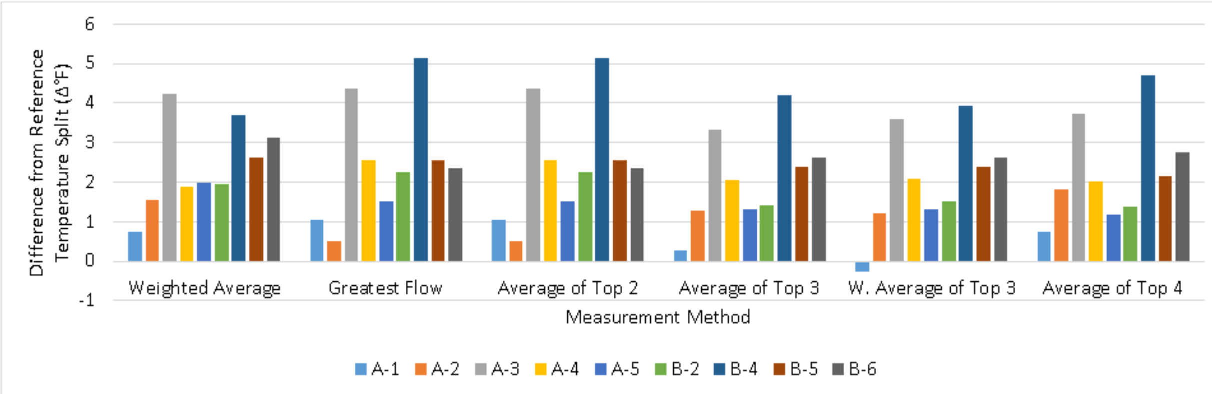


**Figure 9: Results of supply air temperature measurement using different strategies**

Table 5 compares the standard deviations of the six measurement strategies. The table also lists the number of houses for which the difference between the temperature splits obtained using supply grille temperatures vs. those obtained using reference temperatures exceeded 3°F. These differences are a result of heat gain as the air passes through the ducts, and are significant even when ducts are inside conditioned space.

Averaging the three grilles with the highest flow (not airflow-weighted) yielded the lowest standard deviation. Since the coil entering wet bulb temperature was not measured it was not possible to compare measured temperature splits to target values. Given that the best of these measurement strategies produced a greater than 3°F "error" in two of the houses, a 5°F temperature split tolerance ("measured" vs. "target") will yield fewer false indications of faults ("false alarms").

**Table 5: Summary of Air Temperature Measurement Strategies**

| | Standard Deviation | | Homes with Δ > 3 | |
|---|---|---|---|---|
| **Measurement Method** | **All 9** | **DCS (5)** | **All 9** | **DCS (5)** |
| Weighted average, all supplies | 1.1 | 1.3 | 3 | 1 |
| One, highest flow | 1.5 | 1.5 | 2 | 1 |
| Average, two with highest flow | 1.5 | 1.5 | 2 | 1 |
| Average, three with highest flow | 1.2 | 1.1 | 2 | 1 |
| Average, four with highest flow | 1.3 | 1.1 | 2 | 1 |

Lab test and other data can shed light on how much variance between target and measured temperature split is needed to capture faults while avoiding false alarms. Southern California Edison evaluated the impact of numerous faults using a three ton 13 SEER split system that was operated under a variety of outdoor and indoor temperature conditions (SCE 2012). The following faults were imposed, with corresponding test results as shown in Figure 10:

- Low refrigerant charge (13-40 percent)
- High refrigerant charge (10-30 percent)
- Refrigerant line restrictions (32-96 psi drop)
- Non-condensable gas in refrigerant (0.3-0.8 oz. nitrogen gas)
- Evaporator heat transfer reduction (9-22 percent)
- Condenser heat transfer reduction (5-18 percent)

Data from these tests were used to compare temperature split variance (measured vs. target) to the impact on EER. Baseline test data were used to estimate the EER at each outdoor condition. As shown in Figure 10, excluding low condenser and evaporator airflow test cases, a 5°F variance was sufficient to identify all other faults that resulted in a ten percent or greater reduction in EER. Newly installed systems are unlikely to have low condenser or evaporator airflow, particularly since evaporator airflow is generally HERS verified.

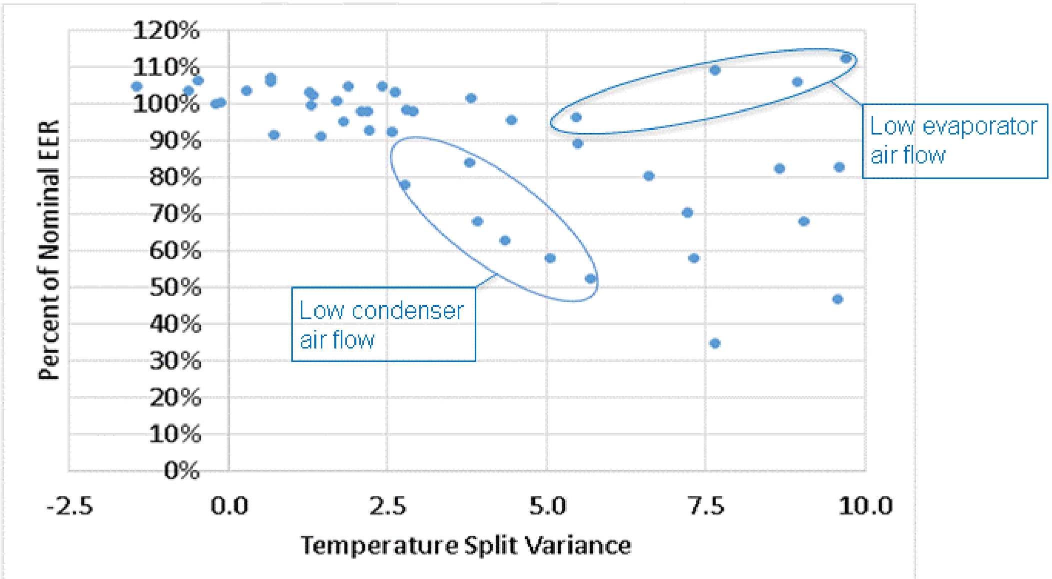


**Figure 10: Comparison of temperature split variance to the impact on EER of various imposed faults**

A recent laboratory test of a two-ton variable speed heat pump (with TXV) at PG&E's Applied Technology Services (ATS) lab showed that less than a 5°F temperature split variance was needed to detect low refrigerant charge. They operated the heat pump at constant indoor (80°F dry bulb and 67°F wet bulb) and outdoor (95°F) conditions while incrementally removing refrigerant. Following a 35 percent reduction in refrigerant charge (by weight), the EER was reduced to 91 percent of the value at full charge, and this corresponded to a 3°F temperature split variance. Given the expected 1 to 2°F increase in temperature split variance that can result from duct heat gains (as in Table 4), a 5°F maximum variance may be the best metric for detecting faults that reduce performance by up to ten percent.

The SCE and PG&E lab tests were conducted on two systems. Some variation in cooling capacity and temperature split will be expected based on equipment differences, for example compressor efficiency, size of the cooling coil, and other parameters. The key concern is that some equipment combinations might show false alarms (temperature split variance > 5°F) even though they are operating without faults.

To evaluate how changes in these parameters affect temperature split, data from expanded performance tables from five manufacturers of 14 SEER and 16 SEER systems were used to calculate temperature split variations. The data set included 21 different combinations of equipment, airflows, and indoor/outdoor temperature conditions that were randomly extracted from the tables.

Figure 11 plots the ratio of the capacity reported in the manufacturers expanded tables to the nominal capacity against the temperature split variance. The total capacity is as reported in the expanded tables, and nominal capacity is the nominal condensing unit tons times 12 kBtuh/ton. A negative variance indicates that the reported capacity is greater than that predicted by the temperature split tables and a positive variance indicates the opposite. The key value of this information is to show that too low a temperature split tolerance, for example less than a +3°F variance, could trigger a false alarm even for properly charged and commissioned systems. Adding 2°F to the maximum variance shown in Figure 11 to account for heat added by ducts will result in an overall temperature split variance of just under 5°F. Another observation is that the slope of the trendline shows a tendency for higher temperature split variations at lower equipment capacity ratios.

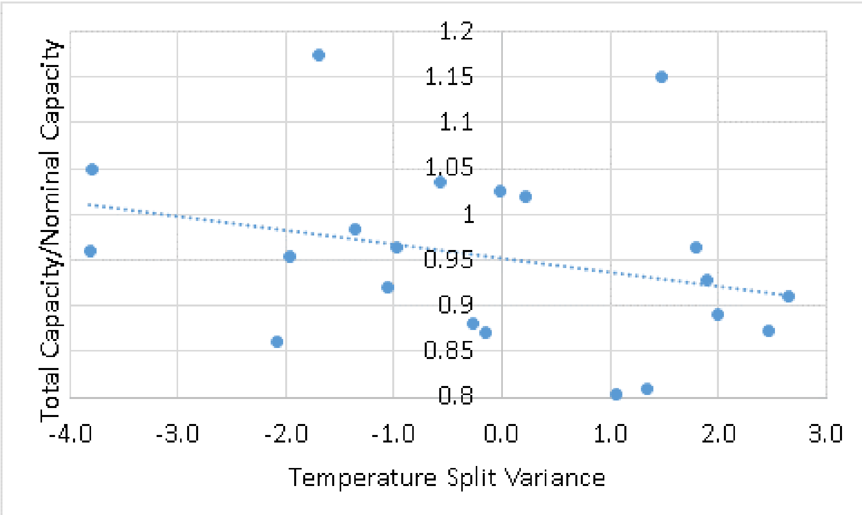


**Figure 11: Correlation of temperature split variance to capacity ratio using randomly selected data from manufacturers expanded performance tables**

Field trials of the temperature split method were completed on two systems in 2016, and at another six sites in 2017. In all cases the refrigerant charge had been verified in advance. Using only the supply temperature from the largest duct in each house, the temperature split variance was between ±2°F for both systems for the 2016 tests.

For the 2017 tests, supply air temperature was estimated by averaging the temperatures from the largest three supplies, typically one in the living area, one in the master bedroom, and one in either the living area or a second bedroom. Results from these tests are included in Table 6 and provide further evidence of the validity of temperature split tests as a verification method. None of the field trials resulted in a variance between measured and target temperature split of greater than 3°F.

**Table 6: Results of Temperature Split Tests from Six Central Valley Homes**

| | |
|---|---|
| System Size Range | 2.5 to 3.5 tons |
| Outdoor Temperature Range | 87°F to 105°F |
| Indoor Temperature Range | 66°F to 80°F |
| Temperature Split Variance | -2.9°F to +2.4°F |

The Statewide CASE Team believes this verification method has strong merit as a means of detecting faults that degrade performance by more than ten percent and will reduce the time required for verification. The temperature split method will be limited to split system air conditioners with ten feet or more of ducting (not applicable to mini-splits). Residential Appendices Section RA1.2.1 defines special charge procedures for outdoor temperatures below 55°F.[6] The RA1.2.1 procedure could not be used with temperature split, because the method requires measurement of outdoor temperature. Temperature split tables are available for as low as 50°F outdoor temperature. The proposed protocol will allow the

[6] Anecdotal information from contractors and raters suggests this winter setup procedure is not being used because it is not permitted by manufacturers.

HERS Rater to select the most appropriate verification approach given the conditions (refrigerant charge or temperature split).

## 2.3 Summary of Proposed Changes to Code Documents

The sections below provide a summary of how each Title 24, Part 6 documents will be modified by the proposed change. See Section 7 of this report for detailed proposed revisions to code language.

### *2.3.1 Standards Change Summary*

This proposal will modify the following sections of the Building Energy Efficiency Standards as shown below. See Section 7.1 of this report for the detailed proposed revisions to the code language.

***NOTE:*** *At the time of writing, the Energy Commission has indicated they will only consider the mandatory fan efficacy measure for the 2019 Title 24, Part 6 Standards. The FDD and temperature split measures are documented for potential use in future proceedings. Sections that pertain to the FDD and temperature split proposals, which may not be adopted during the 2019 code cycle, are highlighted in gray.*

**SECTION 150.0 – MANDATORY FEATURES AND DEVICES**

**Subsection150.0(m)13B & 13C:** The proposed requirements will replace the current 0.58 W/cfm with a lower value of 0.45 W/cfm, which aligns with the pending 2019 DOE standard (Code of Federal Regulations 10 CFR Part 430, Subpart B, Appendix AA (2016)). The same W/cfm value will be required on all residential central forced air systems, including furnaces and heat pumps.

**SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW-RISE RESIDENTIAL BUILDINGS**

**Subsection 150.1(c)7Ai(c):** The proposed requirements will add temperature split as an acceptable option to meet refrigerant charge verification requirements for new construction. The language will also be changed in Table 150.1-A and elsewhere as appropriate to indicate that alternative methods for refrigerant charge verification are acceptable as defined in the standards and the Reference Appendices.

**Subsection 150.1(c)10:** The proposed requirements will replace the current 0.58 W/cfm with 0.45 W/cfm to align with DOE's 2019 requirements.

**SECTION 150.2 – ENERGY EFFICIENCY STANDARDS FOR ADDITIONS AND ALTERATIONS TO EXISTING LOW-RISE RESIDENTIAL BUILDINGS**

**Subsection 150.2(b)1Fii(b):** The proposed requirements will change the language in this section to reference 150.1(c)7Aic instead of repeating the allowable methods for refrigerant charge verification. This simplifies the standards language.

### *2.3.2 Reference Appendices Change Summary*

This proposal will modify the following sections of the Standards Appendices as shown below. See Section 7.2 of this report for the detailed proposed revisions to the text of the reference appendices.

**JOINT APPENDICES**

**JA1 - Glossary:** The proposed requirements will add definitions for fault indicator display (FID), fault detection & diagnosis device (FDD), and temperature split.

**JA6 – HVAC System Fault Detection and Diagnostic Technology:** The proposed requirements will revise the specification for FIDs (JA6.1) and add a section to define FDD technology requirements.

**RESIDENTIAL APPENDICES**

**RA2 – Residential HERS Verification, Testing, and Documentation Procedures:** The proposed requirements add FDD as a verification measure. A measure reflecting this will be added to Table RA2-1 under the Air Conditioning Measures. Language revisions will be made to the FID and Improved Refrigerant Charge Measures in the table.

**RA3 – Residential Field Verification and Diagnostic Test Protocols:** The proposed requirements will add a description of the temperature split measurement protocol for verifying system performance as an alternative to refrigerant charge verification in RA3.2.

The proposed requirements will also add FDD as a verification measure. A new section "RA3.4.5 Fault Detection & Diagnosis (FDD) Device Verification Procedure" will be added, similar to RA3.4.2, which describes field verification protocols for FDD devices. Revisions may be necessary to Section RA3.4.2 as well.

### *2.3.3 Alternative Calculation Method (ACM) Reference Manual Change Summary*

This proposal will modify the following sections of the Alternative Calculation Method (ACM) Reference Manual as shown below. See Section 7.3 of this report for the detailed proposed revisions to the text of the ACM Reference Manual.

**SECTION 2 – THE PROPOSED DESIGN AND STANDARD DESIGN**

**Subsection 2.4.5:** The proposed requirements will add a compliance credit for qualifying FDD and FID devices. The credit will be applied as a factor on the system energy efficiency ratio, similar to the current refrigerant charge credit; however, the factor will differ for all three compliance credits. Also, the refrigerant charge credit will be extended to include temperature split as well as refrigerant charge and FID methods of performance verification. The software user will be allowed to indicate if refrigerant charge or an equivalent verification procedure will be conducted and if an FDD or FID device is to be installed. The *Proposed Design* language in this section will be revised to reflect this. This section and Appendix E will also define the compressor efficiency multiplier that is applied in the software when the compliance credit for an FDD or FID device is taken. This change does not modify the basis of the *Standard Design*, which currently applies a default "refrigerant charge factor" of 0.90 (Appendix E – 2.15.1).

The proposed requirements will reduce the current requirement for verified air handling unit fan efficacy from 0.58 W/cfm to 0.45 W/cfm. The *Standard Design* will be updated to reflect this new mandatory measure. Credit will still be allowed as it is currently for the *Proposed Design*.

### *2.3.4 Compliance Manual Change Summary*

The proposed code change will modify the following section of the Title 24, Part 6 Residential Compliance Manual:

- Subsection 4.3.2.4 – Fault Indicator Display
- Section 4.3.2.5 – Temperature Split *(new section)*
- Subsection 4.3.3.3 – Fault Detection & Diagnosis (FDD) & Fault Indicator Display (FID) *(new section)*

### *2.3.5 Compliance Documents Change Summary*

The proposed code change will modify the compliance documents listed below. Examples of the revised forms are presented in Section 7.5.

- CF1R – The 'Verified Refrigerant Charge' box will indicate if an FDD or FID device is included in the project, in addition to indicating if performance is verified using refrigerant charge testing or other methods (as prescriptively required in Climate Zones 2 and 8 through15).

The proposed code change adds to and modifies the compliance documents listed below. Examples of the revised documents are presented in Section 7.5.

- Check boxes will be added to CF2R-MCH-01 or other forms for installer verification of permanently installed FDD or FID devices.
- A new CF3R form (e.g., CF3R-25f) will be added to provide for HERS verification of performance using temperature split. This will be used in lieu of CF3R-25a-e.
- Check boxes will be added to CF3R-MCH-26 to provide for verification of permanently installed FID and FDD devices.

## 2.4 Regulatory Context

### *2.4.1 Existing Title 24, Part 6 Standards*

Fan efficacy and refrigerant charge are already included in Title 24, Part 6 Standards. FID devices are currently also included, although part of this proposal is to revise the specification to accommodate existing technologies. Temperature split verification and FDD devices are not included in the current code.

### *2.4.2 Relationship to Other Title 24 Requirements*

This measure does not impact any other Title 24 requirements. FDD devices are required under Title 24, Part 6 120.2(i), but only to identify economizer faults in nonresidential buildings.

### *2.4.3 Relationship to State or Federal Laws*

The proposed change in the fan efficacy requirement is intended to make efficiency improvements that are supported by the DOE's Furnace Fan Standards. The effective date of the ruling is September 2, 2014 and compliance with the prescribed standards is required on and after July 3, 2019 (DOE 2014).

There are no other federal regulatory requirements related to these measures.

### *2.4.4 Relationship to Industry Standards*

ASHRAE SPC 207 is developing test standards for FDD devices used in commercial applications; portions of the standard might be applied to devices used with smaller residential systems.

ANSI/ACCA 4 QM – 2013 - Maintenance of Residential HVAC Systems, Checklist 5.7(h) (ACCA 2013) includes a measurement of temperature difference across the evaporator coil and comparison to the original equipment manufacturer (OEM) tables. Only if these measured temperatures are outside of appropriate OEM ranges is additional diagnostic testing recommended. OEMs typically require measurement of sub-cooling (for TXV-equipped systems) and OEM tables for temperature split are uncommon. A temperature split measurement must be done correctly using procedures described in this report if it is to serve as a replacement for refrigerant charge verification.

## 2.5 Compliance and Enforcement

The Statewide CASE Team collected input during the stakeholder outreach process on what compliance and enforcement issues may be associated with these measures. This section summarizes how the proposed code change will modify the code compliance process. Appendix B presents a detailed description of how the proposed code changes could impact various market actors. 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 code change proposal will affect buildings that use either the prescriptive or the performance approaches to compliance. The key steps changes to the compliance process are summarized below:

- **Design Phase**: This measure will not have an impact on the existing design phase process.
- **Permit Application Phase**: This measure will not have an impact on the existing permit application phase process.
- **Construction Phase**: This measure will not have an impact on the existing construction phase process unless an FID or FDD device is to be installed in the field.
- **Inspection Phase**: This measure will have minimal impact on the existing inspection phase process. The fan watt draw verification process will remain the same, but will require a lower W/cfm value. If compliance credit is taken for installation of an FDD or FID device the HERS Rater will complete a new CF3R form to verify correct installation and operation. To meet refrigerant charge verification requirements the HERS Rater will have an additional alternative procedure, the temperature split and airflow method, and will be able to choose from the allowable options as defined in Title 24, Part 6. Using the TSA approach may result in less inspection time for the HERS verification and ultimately lower cost compared to refrigerant charge testing.

There are no identified challenges for compliance and enforcement of this measure. It will not add any additional burden on building officials.

If this code change proposal is adopted, the Statewide CASE Team recommends that information presented in this section, Section 3, and Appendix B be used to develop a plan that identifies a process to develop compliance documentation and how to minimize barriers to compliance.

# 3. MARKET ANALYSIS

The Statewide CASE Team performed a market analysis with the goals of identifying current technology availability, current product availability, and market trends. The Statewide CASE Team considered how the proposed standard may impact the market in general and individual market actors. The Statewide CASE Team gathered information about the incremental cost of complying with the proposed measure. 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 players who were invited to participate in utility-sponsored stakeholder meetings held on held on September 27, 2016 and March 16, 2017.

## 3.1 Market Structure

### *3.1.1 Potential Market Volume*

Per the 2009 Residential Appliance Saturation Survey (RASS), 84 percent of existing single family homes have air conditioning. If that trend continues, and given the estimated annual new home construction volume of 117,079 single family units, over 98,000 new homes will receive air conditioners. An unpublished draft report to the CPUC estimates there are 631,277 air conditioner replacements and 45,655 heat pump replacements annually, though only 8 to 29 percent of those are permitted. These volumes will impact energy savings for improved fan efficacy as well as the potential savings resulting from deployment of fault detection devices and from improved methods of performance verification.

DOE’s furnace fan efficiency requirements may compel manufacturers to provide electronically commutated motors (ECMs), also referred to as brushless permanent magnet (BPM) motors, to meet the new DOE Furnace Fan Efficacy Standard (Code of Federal Regulations 10 CFR Part 430, Subpart B,

Appendix AA (2016)). There are currently three manufacturers of ECMs serving the United States (U.S.) HVAC market: Emerson Climate Technologies, Regal Beloit (formerly GE), and Nidec Motor Corporation.

In addition to furnaces and heat pumps, products like mini-split heat pumps, heat recovery ventilators (HRVs) or energy recovery ventilators (ERVs), and whole house fans also use this technology. ECMs, particularly the lower cost constant torque type (Regal Beloit X13 for example), are increasingly used in medium and high efficiency systems and are favored by manufacturers and HVAC contractors, because of the increased number of speed settings they provide compared to PSC motors, which allows one furnace or air handler to flexibly accommodate a variety of airflow rates and match to a variety of condensing unit sizes. This attribute also reduces inventory requirements for distributors and wholesalers. The incremental cost for furnaces and heat pumps equipped with ECMs has been falling, and once federal standards become effective, the cost is expected to decline further.

As discussed in Appendix D, the Statewide CASE Team conducted laboratory testing of ten packaged residential furnaces for blower performance at different levels of external resistance. The purpose of these tests is to determine whether the ECM blower motors in a representative sample of non-weatherized furnaces can meet the proposed efficacy requirement of delivering at least 350 cfm/ton of air using 0.45 W/cfm or less, at reasonable levels of duct static pressure. A secondary purpose is to evaluate the federal Fan Efficiency Ratio (FER) requirement of each motor that takes effect on July 3, 2019. The Statewide CASE Team updated Appendix D in November 2017 with the results of the furnace fan performance testing.

### *3.1.2 FID and FDD Devices*

Proposed FID and FDD measures are the only Title 24 measures that intentionally address the persistence of energy savings and comfort. Currently there are no FID devices marketed that meet the JA6 specification. However, there are at least two manufacturers that provide products that meet the intent of the FID specification, that is, the ability to serve as a substitute for refrigerant charge verification. Any device that can either verify refrigerant charge, or better still, verify system capacity and efficiency at the time of installation, should qualify to meet the intent of the standards.

A review of the Western HVAC Performance Alliance (WHPA) FDD committee's FDD master list (WHPA 2017) shows there is currently just one manufacturer of an FDD device designed for residential applications that provides detailed diagnostic information while meeting the objective of low cost, which is Emerson's CoreSense. The WHPA list also includes Emerson's ComfortGuard and the Lennox iComfort.

The Emerson Climate Solutions CoreSense product can be installed either in the factory or as a replacement for the compressor contactor in new or existing air conditioners and heat pumps at a cost of less than $100. Their ComfortGuard product has additional features that may support its use as an FID, including the ability to communicate faults to the homeowner and an Emerson analyst who can relay the information to a service company. ComfortGuard also measures return/supply temperatures and inlet/outlet refrigerant coil temperatures and includes furnace diagnostics. Both Emerson products can only be applied to systems using Copeland scroll compressors.

Truveon manufacturers the only known permanently installed FDD system that can be used to instantaneously assess air conditioner performance. It continuously monitors system airflow, latent and sensible capacity, power, and EER, and communicates with the service contractor to provide notification of faults before the homeowner is aware of them. It is compatible with any residential or light commercial air conditioning product, and can be used by the installer and HERS inspector to verify performance at the time of installation.

Lennox's iComfort system monitors system operating conditions, displays information for the homeowner, and can also deliver information about faults to a service provider. Like the Truveon product and ComfortGuard, it does not meet the JA6 specification, but appears to accomplish the intent, which is to verify that installed systems are delivering their rated capacity and efficiency. The iComfort system requires a compatible Lennox thermostat, furnace or air handler, and outdoor unit.

### *3.1.3 Refrigerant Charge Verification*

In interviews with several HERS Raters, the Statewide CASE Team has learned that it is common practice for the installing contractor to arrange to charge systems coincident with the HERS verification so that the contractor is assured that the system will pass. This process may consume more of the HERS Raters' time to coordinate scheduling and to wait while the contractor adds refrigerant, but can save time for the contractor.

Information obtained from CalCERTS database spanning January 1, 2015 to April 30, 2016 show that, in climate zones where refrigerant charge verification is prescriptively required, this compliance credit was used for 27 percent of new single family and 19 percent of new multifamily systems. The use of this credit was highest in the hottest climates zones where it has a large impact on time dependent valuation (TDV) energy use. As previously noted, about 8 to 29 percent of replacement systems are permitted.

## 3.2 Technical Feasibility, Market Availability, and Current Practices

### *3.2.1 Ability of the Market to Supply the Measure*

For FDD devices, Emerson cites over 2.2 million systems that are equipped with CoreSense or ComfortAlert (a prior version with similar capabilities). They clearly have the capability to respond to the change in California market demand resulting from the proposed code change.

For FID devices, Truveon will probably have a slower market entry, partly as result of its higher cost, the need to establish a foothold in California, and production capacity that can ramp up in line with market demand. Lennox is one of the larger original equipment manufacturers of residential heating and air conditioning products in North America. It is unique in that it owns its wholesale distribution and should also have no difficulty meeting California market demand.

Furnaces and heat pumps with ECMs driven fans are already pervasive in the marketplace. Manufacturers should have no difficulty transitioning their production lines from PSC to ECM driven fans.

### *3.2.2 Product Availability*

The components that make up FDD and FID devices are the same that are used in HVAC controls. Emerson's products are widely distributed through dealers and can be installed at the factory or by HVAC contractors. There are currently no known competing low cost FDD products, but stimulating the California market by providing compliance credits may encourage interest from other producers. Truveon is a small and relatively new company, but is partnering with at least one large California residential HVAC contractor, who sees an opportunity to defray warranty costs and profit from increased service activity for out-of-warranty systems.

With three manufacturers serving the ECM market, there are no issues with availability of products that can meet the DOE fan efficacy requirements. Manufacturers participated in the DOE rulemaking process and would have moved to block the standard if product availability was a barrier.

### *3.2.3 Inspection Challenges*

The proposed inspection and verification process for FDD devices will in general consist of verifying their presence and confirming that the model numbers are listed with the Energy Commission. The listing for each product will include procedures for determining that they are active and functional, for example by creating a temporary fault and observing the fault code. The verification process for FID devices can be similar, but will be more critical where they are being used as a substitute for refrigerant charge verification. Since each product will have different verification procedures, and products can evolve over three years, it is not practical to define each product procedure in the Residential Appendices. Articulation of procedures specific to each product must be part of applications for Energy Commission approval, which will likely occur after the adoption of the 2019 Standards. Compared to the current specific requirements that are described in RA3.4.2, verification methods that are tailored to each device will improve the likelihood that manufacturers will take an interest in serving this market. To avoid the current non-participation of FID manufacturers, it will be important to strike a balance between minimal verification and extreme diligence. The primary challenge will be to ensure that the HERS Raters have access to the necessary information needed for verification.

Furnaces, heat pumps, and combined hydronic fan coil systems meeting the lower 0.45 W/cfm efficacy requirement will be no more difficult to verify than current systems that meet the 0.58 W/cfm target. DOE applies an external static pressure of from 0.65 to 0.70 inch w.c. to the test of furnaces (excluding cooling coils) to achieve efficacies ranging from about 0.20 to 0.28 inch w.c., so 0.45 W/cfm should not be difficult for installers to meet and HERS Raters to verify.

The intent of adding temperature split to current prescriptive air conditioner verification requirements is to simplify verification as well as to identify faults that refrigerant charge does not capture. The hoped-for impact will be an increase of the current low percentages of air conditioner verification in new construction, as well as an increase in the percentage of permitted systems in existing buildings. For equipment replacements, refrigerant charge and airflow verification (and watt draw) are only triggered if entire systems including ducts are replaced. Airflow measurement is a prerequisite of the temperature split method, so unless requirements in 150.2(b)1D are modified to require airflow measurement for component replacement (furnaces, coils, condensers), the time-saving value of temperature split will not materialize in these cases. There is no proposal to change these requirements.

### *3.2.4 Building/System Longevity, Occupant Health and Comfort, and Other Considerations*

The three measures proposed will contribute to prolonging the life of equipment while ensuring delivery of comfort and maintaining health. Higher airflow through cooling coils resulting from improved efficacy (which requires proper duct, filter, and grille sizing) will reduce the amount of latent cooling. The higher airflow will also improve air delivery to all rooms and break up thermal stratification, improving comfort.

The presence of fault detection systems will prolong equipment life by notifying owners or service providers of defects that may cause catastrophic failure, and by locking out condensing units when such conditions exist. Advanced warning of problems provided by FDDs and FIDs will facilitate more rapid diagnosis, which will also preserve comfort.

Application of the temperature split test when new systems are installed will serve to identify hidden faults that may affect system capacity, and therefore comfort.

## 3.3 Market Impacts and Economic Assessments

### *3.3.1 Impact on Builders*

It is expected that builders will not be impacted significantly by any one proposed code change or the collective effect of all of the proposed changes to Title 24, Part 6. Builders could be impacted for change in demand for new buildings and by construction costs. Demand for new buildings is driven more by factors, such as the overall health of the economy and population growth than the cost of construction. The cost of complying with Title 24, Part 6 requirements represents a very small portion of the total building value. Increasing the building cost by a fraction of a percent is not expected to have a significant impact on demand for new buildings or the builders' profits. As shown in Figure 12, California home prices have increased by about $300,000 in the last 20 years. In the six years between the peak of the market bubble in 2006 and the bottom of the crashing in 2012, the median home price dropped by $250,000. The current median price is about $500,000 per single family home. The combination of all single family measures for the 2016 Title 24, Part 6 Standards was around $2,700 (California Energy Commission 2015). This is a cost impact of approximately half of one percent of the home value. The cost impact is negligible as compared to other variables that impact the home value.

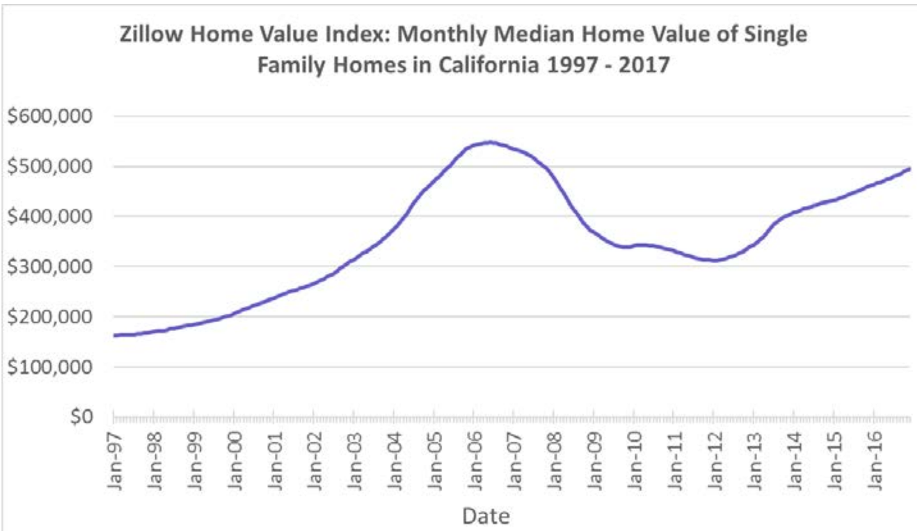


**Figure 12: California median home values 1997 to 2017**

Source: (Zilllow 2017)

Market actors will need to invest in training and education to ensure the workforce, including designers and those working in construction trades, know how to comply with the proposed requirements. Workforce training is not unique to the building industry, and is common in many fields associated with the production of goods and services. Costs associated with workforce training are typically accounted for in long-term financial planning and spread out across the unit price of many units as to avoid price spikes when changes in designs and/or processes are implemented.

### *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 Building code and model national building codes published by the International Code Council, the International Association of Plumbing and Mechanical Officials and ASHRAE 90.1) are typically updated on a three-year revision cycles. As discussed in Section 3.3.1, all market actors, including building designers and energy consultants, should (and do) plan for training and education that may be required to adjusting design practices to accommodate compliance with new building codes. As a whole, the measures the Statewide CASE Team is proposing for the 2019 code cycle aim to provide designers and energy consultants with opportunities to comply with code requirements in multiple ways, thereby providing flexibility in how requirements can be met.

Energy consultants are responsible for identifying what measures are needed to obtain compliance, both for mandatory requirements and to meet prescriptive or performance requirements, and for conveying this information to architects and builders (the design-build team). The addition of compliance options for FDD and FID devices and the simplification of air conditioner compliance will provide additional tools consultants can offer builders to improve performance at minimal cost.

Architects and engineers are responsible for developing building plans and specifications that detail mechanical equipment requirements and locations, and that ensure compliance with codes. For low-rise buildings, mechanical contractors typically have the responsibility for equipment sizing, duct design, and other installation requirements, whereas for larger multifamily projects this responsibility falls on the mechanical engineer. All design-build team participants will need to be informed of these code changes. Energy Code Ace will be useful in providing this needed guidance.

Refer to Appendix B for additional information on how the compliance process will impact building designers and energy consultants.

### *3.3.3 Impact on Occupational Safety and Health*

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

Building owners and occupants will benefit from lower energy bills. For example, the Energy Commission estimates that on average the 2016 Title 24, Part 6 Standards will increase the construction cost by $2,700 per single family home, but the standards will also result in a savings of $7,400 in energy and maintenance cost savings over 30 years. This is roughly equivalent to an $11 per month increase in payments for a 30-year mortgage and a monthly energy cost savings of $31 per month. Overall, the 2016 Title 24, Part 6 Standards are expected to save homeowners about $240 per year relative to homeowners whose single family homes are minimally compliant with the 2013 Title 24, Part 6 requirements (California Energy Commission 2015). As discussed in Section 3.4.1, when homeowners or building occupants save on energy bills, they tend to spend it elsewhere in the economy thereby creating jobs and economic growth for the California economy. Energy cost savings can be particularly beneficial to low income homeowners who typically spend a higher portion of their income on energy bills, often have trouble paying energy bills, and sometimes go without food or medical care to save money for energy bills (Association, National Energy Assistance Directors 2011).

Building owners and occupants will benefit from these measures that ensure that systems are operating near their optimal potential, and that intentionally address the persistence of performance, energy savings, and comfort. FDD and FID devices will reduce response time of service providers and shorten the time required for proper diagnosis, thereby lowering maintenance costs.

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

The code change proposal is expected to spur growth in the development of FDD and FID devices. If so, this will impact growth of businesses who manufacturer, distribute, and sell HVAC products.

When problems with equipment occur, it is not uncommon for the equipment to be replaced rather than diagnosed and repaired. This practice results in equipment being returned on warranty claims, which increases the cost to the installing contractors, distributors, and manufacturers. Emerson claims that CoreSense has cut the warranty rate by 48 percent. Resulting cost savings can translate to lower warranty margins and reduced costs to contractors.

### *3.3.6 Impact on Building Inspectors*

None of the proposed measures will impact the work scope of building inspectors.

### *3.3.7 Impact on Statewide Employment*

Section 3.4.1 discusses statewide job creation from the energy efficiency sector in general, including updates to Title 24, Part 6.

## 3.4 Economic Impacts

### *3.4.1 Creation or Elimination of Jobs*

In 2015, California's building energy efficiency industry employed more than 321,000 workers who worked at least part time or a fraction of their time on activities related to building efficiency. Employment in the building energy efficiency industry grew six percent between 2014 and 2015 while the overall statewide employment grew three percent (BW Research Partnership 2016). Lawrence Berkeley National Laboratory's report titled *Energy Efficiency Services Sector: Workforce Size and Expectations for Growth* (2010) provides details on the types of jobs in the energy efficiency sector that are likely to be supported by revisions to building codes (Goldman, et al. 2010).

Building codes that reduce energy consumption provide jobs through *direct employment*, *indirect employment*, and *induced employment*.[7] Title 24, Part 6 creates jobs in all three categories with a significant amount attributed to induced employment, which accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees (e.g., nonindustry jobs created such as teachers, grocery store clerks, and postal workers). A large portion of the induced jobs from energy efficiency are the jobs created by the energy cost savings due to the energy efficiency measures. For example, as mentioned in Section 3.3.4, the 2016 Standards are expected to save single family homeowners about $240 per year. Money saved from hundreds of thousands of homeowners over the entire life of the building will be reinvested in local businesses. Wei, Patadia, and Kammen (2010) estimate that energy efficiency creates 0.17 to 0.59 net job-years[8] per GWh saved. By comparison, they estimate that the coal and natural gas industries create 0.11 net job-years per GWh produced.

Using the mid-point for the energy efficiency range (0.38 net job-years per GWh saved) and estimates that this proposed code change will result in a statewide first-year savings of 8.7 GWh, this measure will result in approximately 3.3 jobs created during the first year. See Section 6.1 for statewide savings estimates.

Improved fan efficacy is expected to have a negligible impact on labor hours since there will be no difference in the time to install the higher performing indoor units, to provide duct systems that are properly sized, or to measure and verify airflow and fan power.

The time required to install and verify FDD/FID components will tend to increase labor hours, but service time will be reduced due to faster diagnosis and fewer warranty replacements. FDD/FDD devices create an opportunity for service contractors to increase their volume while improving customer satisfaction. Market success of this measure will result in some job growth, particularly for service technicians. There is also an opportunity for California businesses in the controls industry to add these devices to their product lines.

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[7] The definitions of direct, indirect, and induced jobs vary widely by study. Wei et al (2010) describes the definitions and usage of these categories as follows: "*Direct employment* includes those jobs created in the design, manufacturing, delivery, construction/installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration. *Indirect employment* refers to the ''supplier effect'' of upstream and downstream suppliers. For example, the task of installing wind turbines is a direct job, whereas manufacturing the steel that is used to build the wind turbine is an indirect job. *Induced employment* accounts for the expenditure-induced effects in the general economy due to the economic activity and spending of direct and indirect employees, e.g., non-industry jobs created, such as teachers, grocery store clerks, and postal workers."

[8] One job-year (or ''full-time equivalent'' (FTE) job) is full time employment for one person for a duration of one year.

For temperature split verification there will be trade-offs between time savings resulting from faster verification, an increase in time required for installers to correct identified faults, and a decrease in service calls. This report assumes no net increase in labor hours related to this measure.

### *3.4.2 Creation or Elimination of Businesses in California*

There are approximately 43,000 businesses that play a role in California's advanced energy economy (BW Research Partnership 2016). California's clean economy grew ten times more than the total state economy between 2002 and 2012 (20 percent compared to 2 percent). The energy efficiency industry, which is driven in part by recurrent updates to the building code, is the largest component of the core clean economy (Ettenson and Heavey 2015). Adopting cost-effective code changes for the 2019 Title 24, Part 6 code cycle will help maintain the energy efficiency industry.

Table 7 lists industries that will likely benefit from the proposed code change classified by their North American Industry Classification System (NAICS) Code. There are no known California manufacturers of HVAC or FDD products that will be affected by the proposed measures. There will be a slight impact on stocking distributors of furnaces and heat pumps equipped with ECMs or with FDD devices in that they will be handling equipment with new sets of model numbers, but there will be no change in the volume of equipment processed and a minor increase in the pricing, which will increase state sales tax revenue.

California businesses engaged in controls development could benefit by entering the market with FDD and FID devices. The currently available products are all produced out of state.

Implementation of the temperature split verification method will have no effect on California manufacturers or supply chains. Shortened time requirements for verification could apply a downward pressure on employment needs of HERS Rater's businesses, but this may be offset by higher rates of permitted installations that result from simplification of verification methods.

**Table 7: Industries Receiving Energy Efficiency Related Investment, by North American Industry Classification System (NAICS) Code**

| Industry | NAICS Code |
|---|---|
| Residential Building Construction | 2361 |
| Plumbing, Heating, and Air-Conditioning Contractors | 23822 |
| Ventilation, Heating, Air-Conditioning, & Commercial Refrigeration Equipment Manf. | 3334 |
| Computer and Peripheral Equipment Manufacturing | 3341 |
| Engineering Services | 541330 |
| Building Inspection Services | 541350 |
| Office Administrative Services | 5611 |

### *3.4.3 Competitive Advantages or Disadvantages for Businesses in California*

In 2014, California's electricity statewide costs were 1.7 percent of the state's gross domestic product (GPD) while electricity costs in the rest of the U.S. were 2.4 percent of GDP (Thornberg, Chong and Fowler 2016). As a result of spending a smaller portion of overall GDP on electricity relative to other states, Californians and California businesses save billions of dollars in energy costs per year relative to businesses located elsewhere. Money saved on energy costs can be otherwise invested, which provides California businesses with an advantage that will only be strengthened by the adoption of the proposed code changes that impact residential buildings.

### *3.4.4 Increase or Decrease of Investments in the State of California*

The proposed changes to the building code are not expected to impact investments in California on a macroeconomic scale, nor are they expected to affect investments by individual firms. The allocation of resources to produce goods in California is not expected to change as a result of this code change proposal.

### 3.4.5 Effects on the State General Fund, State Special Funds, and Local Governments

The proposed code changes are not expected to have a significant impact on the California's General Fund, any state special funds, or local government funds. Revenue to these funds comes from taxes levied. The most relevant taxes to consider for this proposed code change are: personal income taxes, corporation taxes, sales and use taxes, and property taxes. The proposed changes for the 2019 Title 24, Part 6 Standards are not expected to result in noteworthy changes to personal or corporate income, so the revenue from personal income taxes or corporate taxes is not expected to change. As discussed, reductions in energy expenditures are expected to increase discretionary income. State and local sales tax revenues may increase if homeowners spend their additional discretionary income on taxable items. Although logic indicates there may be changes to sales tax revenue, the impacts that are directly related to revisions to Title 24, Part 6 have not been quantified. Finally, revenue generated from property taxes is directly linked to the value of the property, which is usually linked to the purchase price of the property. The proposed changes will increase construction costs. As discussed in Section 3.3.1, however, there is no statistical evidence that Title 24, Part 6 drives construction costs or that construction costs have a significant impact on home price. Since compliance with Title 24, Part 6 does not have a clear impact on purchase price, it can follow that Title 24, Part 6 cannot be shown to impact revenues from property taxes.

#### 3.4.5.1 Cost of Enforcement

*Cost to the State*

State government already has budget for code development, education, and compliance enforcement. While state government will be allocating resources to update the Title 24, Part 6 Standards, including updating education and compliance materials and responding to questions about the revised requirements, these activities are already covered by existing state budgets. The costs to state government are small when compared to the overall costs savings and policy benefits associated with the code change proposals. The proposed residential code changes will have no impact on state buildings.

*Cost to Local Governments*

All revisions to Title 24, Part 6 will result in changes to compliance determinations. Local governments will need to train building department staff on the revised Title 24, Part 6 Standards. While this re-training is an expense to local governments, it is not a new cost associated with the 2019 code change cycle. The building code is updated on a triennial basis, and local governments plan and budget for retraining every time the code is updated. There are numerous resources available to local governments to support compliance training that can help mitigate the cost of retraining, including tools and resources provided by the IOU codes and standards program (such as Energy Code Ace). As noted in Section 2.5 and Appendix B, the Statewide CASE Team considered how the proposed code change might impact various market actors involved in the compliance and enforcement process and aimed to minimize negative impacts on local governments.

### 3.4.6 Impacts on Specific Persons

The proposed changes to Title 24, Part 6 are not expected to have a differential impact on any groups relative to the state population including migrant workers, commuters, or persons by age, race, or religion. Given construction costs are not well correlated with home prices, the proposed code changes are not expected to have an impact on financing costs for business or home-buyers. Some financial institutions have progressive policies that recognize the financial implications associated with occupants of energy efficient homes saving on energy bills and therefore have more discretionary income.[9]

Renters will typically benefit from lower energy bills if they pay energy bills directly. These savings should more than offset any capital costs passed-through from landlords. Renters who do not pay directly for energy costs may see some of the net savings depending on if and how landlords account for energy cost when determining rent prices.

On average, low-income families spend less on energy than higher income families, however lower income families spend a much larger portion of their incomes on energy (Association, National Energy Assistance Directors 2011). Thus, low-income families are likely to disproportionately benefit from Title 24, Part 6 Standards that reduce residential energy costs. The proposed changes are not known or expected to result in impacts on any specific persons.

# 4. ENERGY SAVINGS

## 4.1 Key Assumptions for Energy Savings Analysis

The energy savings analysis relied on the CBECC-Res software to estimate energy use for single family and multifamily prototype buildings. Energy use of the proposed code changes was evaluated and compared to a building that minimally complies with the 2016 Title 24, Part 6 Standards. All climates zones were evaluated.

## 4.2 Energy Savings Methodology

To assess the energy, demand, and energy cost impacts, the Statewide CASE Team compared current design practices to design practices that will comply with the proposed requirements. There is an existing Title 24, Part 6 Standard that covers the building system in question and applies to both new construction and alterations, so the existing conditions assume a building minimally complies with the 2016 Title 24, Part 6 Standards. The per-unit energy savings estimates do not take naturally occurring market adoption or compliance rates into account. Under the 2016 Title 24, Part 6 fan performance testing is mandatory for all ducted space conditioning systems in all climate zones and must be equal to or lower than 0.58 W/cfm.

Refrigerant charge verification is a prescriptive requirement for Climate Zones 2 and 8 through 15. FID devices are currently allowed as an alternative to refrigerant charge verification though none have been submitted for Energy Commission approval. Compliance option credits for the use of FID or FDD devices to improve persistence of air conditioner (and heat pump cooling) performance has not previously been provided for under Title 24, Part 6.

The proposed conditions are defined as the design conditions that will comply with the proposed code change. The only proposed mandatory or prescriptive code change is to lower the mandatory fan efficacy requirement to 0.45 W/cfm.

The Energy Commission provided guidance on the type of prototype buildings that must be modeled. Residential single family energy savings are calculated using two prototypes (a 2,100 square foot single story and a 2,700 square foot two story) available in CBECC-Res. Residential results are weighted 45 percent for the 2,100 square foot prototype and 55 percent for the 2,700 square foot prototype. Multifamily savings are calculated based on a multifamily prototype (an 8-unit, 6,960 square foot two

[9] See the U.S. Environmental Protection Agency's ENERGY STAR® website for examples: http://www.energystar.gov/index.cfm?fuseaction=new_homes_partners.showStateResults&s_code=CA.

story building) available in CBECC-Res. Details on the prototypes are available in the ACM Approval Manual (California Energy Commission 2015).

Table 8 presents the details of the prototype buildings used in the analysis.

**Table 8: Prototype Buildings Used for Energy, Demand, Cost, and Environmental Impacts Analysis**

| Prototype ID | Occupancy Type | Area (square feet) | Number of Stories | Statewide Area (million square feet) |
|---|---|---|---|---|
| New Construction Prototype 1 | Residential single family | 2,100 | 1 | 110.6 |
| New Construction Prototype 2 | Residential single family | 2,700 | 2 | 173.8 |
| New Construction Prototype 3 | Residential low-rise multifamily | 6,960 | 2 | 45.7 |

The energy savings from this measure varies by climate zone, thus the energy impacts and cost-effectiveness were evaluated by climate zone. Energy savings, energy cost savings, and peak demand reductions were calculated using a TDV methodology. The 2019 TDV multipliers were applied.

To estimate energy savings resulting from lowering the fan efficacy, the default value of 0.58 W/cfm was replaced with the proposed 0.45 W/cfm value and energy use impacts were compared.

CBECC-Res analysis was also completed to estimate energy savings resulting from the application of the FDD compliance option. The EER multipliers used in the CBECC-Res analysis are listed in Table 9. These values are estimates and are not supported by research, but are intended to stimulate the market so that there will be sufficient installations to facilitate a future evaluation of energy savings. The multipliers in bold are currently implemented in the 2016 ACM Reference Manual and compliance software; the multipliers that are not in bold are proposed.

**Table 9: EER Multipliers Used for Estimation of FDD/FID Energy Savings**

| Case | Climate Zone | EER Multiplier |
|---|---|---|
| No refrigerant charge or FDD, all climate zones [a] | All | 90% |
| No refrigerant charge, FDD installed [b] | 1, 3 - 7, 16 | 94% |
| Refrigerant charge, OR<br>Temperature split, OR<br>Weigh-in method (no FDD) [a] | 2, 8 - 15 | 96% |
| FID OR<br>FDD & refrigerant charge [b] | All | 98% |

a. Multipliers are included in the 2016 ACM Reference Manual and compliance software; included for reference, but not recommending a revision.

b. Multipliers are not included in the 2016 ACM Reference Manual and compliance software; Statewide CASE Team is proposing the multiplier listed in the table.

# Per-Unit Energy Impacts Results

All results tables in Sections 4 and 5 present results for a composite "average" dwelling unit across the total estimated building starts by climate zone based on the 2019 construction estimates for the three new construction prototypes. See Section 6.1 of this report for estimated statewide savings from additions and alterations. Energy impact for each prototype are presented in Appendix C.

Energy savings and peak demand reductions per unit for the fan efficacy measure for single family new construction are listed in Table 10 by climate zone. Per-unit TDV savings for the first year are expected to range from a high of 12,502 kBtu/year to a low of 243 kBtu per year. Site energy savings are predicted to range from a high of 305 kilowatt-hours per year (kWh/yr) and 0 therms/year to a low of 7 kWh/year and -5 therms/year. Demand reductions are expected to range between 0 kilowatts (kW) and 0.20 kW. More therms are used because there is less heat from the fan motor which is located in the airstream. In cooling mode, less motor heat has a positive savings impact.

Energy savings and peak demand reductions per unit for the fan efficacy measure for multifamily new construction are listed in Table 11 by climate zone. Per-unit TDV savings for the first year are expected to range from a high of 38,957 kBtu/year to a low of 1,458 kBtu per year. Site energy savings are predicted to range from a high of 932 kWh/yr and 0 therms/year to a low of 25 kWh/year and -8 therms/year. Demand reductions are expected to range between 0 and 0.63 kW.

**Table 10: First-Year Energy Impacts Per Dwelling Unit for Reduced Fan Efficacy Mandatory Measure (Single Family) – New Construction**

| Climate Zone | Electricity Savings (kWh/yr) | Peak Electricity Demand Reductions (kW) | Natural Gas Savings (therms/yr) | TDV Energy Savings (TDV kBtu/yr) |
|---|---|---|---|---|
| 1 | 74 | 0.00 | -3 | 1,385 |
| 2 | 55 | 0.01 | -2 | 1,287 |
| 3 | 32 | 0.00 | -1 | 549 |
| 4 | 42 | 0.02 | -2 | 1,496 |
| 5 | 26 | 0.00 | -1 | 419 |
| 6 | 21 | 0.02 | -1 | 876 |
| 7 | 7 | 0.00 | 0 | 243 |
| 8 | 19 | 0.04 | 0 | 1,783 |
| 9 | 41 | 0.09 | -1 | 3,443 |
| 10 | 53 | 0.10 | -1 | 3,914 |
| 11 | 132 | 0.11 | -2 | 5,761 |
| 12 | 65 | 0.07 | -2 | 3,669 |
| 13 | 138 | 0.15 | -2 | 7,251 |
| 14 | 129 | 0.12 | -2 | 5,790 |
| 15 | 305 | 0.20 | 0 | 12,502 |
| 16 | 113 | 0.02 | -5 | 2,468 |

**Table 11: First-Year Energy Impacts Per 8-Unit Building for Reduced Fan Efficacy Mandatory Measure (Multifamily) – New Construction**

| Climate Zone | Electricity Savings (kWh/yr) | Peak Electricity Demand Reductions (kW) | Natural Gas Savings (therms/yr) | TDV Energy Savings (TDV kBtu/yr) |
|---|---|---|---|---|
| 1 | 97 | 0.00 | -4 | 1,759 |
| 2 | 99 | 0.10 | -3 | 5,278 |
| 3 | 38 | 0.04 | -1 | 1,609 |
| 4 | 88 | 0.17 | -2 | 6,484 |
| 5 | 29 | 0.03 | -1 | 1,458 |
| 6 | 51 | 0.11 | 0 | 4,625 |
| 7 | 25 | 0.12 | 0 | 3,569 |
| 8 | 129 | 0.24 | 0 | 9,299 |
| 9 | 187 | 0.32 | 0 | 12,516 |
| 10 | 224 | 0.31 | -1 | 12,969 |
| 11 | 405 | 0.42 | -3 | 20,810 |
| 12 | 208 | 0.32 | -3 | 13,220 |
| 13 | 427 | 0.42 | -2 | 21,062 |
| 14 | 385 | 0.39 | -3 | 18,599 |
| 15 | 932 | 0.63 | 0 | 38,957 |
| 16 | 242 | 0.14 | -8 | 6,685 |

# 5. Lifecycle Cost and Cost-Effectiveness

## 5.1 Energy Cost Savings Methodology

Time Dependent Valuation (TDV) energy is a normalized format for comparing electricity and natural gas cost savings that takes into account the cost of electricity and natural gas consumed during each hour of the year. The TDV values are based on long term discounted costs (30 years for all residential measures and nonresidential envelope measures and 15 years for all other nonresidential measures). In this case, the period of analysis used is 30 years. The TDV cost impacts are presented in 2020 present value (PV) dollars. The TDV energy estimates are based on present-valued cost savings but are normalized in terms of "TDV kBtu." Peak demand reductions are presented in peak power reductions (kW). The Energy Commission derived the 2020 TDV values that were used in the analyses for this report (Energy + Environmental Economics 2016).

The 2016 CBECC-Res software was used to quantify energy savings and peak electricity demand reductions resulting from the proposed measure. Simulations were conducted using the 2016.2.0+ (864) version of the software and the 2016.2.0+ (626) version of the BEM Compliance Manager with minor updates described below to the *Standard Design* to better reflect existing conditions.

1. The Energy Commission expects to adopt the ANSI/ASHRAE Standard 62.2-2016 (ASHRAE 2016), which requires higher mechanical ventilation airflows in most cases than the 2010 version of the standard, which is the current requirement in California. The proposed 2016 airflows have been included in both the Standard Design and the Proposed Design for the single family analysis. The change in ventilation requirements for multifamily are not as significant, and the approach for calculating airflows for dwelling units is still being determined, therefore these ventilation rates were not adjusted for the multifamily prototype.

2. The 2016 California Plumbing Code (CA BSC 2016b) includes requirements that all hot water pipes be insulated. The next release of CBECC-Res is expected to incorporate this requirement, but the current release does not. The Standard Design and the Proposed Design have been adjusted to include pipe insulation for both the single family and the multifamily analyses.
3. The next release of CBECC-Res is expected to automatically degrade all R-19 insulation to an installed value of R-18, due to compression of the batt in a 2x6 wall cavity. This affects the Standard Design because the 0.051 U-value requirement is modeled as a wall with R-19 cavity insulation. This was applied to the Standard Design for the single family and multifamily analyses.

The proposed code change related to fan efficacy only applies to additions and alterations where full replacement of the HVAC system (e.g., furnace, indoor coil, and ducting) is to be completed.

## 5.2 Energy Cost Savings Results

Per-unit energy cost savings for newly constructed buildings over the 30-year period of analysis are presented in Table 12 and Table 13. Per-unit savings over the 30-year period of analysis are expected to range from a high of $2,163 to a low of $42 for single family, and a high of $6,740 to a low of $252 for multifamily, depending upon the climate zone. The TDV methodology allows peak electricity savings to be valued more than electricity savings during non-peak periods.

**Table 12: TDV Energy Cost Savings Over 30-Year Period of Analysis for Fan Efficacy Mandatory Measure – Per Dwelling Unit (Single Family) – New Construction**

| Climate Zone | 30-Year TDV Electricity Cost Savings (2020 PV $) | 30-Year TDV Natural Gas Cost Savings (2020 PV $) | Total 30-Year TDV Energy Cost Savings (2020 PV $) |
|---|---|---|---|
| 1 | $360 | -$120 | $240 |
| 2 | $311 | -$88 | $223 |
| 3 | $146 | -$51 | $95 |
| 4 | $323 | -$64 | $259 |
| 5 | $116 | -$44 | $73 |
| 6 | $183 | -$32 | $151 |
| 7 | $52 | -$10 | $42 |
| 8 | $327 | -$18 | $309 |
| 9 | $621 | -$25 | $596 |
| 10 | $706 | -$29 | $677 |
| 11 | $1,076 | -$79 | $997 |
| 12 | $718 | -$84 | $635 |
| 13 | $1,327 | -$72 | $1,254 |
| 14 | $1,078 | -$76 | $1,002 |
| 15 | $2,170 | -$7 | $2,163 |
| 16 | $602 | -$175 | $427 |

**Table 13: TDV Energy Cost Savings Over 30-Year Period of Analysis for Fan Efficacy Mandatory Measure – Per 8-Unit Building (Multifamily) – New Construction**

| Climate Zone | 30-Year TDV Electricity Cost Savings (2020 PV $) | 30-Year TDV Natural Gas Cost Savings (2020 PV $) | Total 30-Year TDV Energy Cost Savings (2020 PV $) |
|---|---|---|---|
| 1 | $461 | -$157 | $304 |
| 2 | $1,026 | -$113 | $913 |
| 3 | $330 | -$52 | $278 |
| 4 | $1,191 | -$70 | $1,122 |
| 5 | $287 | -$35 | $252 |
| 6 | $817 | -$17 | $800 |
| 7 | $626 | -$9 | $617 |
| 8 | $1,609 | $0 | $1,609 |
| 9 | $2,183 | -$17 | $2,165 |
| 10 | $2,261 | -$17 | $2,244 |
| 11 | $3,713 | -$113 | $3,600 |
| 12 | $2,400 | -$113 | $2,287 |
| 13 | $3,739 | -$96 | $3,644 |
| 14 | $3,322 | -$104 | $3,218 |
| 15 | $6,740 | $0 | $6,740 |
| 16 | $1,461 | -$304 | $1,157 |

## 5.3 Incremental First Cost

For the fan efficacy mandatory measure there is no incremental cost for furnaces since the DOE standard will require fan motors that meet the proposed requirement. Incremental first costs for heat pump air handlers were estimated from interviews with HVAC contractors, cost databases (such as NREL's BEopt software), and internet research. These costs are as follows and assume a 30 percent overhead and profit markup:

- $186 for single family (both the 2,100 $ft^2$ and 2,700 $ft^2$ prototypes)
- $1,082 for multifamily (8-unit 6,960 $ft^2$ prototype)

It was assumed that 75 percent of all new houses will use gas furnaces. The 2009 RASS (KEMA 2010) lists a 78 percent saturation of gas primary heating in California homes. The lower 75 percent value was used based on the consideration that some gas heating uses combined hydronic technology, and recent discussions about a shift toward heat pump heating. The incremental costs applied an average cost of $0 for 75 percent of the building stock, and the costs listed above for the remaining 25 percent.

This analysis applied current incremental costs. Only minor changes are anticipated between the current time and when the code will take effect, and the changes would only affect heat pumps.

In accordance with Energy Commission guidance, design costs are not included in the incremental first cost.

## 5.4 Lifetime Incremental Maintenance Costs

The useful life of the proposed fan efficacy measure is less than the expected lifetime of the home. However, by the time the HVAC equipment has reached the end of its lifetime it's expected that ECM driven fans will be standard in air handlers and fan coils, not just furnaces. Therefore, there is a net increase in the maintenance cost for the proposed measures relative to existing conditions.

## 5.5 Lifecycle Cost-Effectiveness

The fan efficacy measure is proposed as a mandatory requirement. As such, a lifecycle cost analysis is required to demonstrate that the measure is cost-effective over the 30-year period of analysis.

The Energy Commission establishes the procedures for calculating lifecycle cost-effectiveness. The Statewide CASE Team collaborated with Energy Commission staff to confirm that the methodology in this report is consistent with their guidelines, including which costs were included in the analysis. In this case, incremental first cost and incremental maintenance costs over the 30-year period of analysis were included. The TDV energy cost savings from electricity savings and increases in natural gas use were also included in the evaluation.

Design costs were not included nor were the incremental cost of code compliance verification.

According to the Energy Commission's definitions, a measure is cost-effective if the benefit-to-cost (B/C) ratio is greater than 1.0. The B/C ratio is calculated by dividing the total present lifecycle cost benefits by the present value of the total incremental costs. Results of the per-unit lifecycle cost-effectiveness analyses are presented in Table 14 for single family and Table 15 for multifamily.

The proposed measure demonstrates a favorable B/C ratio over the 30-year period of analysis relative to the existing conditions in all climate zones with the exception of Climate Zone 7 for the single-family case and climate zone 5 for the multifamily case. It is recommended that the 0.45 W/cfm be a statewide mandatory feature because it continues the "all Climate Zone approach" and both Climate Zone 5 and 7 are within in a few dollars of achieving a B/C ratio of 1.0.

The refrigerant charge and fault detection compliance options are neither mandatory nor prescriptive requirements. A lifecycle cost analysis is not necessary because the measure is not proposed to be part of the baseline level of stringency.

The fan efficacy measure applies to new construction as well as additions and alterations, but only where complete systems are being replaced (e.g., furnace, indoor coil, and ducting). The measure has the same cost-effectiveness for equipment replacements as for new home installations.

**Table 14: Lifecycle Cost-effectiveness Summary for Fan Efficacy Mandatory Measure Per Dwelling Unit (Single Family) – New Construction**

| Climate Zone | Benefits TDV Energy Cost Savings + Other PV Savings[a] (2020 PV $) | Costs Total Incremental PV Costs[b] (2020 PV $) | Benefit-to-Cost Ratio |
|---|---|---|---|
| 1 | $240 | $46 | 5.15 |
| 2 | $223 | $46 | 4.79 |
| 3 | $95 | $46 | 2.04 |
| 4 | $259 | $46 | 5.57 |
| 5 | $73 | $46 | 1.56 |
| 6 | $151 | $46 | 3.26 |
| 7 | $42 | $46 | 0.90 |
| 8 | $309 | $46 | 6.64 |
| 9 | $596 | $46 | 12.82 |
| 10 | $677 | $46 | 14.57 |
| 11 | $997 | $46 | 21.45 |
| 12 | $635 | $46 | 13.66 |
| 13 | $1,254 | $46 | 26.99 |
| 14 | $1,002 | $46 | 21.55 |
| 15 | $2,163 | $46 | 46.54 |
| 16 | $427 | $46 | 9.19 |

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if PV of proposed maintenance costs is less than the PV of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) three percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes PV of maintenance incremental cost if PV of proposed maintenance costs is greater than the PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the B/C ratio is infinite.

**Table 15: Lifecycle Cost-effectiveness Summary for Fan Efficacy Mandatory Measure Per Dwelling Unit (Multifamily) – New Construction**

| Climate Zone | Benefits TDV Energy Cost Savings + Other PV Savings[a] (2020 PV $) | Costs Total Incremental PV Costs[b] (2020 PV $) | Benefit-to-Cost Ratio |
|---|---|---|---|
| 1 | $304 | $270 | 1.13 |
| 2 | $913 | $270 | 3.38 |
| 3 | $278 | $270 | 1.03 |
| 4 | $1,122 | $270 | 4.15 |
| 5 | $252 | $270 | 0.93 |
| 6 | $800 | $270 | 2.96 |
| 7 | $617 | $270 | 2.28 |
| 8 | $1,609 | $270 | 5.95 |
| 9 | $2,165 | $270 | 8.01 |
| 10 | $2,244 | $270 | 8.30 |
| 11 | $3,600 | $270 | 13.31 |
| 12 | $2,287 | $270 | 8.46 |
| 13 | $3,644 | $270 | 13.48 |
| 14 | $3,218 | $270 | 11.90 |
| 15 | $6,740 | $270 | 24.92 |
| 16 | $1,157 | $270 | 4.28 |

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes present value maintenance cost savings if PV of proposed maintenance costs is less than the PV of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) three percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes PV of maintenance incremental cost if PV of proposed maintenance costs is greater than the PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the B/C ratio is infinite.

# 6. First-Year Statewide Impacts

## 6.1 Statewide Energy Savings and Lifecycle Energy Cost Savings

The Statewide CASE Team calculated the first-year statewide savings for the fan efficacy measure for new construction by multiplying the per-unit savings, which are presented in Section a, by the statewide new construction forecast for 2020, which is presented in more detail in Appendix A.

The approach to estimate energy savings for additions and alterations is based on the methodology applied in the impact analysis report for the 2016 Title 24, Part 6 updates (NORESCO and Nittler 2015). In the impact analysis, the projected savings for new construction buildings were increased by 43 percent to account for additions and alterations. The 43 percent factor was based on the dollars spent on new construction compared to that spent on additions and alterations according to 2011 data from the Construction Industry Research Board. For this proposal, the 43 percent is revised to reflect that the proposed code change only applies to a portion of statewide additions and alterations; specifically, those which install an entirely new or complete replacement space-conditioning system (as defined in Section 150.2(b)1C). In the absence of better information, it is assumed that additions represent half of the total dollars spent on additions and alterations. It is also assumed that 10 percent of additions and 10 percent of alterations include a complete HVAC system replacement and therefore would be subject to the new proposed mandatory requirements. Taking all of this into account the projected savings for new construction have been increased by 2.2 percent[10] to account for additions and 2.2 percent to account for alterations. Note that this approach does not consider differences in incremental costs or energy savings for additions relative to new construction.

The first-year energy impacts represent the first-year annual savings from all buildings that were completed in 2020. Even though the proposed measure is not cost effective in climate zone 7 for single family and climate zone 5 for multifamily, it is cost effective on a statewide basis. Therefore, the proposal is that this mandatory measure apply statewide. The lifecycle energy cost savings represents the energy cost savings over the entire 30-year analysis period. The statewide savings estimates do not take naturally occurring market adoption or compliance rates into account.

Results from new construction by climate zone are presented in Table 16. Table 17 presents first-year statewide savings from new construction, additions and alterations. Given data regarding the new construction forecast and expected alterations in 2020, the Statewide CASE Team estimates that the proposed code change will reduce annual statewide electricity use by 8.7 GWh with an associated demand reduction of 9.6 MW. Natural gas use is expected to be increased by 0.2 million therms. The energy savings for buildings constructed in 2020 are associated with a PV energy cost savings of approximately PV$78 million in (discounted) energy costs over the 30- year period of analysis.

**Table 16: Statewide Energy and Energy Cost Impacts – New Construction**

| Climate Zone | Statewide Construction in 2020 (units) | First-Year[a] Electricity Savings (GWh) | First-Year Peak Electrical Demand Reduction (MW) | First-Year Natural Gas Savings (million therms) | Lifecycle[b] PV Energy Cost Savings (PV $ million) |
|---|---|---|---|---|---|
| 1 | 576 | 0.036 | 0.000 | -0.002 | $0 |
| 2 | 4,672 | 0.189 | 0.048 | -0.008 | $1 |
| 3 | 19,928 | 0.402 | 0.043 | -0.017 | $1 |
| 4 | 11,283 | 0.351 | 0.233 | -0.014 | $2 |
| 5 | 2,191 | 0.040 | 0.003 | -0.002 | $0 |
| 6 | 9,829 | 0.157 | 0.160 | -0.005 | $1 |
| 7 | 9,718 | 0.056 | 0.083 | -0.002 | $1 |
| 8 | 15,100 | 0.276 | 0.594 | -0.005 | $4 |
| 9 | 22,642 | 0.743 | 1.555 | -0.009 | $10 |
| 10 | 22,590 | 1.092 | 2.035 | -0.015 | $14 |
| 11 | 4,695 | 0.560 | 0.485 | -0.009 | $4 |
| 12 | 25,438 | 1.426 | 1.609 | -0.044 | $14 |
| 13 | 8,409 | 1.047 | 1.146 | -0.014 | $9 |
| 14 | 4,240 | 0.486 | 0.447 | -0.007 | $4 |
| 15 | 3,657 | 1.029 | 0.685 | 0.000 | $7 |
| 16 | 4,629 | 0.403 | 0.078 | -0.016 | $2 |
| **TOTAL** | **169,597** | **8.3** | **9.2** | **-0.2** | **$75** |

a. First-year savings from all buildings completed statewide in 2020.

b. Energy cost savings from all buildings completed statewide in 2020 accrued during 30-year period of analysis.

[10] 43 percent of additions and alterations x 50 percent (assumes half additions, half alterations) x 10 percent complete system change-outs = 2.2 percent

**Table 17: Statewide Energy and Energy Cost Impacts – New Construction, Alterations and Additions**

| Construction Type | First-Year[a] Electricity Savings (GWh) | First-Year Peak Electrical Demand Reduction (MW) | First -Year Natural Gas Savings (million therms) | Lifecycle[b] PV Energy Cost Savings (PV $ million) |
|---|---|---|---|---|
| New Construction | 8.3 | 9.2 | -0.2 | $75 |
| Additions | 0.2 | 0.2 | 0 | $1.6 |
| Alterations | 0.2 | 0.2 | 0 | $1.6 |
| **TOTAL** | **8.7** | **9.6** | **-0.2** | **$78** |

a. First-year savings from all buildings completed statewide in 2020.

b. Energy cost savings from all buildings completed statewide in 2020 accrued during 30-year period

## 6.2 Statewide Water Use Impacts

The proposed code change will not result in water savings.

## 6.3 Statewide Material Impacts

The proposed code change will not result in impacts to toxic materials or materials which require significant energy inputs.

## 6.4 Other Non-Energy Impacts

Non-energy benefits of the proposed measures include improved occupancy comfort and increased property valuation.

# 7. Proposed Revisions to Code Language

The proposed changes to the standards, Reference Appendices, and the ACM Reference Manuals are provided below. Changes to the 2016 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

***NOTE:*** *At the time of writing, the Energy Commission has indicated they will only consider the mandatory fan efficacy measure for the 2019 Title 24, Part 6 Standards. The FDD and temperature split measures are documented for potential use in future proceedings. Code language changes related to the FDD and temperature split measures are documented for potential use in future rulemakings, and are highlighted in gray.*

## 7.1 Standards

### SECTION 150.0 – MANDATORY FEATURES AND DEVICES

Subsection 150.0(m)13:

B. **Single Zone Central Forced Air Systems.** Demonstrate, in every control mode, airflow greater than or equal to 350 cfm per ton of nominal cooling capacity through the return grilles, and an air handling unit fan efficacy less than or equal to ~~0.58~~0.45 W/cfm as confirmed by field verification and diagnostic testing in accordance with the procedures given in Reference Residential Appendix RA3.3

C. **Zonally Controlled Central Forced Air Systems**. Zonally controlled central forced air cooling systems shall be capable of simultaneously delivering, in every zonal control mode, an airflow from the dwelling, through the air handler fan and delivered to the dwelling, of greater than or equal to 350 cfm per ton of nominal cooling capacity, and operating at an air handling unit fan efficacy of less than or equal to ~~0.58~~0.45 W/cfm as confirmed by field verification and diagnostic testing in accordance with the applicable procedures specified in Reference Residential Appendix RA3.3.

## SECTION 150.1 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES FOR LOW-RISE RESIDENTIAL BUILDINGS

Subsection 150.1(b)4(B)iv: Fault Detection Devices and Fault Indicator Displays. When performance compliance provides for installation of fault detection devices that meet the qualifications in Reference Joint Appendix JA6.3, the installed devices shall be field verified in accordance with the procedures specified in Reference Residential Appendix RA3.4.2 and RA 3.4.5. Fault indicator displays (FIDs) that are installed to meet 150.1(c)7Ai3 are also eligible for compliance credit as described in the Residential ACM Manual Section 2.4.5.

Subsection 150.1(c)7:

A. **Refrigerant Charge.** When refrigerant charge verification or ~~fault indicator display~~ equivalent is shown as required by TABLE 150.1-A, the system shall comply with either150.1(c)7Ai or 150.1(c)7Aii:

i. Air-cooled air conditioners and air-source heat pumps, including but not limited to ducted split systems, ducted packaged systems, and mini-split systems, shall comply with subsections a, b and c, unless the system is of a type that cannot be verified using the specified procedures:

a. Have measurement access holes (MAH) installed according to the specifications in the Reference Residential Appendix Section RA3.2.2.3; and

b. System airflow rate greater than or equal to 350 cfm per ton shall be demonstrated by the installer and be verified by the HERS Rater as specified by Reference Residential Appendix Section RA3.3 or an approved alternative procedure as specified by RA1; and

c. The installer shall charge the system according to manufacturer's specifications. Refrigerant charge shall be verified according to one of the following options, as applicable:

1. The installer and rater shall perform the standard charge procedure as specified by Reference Residential Appendix Section RA3.2.2 or an approved alternative procedure as specified by RA1; or
2. The installer shall perform the standard charge procedure as specified by Reference Residential Appendix Section RA3.2.2. The HERS Rater shall perform the standard charge procedure, or the temperature split procedure as specified by RA3.2.4; or
3. The system shall be equipped with a fault indicator display (FID) device that meets the specifications of Reference Joint Appendix JA6. The installer shall verify the refrigerant charge and FID device in accordance with the procedures in Reference Residential Appendix Section RA3.4.2. The HERS Rater shall verify FID device in accordance with the procedures in Section RA3.4.2; or
4. The installer shall perform the weigh-in charging procedure as specified by Reference Residential Appendix Section RA3.2.3.1 provided the system is of a type that can be verified using the RA3.2.2 standard charge verification procedure and RA3.3 airflow rate verification procedure or approved alternatives in RA1. The HERS Rater shall verify the charge using RA3.2.2 and the airflow rate using RA3.3 or approved alternatives in RA1.

Subsection 150.1(c)10:

**Central Fan Integrated Ventilation Systems.** Central forced air system fans used to provide outside air, shall have an air handling unit fan efficacy less than or equal to ~~0.58~~0.45 W/cfm as confirmed through field verification and diagnostic testing in accordance with all applicable procedures specified in Reference Residential Appendix

RA3.3. Central Fan Integrated Ventilation Systems shall be certified to the Energy Commission as Intermittent Ventilation Systems as specified in Reference Residential Appendix RA3.7.4.2.

TABLE 150.1-A: COMPONENT PACKAGE-A STANDARD BUILDING DESIGN

| | | | Climate Zone | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| **HVAC SYSTEM** | **Space Cooling** | **Refrigerant Charge Verification or <u>Equivalent Fault</u> ~~Indicator Display~~** | NR | REQ | NR | NR | NR | NR | NR | REQ | REQ | REQ | REQ | REQ | REQ | REQ | REQ | NR |

## SECTION 150.2 – ENERGY EFFICIENCY STANDARDS FOR ADDITIONS AND ALTERATIONS TO EXISTING LOW-RISE RESIDENTIAL BUILDINGS

Subsection 150.2(b)1F:

ii. In Climate Zones 2, 8, 9, 10, 11, 12, 13, 14, and 15, air-cooled air conditioners and air-source heat pumps, including but not limited to ducted split systems, ducted package systems, and mini-split systems, shall comply with subsections a and b, unless the system is of a type that cannot be verified using the specified procedures. Systems that cannot comply with the requirements of 150.2(b)1Fii shall comply with 150.2(b)1Fiii.

a. Minimum system airflow rate greater than or equal to 300 cfm per ton shall be demonstrated by the installer and be verified by the HERS Rater according to the procedures specified in Reference Residential Appendix Section RA3.3 or an approved alternative procedure as specified in Section RA1; and

b. <u>The system shall comply with the requirements of 150.1(c)7Aic.</u> ~~The installer shall charge the system according to manufacturer's specifications. Refrigerant charge shall be verified according to one of the following options, as applicable.~~

~~1. The installer and rater shall perform the standard charge verification procedure as specified in Reference Residential Appendix Section RA3.2.2, or an approved alternative procedure as specified in Section RA1; or~~

~~2. The system shall be equipped with a fault indicator display (FID) device that meets the specifications of Reference Joint Appendix JA6. The installer shall verify the refrigerant charge and FID device in accordance with the procedures in Reference Residential Appendix Section RA3.4.2. The HERS Rater shall verify FID device in accordance with the procedures in Section RA3.4.2; or~~

~~3. The installer shall perform the weigh-in charging procedure as specified by Reference Residential Appendix Section RA3.2.3.1 provided the system is of a type that can be verified using the RA3.2.2 standard charge verification procedure and RA3.3 airflow rate verification procedure or approved alternatives in RA1. The HERS Rater shall verify the charge using RA3.2.2 and RA3.3 or approved alternatives in RA1.~~

**EXCEPTION 1 to Section 150.2(b)1Fiia**: Systems unable to comply with the minimum 300 cfm per ton airflow rate requirement shall demonstrate compliance using the procedures in Section RA3.3.3.1.5; and the system's thermostat shall conform to the specifications in Reference Joint Appendix JA5.

**EXCEPTION 2 to Section 150.2(b)1Fiia:** The Executive Director may approve alternate airflow and fan efficacy requirements for small duct high velocity systems.

**EXCEPTION 3 to Section 150.2(b)<u>1</u>Fiia:** Entirely new or complete replacement space conditioning systems, as specified by Section 150.2(b)1C, without zoning dampers may comply with the minimum airflow rate by meeting the applicable requirements in TABLE150.0-B or 150.0-C as confirmed by field verification and diagnostic testing in accordance with the procedures in Reference Residential Appendix Section RA3.1.4.4 and RA3.1.4.5. The design clean-filter pressure drop requirements of Section 150.0(m)12C for the system air filter device(s) shall conform to the requirements given in TABLES 150.0-B and 150.0-C.

**EXCEPTION 1 to Section 150.2(b)1Fiib:** When the outdoor temperature is less than 55°F and the installer utilizes the weigh-in charging procedure in Reference Residential Appendix Section RA3.2.3.1 to verify the refrigerant charge ~~demonstrate compliance~~, the installer may elect to utilize the HERS Rater verification procedure in Reference Residential Appendix Section RA3.2.3.2. If the HERS Rater verification procedure in Section RA3.2.3.2 is used for compliance, the system's thermostat shall conform to the specifications in Reference Joint Appendix JA5. Ducted systems shall comply with the minimum system airflow rate requirements in Section 150.2(b)1Fiia.

~~**EXCEPTION to Section 150.2(b)1Fii**: Entirely new or complete replacement packaged systems for which the manufacturer has verified correct system refrigerant charge prior to shipment from the factory are not required to have refrigerant charge confirmed through field verification and diagnostic testing. The installer of these packaged systems shall certify on the Certificate of Installation that the packaged system was pre-charged at the factory and has not been altered in a way that would affect the charge. Ducted systems shall comply with minimum system airflow rate requirement in Section 150.2(b)1Fiia, provided that the system is of a type that can be verified using the procedure specified in RA3.3 or an approved alternative in RA1~~. [Covered by Exception to Section 150.2(b)1Fiii]

## 7.2 Reference Appendices

**JOINT APPENDICES**

[The following definitions are to be developed following Energy Commission acceptance of the proposed measures.]

**Appendix JA1 - Glossary**

**Fault Detection and Diagnosis** is a …

**Fault Indicator Display** is a …

**Temperature Split** is a …

**Appendix JA6 – HVAC System Fault Detection and Diagnostic Technology**

***JA6.1 Fault Indicator Display (FID)***

***JA6.6.1 Purpose and Scope***

Fault indicator display technologies other than what is described in Section JA6.1 are possible, and when vapor compression air conditioner and heat pump system faults ~~refrigerant charge, metering device and airflow operating performance~~ can be reliably determined and displayed by methods and instrumentation other than those specifically defined in Section JA6.1 such alternative fault indicator display technologies may be allowed for Fault Indicator Display compliance credit if the manufacturer of the product requests approval from the Energy Commission.

***JA6.3 Fault Detection & Diagnosis (FDD)***

[New language will be developed that provides the general specifications for devices meeting requirements for FDD devices.]

**RESIDENTIAL APPENDICES**

**Appendix RA2 – Residential HERS Verification, Testing, and Documentation Procedures**

***RA2.2 – Measures That Require Field Verification and Diagnostic Testing***

Table RA2-1: *Summary of Measures Requiring Field Verification and Diagnostic Testing*

| Measure Title | Description | Procedure(s) |
|---|---|---|
| | Air Conditioning Measures | |
| Improved Refrigerant Charge or performance verification, and Fault Detection | Component Packages require in some climate zones that air-cooled air conditioners and air-source heat pumps be diagnostically tested in the field to verify that the system has the correct refrigerant charge or meets capacity criteria as determined using a temperature split test. For the performance method, the Proposed Design is modeled with less efficiency if diagnostic testing and field verification is not performed. The system must also meet the prerequisite minimum System Airflow requirement. | RA3.3<br>RA3.2<br>RA1.2 |
| Installation of Fault Indicator Display | ~~Component Packages specify that a~~A Fault Indicator Display can be installed as an alternative to refrigerant charge testing. When using the performance approach to compliance t~~T~~he existence of a Fault Indicator Display has a higher ~~the same~~ calculated benefit than ~~as~~ refrigerant charge testing. Field verification is required. | RA3.4.2 |
| Installation of Fault Detection & Diagnosis | Compliance credit can be taken for installation of a Fault Detection and Diagnosis device. Field verification is required. | RA3.4.5 |

**Appendix RA3 – Residential Field Verification and Diagnostic Test Protocols**

***RA3.2 – Field Verification and Diagnostic Testing of Refrigerant Charge for Air Conditioners and Heat Pumps***

RA3.2.4 Temperature Split Verification Procedure

[Language to be added after procedure is adopted and finalized]

***RA3.4 – Field Verification of Installed HVAC System Components and Devices***

RA3.4.2 Fault Indicator Display (FID) Verification Procedure

The FID verification procedure shall consist of visual inspection to confirm that the FID is installed on the system, and that the manufacturer has certified to the Energy Commission that the FID model meets the applicable requirements of Reference Joint Appendix JA6. In addition, the space conditioning system shall comply with the procedures specified in Sections RA3.4.2.1, or RA3.4.2.2, or RA3.4.2.3~~.~~, or other verification procedure submitted to the Energy Commission for devices that are approved, but that do not meet the specifications provided in JA6.

RA3.4.5 Fault Detection and Diagnosis (FDD) Device Verification Procedure

[Language to be added following the development of the FDD specification.]

## 7.3 ACM Reference Manual

**Subsection 2.4.5:** The proposed requirements will add a compliance credit for qualifying FDD and FID devices. The credit will be applied as a factor on the system energy efficiency ratio, similar to the current refrigerant charge credit (see Table 3). The refrigerant charge credit will also be extended to include temperature split as well as refrigerant charge and FID methods of performance verification. The software user will be allowed to indicate if refrigerant charge or an equivalent verification procedure will be conducted, and if an FDD or FID device is to be installed. The *Proposed Design* language in this section will be revised to reflect this. This section and Appendix E will also define the compressor efficiency multiplier that is applied in the software when the compliance credit for an FDD or FID device is taken. This change does not modify the basis of the *Standard Design*, which currently applies a default "refrigerant charge factor" of 0.90 (Appendix E – 2.15.1).

The proposed requirements will reduce the current requirement for verified air handling unit fan efficacy from 0.58 W/cfm to 0.45 W/cfm. The *Standard Design* will be updated to reflect this new mandatory measure. Credit will still be allowed as it is currently for the *Proposed Design*.

## 7.4 Compliance Manuals

The proposed code change will modify the following section of the Title 24, Part 6 Residential Compliance Manual:

- Subsection 4.3.2.4 – Fault Indicator Display
- Section 4.3.2.5 – Temperature Split *(new section)*
- Subsection 4.3.3.3 – Fault Detection & Diagnosis (FDD) & Fault Indicator Display (FID) *(new section)*

Language will be developed upon Energy Commission approval of proposed changes.

## 7.5 Compliance Documents

The proposed code change will modify the compliance documents listed below. Examples of the revised forms are presented in Section 7.5.

- CF1R – The 'Verified Refrigerant Charge' box will indicate if an FDD or FID device is included in the project, in addition to indicating if performance is verified using refrigerant charge testing or other methods (as prescriptively required in Climate Zones 2, and 8 through 15).

The proposed code change adds to and modifies the compliance documents listed below. Examples of the revised forms are presented in Section 7.5.

- Check boxes will be added to CF2R-MCH-01or other forms for installer verification of permanently installed FDD or FID devices.
- A new CF3R form (e.g., CF3R-25f) will be added to provide for HERS verification of performance using temperature split. This will be used in lieu of CF3R-25a-e.
- Check boxes will be added to CF3R-MCH-26 to provide for verification of permanently installed FID and FDD devices.

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# Appendix A: STATEWIDE SAVINGS METHODOLOGY

The projected residential new construction forecast that will be impacted by the proposed code change in 2020 is presented in Table 18.

The Statewide CASE Team estimated statewide impacts for the first year that new single family and multifamily buildings comply with the 2019 Title 24, Part 6 Standards by multiplying per-unit savings estimates by statewide construction forecasts that the California Energy Commission Demand Analysis Office provided. The construction forecast from the Energy Commission presented annual new construction estimates for single family and multifamily dwelling units by forecast climate zones (FCZ). The Statewide CASE Team converted estimates from FCZ, which are not used for Title 24, Part 6, to building standards climate zones (BSCZ) using a conversion factors that the Energy Commission provided. The conversion factors, which are presented in Table 19, represent the percentage of dwelling units in a FCZ that are also in a BSCZ. For example, looking at the first column of conversion factors in Table 19, 22.5 percent of the homes in FCZ 1 are also in BSCZ 1 and 0.1 percent of homes in FCZ 4 are in BSCZ 1. To convert from FCZ to BSCZ, the total forecasted construction in each FCZ was multiplied by the conversion factors for BSCZ 1, then all homes from all FCZs that are found to be in BSCZ 1 are summed to arrive at the total construction in BSCZ 1. This process was repeated for every climate zone. See Table 20 for an example calculation to convert from FCZ to BSCZ. In this example, BSCZ 1 is made up of homes from FCZs 1, 4, and 14.

After converting the statewide construction forecast to BSCZs, the Statewide CASE Team made assumptions about the percentage of buildings in each climate zone that will be impacted by the proposed code change. Assumptions are presented in Table 18.

**Table 18: Projected New Residential Construction Completed in 2020 by Climate Zone[a]**

| Building Climate Zone | Single Family Buildings | | | | | Multifamily Dwelling Units[b] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total Buildings Completed in 2020 | Percent of Total Construction in Climate Zone | Percent of New Buildings Impacted by Proposal | Buildings Impacted by Proposal | Percent of Total Impacted by Proposal in Climate Zone | Total Dwelling Units Completed in 2020 | Percent of Total Construction in Climate Zone | Percent of New Dwelling Units Impacted by Proposal | Dwelling Units Impacted by Proposal | Percent of Total Impacted by Proposal in Climate Zone |
| 1 | 465 | 0.4% | 100% | 465 | 0.4% | 111 | 0.2% | 100% | 111 | 0.2% |
| 2 | 3,090 | 2.6% | 100% | 3,090 | 2.6% | 1,582 | 3.0% | 100% | 1,582 | 3.0% |
| 3 | 11,496 | 9.8% | 100% | 11,496 | 9.8% | 8,432 | 16.1% | 100% | 8,432 | 16.1% |
| 4 | 7,435 | 6.4% | 100% | 7,435 | 6.4% | 3,848 | 7.3% | 100% | 3,848 | 7.3% |
| 5 | 1,444 | 1.2% | 100% | 1,444 | 1.2% | 747 | 1.4% | 100% | 747 | 1.4% |
| 6 | 6,450 | 5.5% | 100% | 6,450 | 5.5% | 3,379 | 6.4% | 100% | 3,379 | 6.4% |
| 7 | 5,779 | 4.9% | 100% | 5,779 | 4.9% | 3,939 | 7.5% | 100% | 3,939 | 7.5% |
| 8 | 9,948 | 8.5% | 100% | 9,948 | 8.5% | 5,153 | 9.8% | 100% | 5,153 | 9.8% |
| 9 | 12,293 | 10.5% | 100% | 12,293 | 10.5% | 10,350 | 19.7% | 100% | 10,350 | 19.7% |
| 10 | 18,399 | 15.7% | 100% | 18,399 | 15.7% | 4,191 | 8.0% | 100% | 4,191 | 8.0% |
| 11 | 3,947 | 3.4% | 100% | 3,947 | 3.4% | 747 | 1.4% | 100% | 747 | 1.4% |
| 12 | 19,414 | 16.6% | 100% | 19,414 | 16.6% | 6,023 | 11.5% | 100% | 6,023 | 11.5% |
| 13 | 7,034 | 6.0% | 100% | 7,034 | 6.0% | 1,375 | 2.6% | 100% | 1,375 | 2.6% |
| 14 | 3,484 | 3.0% | 100% | 3,484 | 3.0% | 756 | 1.4% | 100% | 756 | 1.4% |
| 15 | 3,203 | 2.7% | 100% | 3,203 | 2.7% | 454 | 0.9% | 100% | 454 | 0.9% |
| 16 | 3,188 | 2.7% | 100% | 3,188 | 2.7% | 1,441 | 2.7% | 100% | 1,441 | 2.7% |
| **Total** | **117,069** | **100%** | | **117,069** | **100%** | **52,528** | **100%** | | **52,528** | **100%** |

Source: Energy Commission Demand Analysis Office

a. Statewide savings estimates do not include savings from mobile homes.

b. Includes high-rise and low-rise multifamily construction.

**Table 19: Translation from Forecast Climate Zone (FCZ) to Building Standards Climate Zone (BSCZ)**

| | | Building Standards Climate Zone (BSCZ) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **Total** |
| **Forecast Climate Zone (FCZ)** | **1** | 22.5% | 20.6% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 9.8% | 33.1% | 0.2% | 0.0% | 0.0% | 13.8% | 100% |
| | **2** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 22.0% | 75.7% | 0.0% | 0.0% | 0.0% | 2.3% | 100% |
| | **3** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 20.9% | 22.8% | 54.5% | 0.0% | 0.0% | 1.8% | 100% |
| | **4** | 0.1% | 13.7% | 8.4% | 46.0% | 8.9% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 22.8% | 0.0% | 0.0% | 0.0% | 0.0% | 100% |
| | **5** | 0.0% | 4.2% | 89.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 6.6% | 0.0% | 0.0% | 0.0% | 0.0% | 100% |
| | **6** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100% |
| | **7** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 75.8% | 7.1% | 0.0% | 17.1% | 100% |
| | **8** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 40.1% | 0.0% | 50.8% | 8.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.5% | 100% |
| | **9** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 6.4% | 0.0% | 26.9% | 54.8% | 0.0% | 0.0% | 0.0% | 0.0% | 6.1% | 0.0% | 5.8% | 100% |
| | **10** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 74.9% | 0.0% | 0.0% | 0.0% | 12.3% | 7.9% | 4.9% | 100% |
| | **11** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 27.0% | 0.0% | 30.6% | 42.4% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100% |
| | **12** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 0.0% | 4.2% | 95.6% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 100% |
| | **13** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 69.6% | 0.0% | 0.0% | 28.8% | 0.0% | 0.0% | 0.0% | 1.6% | 0.1% | 0.0% | 100% |
| | **14** | 2.9% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 97.1% | 100% |
| | **15** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 99.9% | 0.0% | 100% |
| | **16** | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100% |

**Table 20: Converting from Forecast Climate Zone (FCZ) to Building Standards Climate Zone (BSCZ) – Example Calculation**

| Climate Zone | Total Statewide Single Family Homes by FCZ [A] | Conversion Factor FCZ to BSCZ 1 [B] | Single Family Homes in BSCZ 1 [C] = A x B |
|---|---|---|---|
| 1 | 1,898 | 22.5% | 427 |
| 2 | 8,148 | 0.0% | 0 |
| 3 | 9,396 | 0.0% | 0 |
| 4 | 16,153 | 0.1% | 23 |
| 5 | 11,385 | 0.0% | 0 |
| 6 | 6,040 | 0.0% | 0 |
| 7 | 2,520 | 0.0% | 0 |
| 8 | 12,132 | 0.0% | 0 |
| 9 | 9,045 | 0.0% | 0 |
| 10 | 21,372 | 0.0% | 0 |
| 11 | 3,741 | 0.0% | 0 |
| 12 | 4,746 | 0.0% | 0 |
| 13 | 8,309 | 0.0% | 0 |
| 14 | 518 | 2.9% | 15 |
| 15 | 1,509 | 0.0% | 0 |
| 16 | 159 | 0.0% | 0 |
| **Total** | **117,069** | | **465** |

# Appendix B: DISCUSSION OF IMPACTS OF COMPLIANCE PROCESS ON MARKET ACTORS

This section discusses how the recommended compliance process, which is described in Section 2.5, could impact various market actors. The Statewide CASE Team asked stakeholders for feedback on how the measure will impact various market actors during public stakeholder meetings that were held on September 27, 2016, and March 16, 2017 - Statewide CASE Team (Statewide Utility Codes and Standards Team. 2016).

Targeted outreach was conducted with HVAC contractors, HERS verifiers, energy consultants, and manufacturers of FDD and FID systems. A summary of feedback received during stakeholder meetings and other outreach efforts is provided below.

Fan Efficacy

Results from a polling question asked during the second stakeholder meeting showed that 65 percent of the respondents concurred that lowering the fan efficacy to 0.45 W/cfm was reasonable, with 24 percent opposing the idea and 12 percent that didn't have an opinion. Key responses from stakeholders on this topic from both meetings are listed below:

- Could be challenging to align federal fan efficacy requirements with real in-the-field operating conditions.
- In a recent IAPMO-UMC code change proposal, flex ducts longer than five feet would be prohibited, which could have an impact on fan efficacy.
- Should the values in Tables 150.0-B and 150.0-C, which provide an alternative to airflow measurement under 150.1(c)7Aib be made more realistic?
- Why not harmonize with DOE's furnace fan requirements and get rid of the fan efficacy requirement all together?
- Has the combined impact of the proposed 0.45 W/cfm fan efficiency and MERV 13 air filter requirement been analyzed?
- Any consideration for changing from cfm/ton to cfm/Btu? Few if any 5-ton units produce 60,000 Btu's.

FDD/FID

Results from a polling question asked during the second stakeholder meeting showed that 65 percent believe that FDD devices will improve persistence of air conditioner performance, 24 percent believe there will be no improvement, and 12 percent were undecided. If devices are shown to be cost-effective, 60 percent said they would specify them, 10 percent said they would not, and 30 percent did not know. The following feedback was received during the first stakeholder meeting:

- Energy savings are unknown, and their determination would require a large, long-term field. study that is unlikely to occur within the 2019 Title 24, Part 6 Standards cycle.
- Will likely require certification process (Title 20 or Title 24)
- I would not specify a 3rd party FDD device because manufacturer intended conditions vary significantly even within their own product lines.

Temperature Split Test

The temperature split alternative to refrigerant charge was not presented at the first stakeholder meeting. Results from a polling question asked during the second stakeholder meeting showed that 38 percent of those that responded think temperature split should be allowed as an alternative to refrigerant charge verification, with 62 percent indicating the need for further verification of the method. Forty-two percent thought HERS Raters would prefer the method and another 42 percent thought it might be preferable after raters had a chance to try it out.

Other

- The duct leakage to outside test requires a blower door, which most HERS Raters do not carry
- Ensuring ducts are tight is more important than testing leakage to outside because air should be delivered to its intended destination no matter where ducts are located
- Will the HERS data registry support the proposed code changes?

Table 21 identifies the market actors who will play a role in complying with the proposed change, the tasks for which they will 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.

Changes in the proposed compliance process will have minimal impact on the workflow of market actors. The decrease in fan efficacy will not change any of the standard procedures used by all market actors. Factory-installed FDD/FID devices will require no additional attention other than proper training in their use, and field installed devices will require contractor training. They are expected to reduce warranty replacements, which benefits installers and everyone up the supply chain. The temperature split method is being proposed to simplify and speed verification of air conditioning systems. It may adversely impact installers in the short-term when faults are detected, but will save time in call-backs.

Some additional coordination and training may be required between contractors and suppliers of FDD/FID equipment and HERS inspectors. The typical practice wherein the HERS Rater works with the HVAC installer to complete the refrigerant charge will change if temperature split verification is used, particularly if faults are detected. Other than training, there is no anticipated additional need for resources. New documentation methods will be required for FDD/FID and temperature split verification.

**Table 21: 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 Work Flow | Opportunities to Minimize Negative Impacts of Compliance Requirement |
|---|---|---|---|---|
| Title 24 Consultant | • Identify relevant requirements and/or compliance path.<br>• Perform required calculations to confirm compliance.<br>• Coordinate design with other team members (HVAC & builder).<br>• Complete compliance document for permit application. | • Completes compliance documents.<br>• Ensures builder is aware of all requirements | • Advance coordination with HVAC contractor and HERS Rater required.<br>• Verification of Energy Commission approval of devices needed. | • Modeling software will need to be updated to include proposed values.<br>• Software training updates. |
| Builder | • Coordinates with mechanical contractor to ensure that HVAC equipment listed in CF-1R is the same as what will be installed (as typical).<br>• Coordinates with mechanical contractor to ensure that FDD is provided if listed in CF-1R. | • Correct equipment is installed<br>• If FDD device installed, agreement with mechanical contractor obtained as to how it will be monitored.<br>• HERS costs reduced. | Will need to verify installed devices match plans and are certified. | Document compliance on forms in a way easily compared to plans. |
| HVAC Contractor | • Installs HVAC equipment in accordance with specs (with or without FDD).<br>• Coordinates with builder and/or homeowner on operation and use of the FDD/FID device.<br>• Coordinates with HERS Rater on verification method. | • Correct equipment installed and properly commissioned.<br>• Measured fan efficacy meets or exceeds requirements.<br>• Temperature split verification method carried out properly. | • HVAC contractor must commission FDD/FID device.<br>• Upon failure of temperature split test, contractor will be required to diagnose fault (or coordinate with rater to complete alternate verification method).<br>• Fast diagnosis if FDD/FID installed. | • Contractor training on FDD/FID devices and temperature split verification methods. |
| Manufacturer/ Distributor | • Arranges for certification of FDD/FID devices.<br>• Trains HVAC contractor on installation and operation.<br>• Provides certified products. | • FDD devices supplied meet project requirements.<br>• FDD/FID monitoring approach coordinated with contractor. | • Delays in FDD/FID product certification or other approvals.<br>• Delays in product delivery. | FDD/FID manufacturer s informed of standards provisions and certification milestones. |

| Market Actor | Task(s) in Compliance Process | Objective(s) in Completing Compliance Tasks | How Proposed Code Change Could Impact Work Flow | Opportunities to Minimize Negative Impacts of Compliance Requirement |
|---|---|---|---|---|
| Plans Examiner | Verifies that CF1R documents are consistent with plans and meet compliance criteria. | Quick review and processing. | Lack of knowledge of new equipment and procedures. | Training on new code provisions. |
| Building Inspector | • Verifies that required HERS inspections are listed on CF1R have CF2R and CF3R paperwork.<br>• Verifies CF documents are signed off.<br>• Signs certificate of occupancy. | Quick review and processing. | Lack of knowledge of new equipment and procedures. | Training on new code provisions. |
| HERS Rater | • Reviews CF2R's.<br>• Completes air conditioner verifications.<br>• Communicates failures to builder and/or HVAC contractor.<br>• Completes registry entries. | • Reduced time in the field.<br>• Early and quick identification of performance-related problems. | • Reduced time in the field.<br>• Early and quick identification of performance-related problems. | • Training on correct implementation of temperature split verification method.<br>• Training on FDD/FID verification methods for approved devices. |

# Appendix C: ENERGY AND COST-EFFECTIVENESS RESULTS BY PROTOTYPE

This section presents energy and cost-effectiveness results for the individual prototypes.

## Per-Unit Energy Impacts Results

Energy savings and peak demand reductions for the three residential new construction prototypes are presented in Table 22, Table 23, and Table 24.

**Table 22: First-Year Energy Impacts Per Dwelling Unit – 2,100 Square Foot Single Family Prototype**

| Climate Zone | Electricity Savings (kWh/yr) | Peak Electricity Demand Reductions (kW) | Natural Gas Savings (therms/yr) | TDV Energy Savings (TDV kBtu/yr) |
|---|---|---|---|---|
| 1 | 77 | 0.00 | -3 | 1,456 |
| 2 | 52 | 0.00 | -2 | 1,001 |
| 3 | 33 | 0.00 | -1 | 576 |
| 4 | 38 | 0.01 | -2 | 1,107 |
| 5 | 28 | 0.00 | -1 | 455 |
| 6 | 19 | 0.01 | -1 | 682 |
| 7 | 7 | 0.00 | 0 | 182 |
| 8 | 15 | 0.03 | 0 | 1,365 |
| 9 | 33 | 0.08 | -1 | 2,669 |
| 10 | 43 | 0.08 | -1 | 3,049 |
| 11 | 114 | 0.10 | -2 | 5,081 |
| 12 | 56 | 0.05 | -2 | 2,957 |
| 13 | 119 | 0.13 | -2 | 6,127 |
| 14 | 111 | 0.10 | -2 | 4,762 |
| 15 | 273 | 0.17 | 0 | 10,814 |
| 16 | 102 | 0.01 | -4 | 2,123 |

**Table 23: First-Year Energy Impacts Per Dwelling Unit – 2,700 Square Foot Single Family Prototype**

| Climate Zone | Electricity Savings (kWh/yr) | Peak Electricity Demand Reductions (kW) | Natural Gas Savings (therms/yr) | TDV Energy Savings (TDV kBtu/yr) |
|---|---|---|---|---|
| 1 | 72 | 0.00 | -3 | 1,326 |
| 2 | 57 | 0.01 | -2 | 1,521 |
| 3 | 31 | 0.00 | -1 | 526 |
| 4 | 44 | 0.03 | -2 | 1,813 |
| 5 | 24 | 0.00 | -1 | 390 |
| 6 | 23 | 0.02 | -1 | 1,034 |
| 7 | 8 | 0.01 | 0 | 293 |
| 8 | 23 | 0.05 | 0 | 2,126 |
| 9 | 47 | 0.11 | -1 | 4,075 |
| 10 | 61 | 0.12 | -1 | 4,622 |
| 11 | 147 | 0.12 | -2 | 6,318 |
| 12 | 73 | 0.09 | -2 | 4,251 |
| 13 | 155 | 0.17 | -2 | 8,171 |
| 14 | 144 | 0.13 | -2 | 6,630 |
| 15 | 331 | 0.23 | 0 | 13,884 |
| 16 | 122 | 0.02 | -5 | 2,749 |

**Table 24: First-Year Energy Impacts Per 8-Unit Building – Multifamily Prototype**

| Climate Zone | Electricity Savings (kWh/yr) | Peak Electricity Demand Reductions (kW) | Natural Gas Savings (therms/yr) | TDV Energy Savings (TDV kBtu/yr) |
|---|---|---|---|---|
| 1 | 97 | 0.00 | -4 | 1,759 |
| 2 | 99 | 0.10 | -3 | 5,278 |
| 3 | 38 | 0.04 | -1 | 1,609 |
| 4 | 88 | 0.17 | -2 | 6,484 |
| 5 | 29 | 0.03 | -1 | 1,458 |
| 6 | 51 | 0.11 | 0 | 4,625 |
| 7 | 25 | 0.12 | 0 | 3,569 |
| 8 | 129 | 0.24 | 0 | 9,299 |
| 9 | 187 | 0.32 | 0 | 12,516 |
| 10 | 224 | 0.31 | -1 | 12,969 |
| 11 | 405 | 0.42 | -3 | 20,810 |
| 12 | 208 | 0.32 | -3 | 13,220 |
| 13 | 427 | 0.42 | -2 | 21,062 |
| 14 | 385 | 0.39 | -3 | 18,599 |
| 15 | 932 | 0.63 | 0 | 38,957 |
| 16 | 242 | 0.14 | -8 | 6,685 |

## Energy Cost Savings Results

Per-unit energy cost savings over the 30-year period of analysis are presented in Table 25, Table 26, and Table 27 for the three residential new construction prototypes.

**Table 25: TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – 2,100 Square Foot Single Family Prototype**

| Climate Zone | 30-Year TDV Electricity Cost Savings (2020 PV $) | 30-Year TDV Natural Gas Cost Savings (2020 PV $) | Total 30-Year TDV Energy Cost Savings (2020 PV $) |
|---|---|---|---|
| 1 | $375 | -$123 | $252 |
| 2 | $257 | -$84 | $173 |
| 3 | $152 | -$52 | $100 |
| 4 | $252 | -$60 | $192 |
| 5 | $126 | -$47 | $79 |
| 6 | $147 | -$29 | $118 |
| 7 | $42 | -$10 | $31 |
| 8 | $252 | -$16 | $236 |
| 9 | $485 | -$24 | $462 |
| 10 | $554 | -$26 | $527 |
| 11 | $952 | -$73 | $879 |
| 12 | $590 | -$79 | $512 |
| 13 | $1,126 | -$66 | $1,060 |
| 14 | $895 | -$71 | $824 |
| 15 | $1,873 | -$3 | $1,871 |
| 16 | $530 | -$163 | $367 |

**Table 26: TDV Energy Cost Savings Over 30-Year Period of Analysis – Per Dwelling Unit – 2,700 Square Foot Single Family Prototype**

| Climate Zone | 30-Year TDV Electricity Cost Savings (2020 PV $) | 30-Year TDV Natural Gas Cost Savings (2020 PV $) | Total 30-Year TDV Energy Cost Savings (2020 PV $) |
|---|---|---|---|
| 1 | $347 | -$118 | $229 |
| 2 | $354 | -$91 | $263 |
| 3 | $142 | -$51 | $91 |
| 4 | $381 | -$67 | $314 |
| 5 | $108 | -$40 | $67 |
| 6 | $213 | -$34 | $179 |
| 7 | $61 | -$10 | $51 |
| 8 | $388 | -$20 | $368 |
| 9 | $732 | -$27 | $705 |
| 10 | $830 | -$30 | $800 |
| 11 | $1,177 | -$84 | $1,093 |
| 12 | $823 | -$88 | $735 |
| 13 | $1,491 | -$78 | $1,413 |
| 14 | $1,228 | -$81 | $1,147 |
| 15 | $2,412 | -$10 | $2,402 |
| 16 | $661 | -$186 | $476 |

**Table 27: TDV Energy Cost Savings Over 30-Year Period of Analysis – Per 8-Unit Building – Multifamily Prototype**

| Climate Zone | 30-Year TDV Electricity Cost Savings (2020 PV $) | 30-Year TDV Natural Gas Cost Savings (2020 PV $) | Total 30-Year TDV Energy Cost Savings (2020 PV $) |
|---|---|---|---|
| 1 | $461 | -$157 | $304 |
| 2 | $1,026 | -$113 | $913 |
| 3 | $330 | -$52 | $278 |
| 4 | $1,191 | -$70 | $1,122 |
| 5 | $287 | -$35 | $252 |
| 6 | $817 | -$17 | $800 |
| 7 | $626 | -$9 | $617 |
| 8 | $1,609 | $0 | $1,609 |
| 9 | $2,183 | -$17 | $2,165 |
| 10 | $2,261 | -$17 | $2,244 |
| 11 | $3,713 | -$113 | $3,600 |
| 12 | $2,400 | -$113 | $2,287 |
| 13 | $3,739 | -$96 | $3,644 |
| 14 | $3,322 | -$104 | $3,218 |
| 15 | $6,740 | $0 | $6,740 |
| 16 | $1,461 | -$304 | $1,157 |

## Lifecycle Cost-Effectiveness

Lifecycle cost-effectives results per unit are presented in Table 28, Table 29, and Table 30 for the three residential new construction prototypes.

**Table 28: Lifecycle Cost-Effectiveness Summary Per Dwelling Unit – 2,100 Square Foot Single Family Prototype**

| Climate Zone | Benefits TDV Energy Cost Savings + Other PV Savings[a] (2020 PV $) | Costs Total Incremental PV Costs[b] (2020 PV $) | Benefit-to-Cost Ratio |
|---|---|---|---|
| 1 | $252 | $46 | 5.42 |
| 2 | $173 | $46 | 3.73 |
| 3 | $100 | $46 | 2.15 |
| 4 | $192 | $46 | 4.12 |
| 5 | $79 | $46 | 1.69 |
| 6 | $118 | $46 | 2.54 |
| 7 | $31 | $46 | 0.68 |
| 8 | $236 | $46 | 5.08 |
| 9 | $462 | $46 | 9.94 |
| 10 | $527 | $46 | 11.35 |
| 11 | $879 | $46 | 18.91 |
| 12 | $512 | $46 | 11.01 |
| 13 | $1,060 | $46 | 22.81 |
| 14 | $824 | $46 | 17.73 |
| 15 | $1,871 | $46 | 40.25 |
| 16 | $367 | $46 | 7.90 |

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than the PV of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) three percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes PV of maintenance incremental cost if PV of proposed maintenance costs is greater than the PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the B/C ratio is infinite.

**Table 29: Lifecycle Cost-Effectiveness Summary per Dwelling Unit – 2,700 Square Foot Single Family Prototype**

| Climate Zone | Benefits TDV Energy Cost Savings + Other PV Savings[a] (2020 PV $) | Costs Total Incremental PV Costs[b] (2020 PV $) | Benefit-to-Cost Ratio |
|---|---|---|---|
| 1 | $229 | $46 | 4.94 |
| 2 | $263 | $46 | 5.66 |
| 3 | $91 | $46 | 1.96 |
| 4 | $314 | $46 | 6.75 |
| 5 | $67 | $46 | 1.45 |
| 6 | $179 | $46 | 3.85 |
| 7 | $51 | $46 | 1.09 |
| 8 | $368 | $46 | 7.91 |
| 9 | $705 | $46 | 15.17 |
| 10 | $800 | $46 | 17.20 |
| 11 | $1,093 | $46 | 23.52 |
| 12 | $735 | $46 | 15.82 |
| 13 | $1,413 | $46 | 30.41 |
| 14 | $1,147 | $46 | 24.68 |
| 15 | $2,402 | $46 | 51.68 |
| 16 | $476 | $46 | 10.23 |

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than the PV of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) three percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes PV of maintenance incremental cost if PV of proposed maintenance costs is greater than the PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the B/C ratio is infinite.

**Table 30: Lifecycle Cost-Effectiveness Summary Per 8-Unit Building – Multifamily Prototype**
**Lifecycle Cost-Effectiveness Summary Per 8-Unit Building – Multifamily Prototype**

| Climate Zone | Benefits TDV Energy Cost Savings + Other PV Savings[a] (2020 PV $) | Costs Total Incremental PV Costs[b] (2020 PV $) | Benefit-to-Cost Ratio |
|---|---|---|---|
| 1 | $304 | $270 | 1.13 |
| 2 | $913 | $270 | 3.38 |
| 3 | $278 | $270 | 1.03 |
| 4 | $1,122 | $270 | 4.15 |
| 5 | $252 | $270 | 0.93 |
| 6 | $800 | $270 | 2.96 |
| 7 | $617 | $270 | 2.28 |
| 8 | $1,609 | $270 | 5.95 |
| 9 | $2,165 | $270 | 8.01 |
| 10 | $2,244 | $270 | 8.30 |
| 11 | $3,600 | $270 | 13.31 |
| 12 | $2,287 | $270 | 8.46 |
| 13 | $3,644 | $270 | 13.48 |
| 14 | $3,218 | $270 | 11.90 |
| 15 | $6,740 | $270 | 24.92 |
| 16 | $1,157 | $270 | 4.28 |

a. **Benefits: TDV Energy Cost Savings + Other Present Value Savings:** Benefits include TDV energy cost savings over the period of analysis (Energy + Environmental Economics 2016, 51-53). Other savings are discounted at a real (nominal – inflation) three percent rate. Other PV savings include incremental first-cost savings if proposed first cost is less than current first cost. Includes PV maintenance cost savings if PV of proposed maintenance costs is less than the PV of current maintenance costs.

b. **Costs: Total Incremental Present Value Costs:** Costs include incremental equipment, replacement and maintenance costs over the period of analysis. Costs are discounted at a real (inflation adjusted) three percent rate. Includes incremental first cost if proposed first cost is greater than current first cost. Includes PV of maintenance incremental cost if PV of proposed maintenance costs is greater than the PV of current maintenance costs. If incremental maintenance cost is negative, it is treated as a positive benefit. If there are no total incremental PV costs, the B/C ratio is infinite.

# Appendix D: TEST RESULTS RELATED TO FAN EFFICACY RECOMMENDATION[11]

## Executive Summary

The Statewide CASE Team proposes reducing the fan efficacy limit for residential furnaces and heat pumps in Title 24, Part 6 Section 150.0(m)13 from 0.58 watts per cubic foot per minute (W/cfm) to 0.45 W/cfm. As discussed in the body of the CASE Report, this proposal is based on a new federal Fan Efficacy Rating (FER) standard for furnace fans that will go into effect in July 2019. This standard will necessarily require furnaces to use high efficiency electronically commutated motors (ECMs). The FER standard does not apply to heat pump air handlers.

The PG&E Applied Technology Services (ATS) laboratory (lab) collaborated with the Statewide CASE Team to facilitate testing of ten furnaces equipped with ECM-driven fans to confirm they would meet the proposed 2019 Title 24, Part 6 requirements. The ATS lab also tested seven heat pump air handlers to determine whether heat pumps should be included under the proposed 0.45 W/cfm limit.

When operated at multiple speed settings and over a range of external static pressures, all but one furnace maintained efficacies below 0.45 W/cfm at all tested speeds and at an external static pressure of 0.7 inch water column (inch w.c.). Test data from the furnace that did not meet the proposed Title 24, Part 6 efficacy standard at its two highest speed settings was evaluated using the federal standard, and it was found to exceed the maximum allowable federal FER for its product class.

The 0.7 inch w.c. total external static pressure threshold used for qualifying furnaces anticipates that the addition of a cooling coil will contribute about 0.25 inches w.c. of static pressure. Heat pump air handlers were tested with cooling coils installed, so the threshold was lowered to 0.5 inch w.c., which also accounts for a pressure drop through electric strip heaters of 0.5 inch w.c. Six of the seven heat pumps tested maintained efficacies below 0.45 W/cfm at 0.5 inch w.c. at the highest speed setting. In all cases the high-speed setting produced the greatest pressure loss.

## Background

### *Federal Standards and Test Procedures*

The Statewide Residential CASE Report for the 2019 Title 24, Part 6 Standards cycle recommends reducing the fan efficacy in Part 6, 150.0(m) 13 from 0.58 watts per cubic foot per minute of air flow (W/cfm) to 0.45 W/cfm for both furnaces and heat pumps. The impetus for this recommendation is that the United States (U.S.) Department of Energy (DOE) will begin enforcing an efficacy requirement for gas furnaces and other heating ventilation and air conditioning (HVAC) appliances beginning July 3, 2019 (DOE-1 2014). The federal standard will likely compel furnace manufacturers to install brushless permanent magnet (BPM) fan motors, also known as electronically commutated motors (ECMs), in their products instead of permanent split capacitor (PSC) motors to meet the efficacy requirement. Despite their higher cost, furnaces with ECMs are becoming increasingly common as they allow a single furnace to be paired with multiple cooling system sizes, thereby reducing inventory. This same advantage applies to ECM-powered heat pump air handlers.

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[11] Appendix D was updated in the December 2017 report revision to add results from heat pump tests.

The federal standard requires that furnaces not exceed the Fan Efficiency Rating (FER) values calculated as shown in Table 31. Qmax is the airflow in cfm at the maximum airflow-control setting measured using the DOE test procedure specified at 10 CFR part 430, subpart B, appendix AA.

**Table 31: Pending DOE FER Standards for Gas Furnaces**

| Product Class | Fan Efficiency Rating (FER) in W/1000cfm [a] |
|---|---|
| Non-Weatherized, Non-Condensing Gas Furnace Fan | FER – 0.44 x Qmax + 182 |
| Non-Weatherized, Condensing Gas Furnace Fan | FER – 0.44 x Qmax + 195 |
| Weatherized, Non-Condensing Gas Furnace Fan | FER – 0.44 x Qmax + 199 |

a. There is an error in the table published by DOE that lists FER as W/cfm. Note the multiplier in Equation 1

The federal test procedure calculates FER using Equation 1 and weights watt measurements using the annual operating hours for cooling hours (CH), heating hours (HH), and constant circulation hours (CCH) that represent national average operation as shown in Table 32. Power measurements are taken with external static pressures at maximum airflow set to 0.5 inch water column (inch w.c.) for units with an internal evaporator coil and at 0.65 I inch w.c. for units that do not incorporate a coil. “E” in the equation is the fan watts in each mode. For two stage furnaces the value of HH is reduced by dividing by the ratio of stage 1 to stage 2 heating capacity.

$$FER = \frac{(CH \times E_{Max}) + (HH \times E_{Heat}) + (CCH \times E_{Circ})}{(CH + 830 + CCH) \times Q_{Max}} \times 1000$$

**Equation 1**

**Table 32: Operating Hours Used to Calculate FER**

| Operating Mode | Hours | Variable |
|---|---|---|
| Heating | 830[a] | HH |
| Cooling | 640 | CH |
| Constant Circulation | 400 | CCH |

a. For two-speed furnaces, heating hours is determined by multiplying 830 by the ration of the second stage to first stage heating capacity

The three airflow-control settings used in FER tests of single-stage heating products are: the default constant-circulation setting, default heating setting, and the absolute maximum setting. The “absolute maximum” airflow-control setting refers to a setting that achieves the maximum attainable airflow at the operating conditions specified by the test procedure. For products with multi-stage heating or modulating heating, the default low heating setting is used to represent the heating setting. The absolute lowest airflow-control setting is used to represent constant circulation if a default constant-circulation setting is not specified. The federal standards define “default airflow-control settings” as the airflow-control settings for installed use specified by the manufacturer in the product literature shipped with the product in which the furnace fan is integrated. Given the large variability in the way that fan speed settings can be adjusted, it may be challenging to select which settings to apply to meet these federal test definitions.

The federal assumptions for fan run times listed in Table 32, which apply nation-wide, are different than appropriate assumptions for California. A CBECC-Res analysis of the two Energy Commission single family home prototypes (2,100 and 2,700 square feet) showed heating runtimes of 303 hours and cooling runtimes of 364 hours, averaged over all climate zones. No data is available regarding the average number of hours that fans are operated manually for constant circulation by California residents.

### *Prior California Research*

A field study of 60 single family homes completed in 2006 measured airflow, fan watt draw, and system pressure loss (B. J. Wilcox 2006). The 2006 study recommended setting a maximum watt draw of 0.5 W/cfm (0.55 W/cfm for 5-ton systems), and resulted in establishing the 0.58 W/cfm and 350 cfm/ton limits that were added to Title 24, Part 6 for the 2008 code cycle and remain in the 2016 Title 24, Part 6 Standards. An additional study of 80 newly constructed single and multifamily homes was completed in 2011 (Proctor, Efficiency Characteristics and Opportunities for New California Homes 2011). The median values measured through both studies are listed in Table 33. All values are from single family residential furnaces.

**Table 33: Furnace Measurements from 60 Homes in 2006 and 80 Homes in 2011**

| Measurement | 2006 Median | 2011 Median |
|---|---|---|
| Fan Efficacy | 0.51 W/cfm | 0.65 W/cfm |
| Airflow | 358 cfm/ton | 321 cfm/ton |
| External Static Pressure | 0.80 inch w.c. | 0.88 inch w.c. |

As part of the 2006 Wilcox study, Proctor Engineering tested two ECM furnaces and found they operated between 0.3 and 0.4 W/cfm at realistic external static pressures for California homes. The 2006 study also provided details on pressure loss by component and suggested target values expected to result from distribution system improvements, as shown in Table 34.

**Table 34: Typical Pressure Drop Characteristics by Component in Inch w.c. (Wilcox, 2006)**

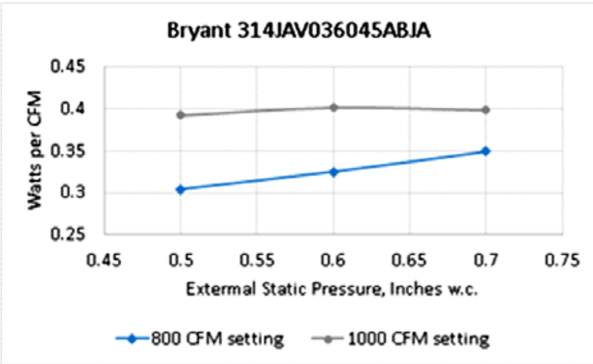
| Component | Survey Median | Target |
|---|---|---|
| Supply Duct | 0.18 | 0.18 |
| Cooling Coil | 0.27 | 0.20 |
| Return Duct | 0.15 | 0.05 |
| Filter | 0.15 | 0.07 |
| **Total** | **0.75** | **0.50** |

### *Characteristics of ECM Powered Fans*

ECM-powered fans have better efficacy (lower W/cfm) due to the improved efficiency of motors that are communicated electronically. ECM fans are more effective at maintaining high airflow as pressure resistance increases than is the case for PSC motors. ECMs can be programmed to maintain a nearly constant airflow over a wide range of static pressures, but the current HVAC industry trend appears to be toward using constant torque rather than constant airflow motor programming. ECM-equipped furnaces typically use numerous tap settings to control motor speed rather than the three speed settings (or “taps”) commonly seen with PSC motors, which allows ECMs to be tailored to the capacity of the cooling equipment while maintaining individual airflow rates for heating.

### *Preliminary Tests*

Section 2.2.1 of this report describes lab testing of two ECM furnaces, a Bryant 314JAVF036045ABJA, and a Goodman GMEC961004. The Byrant is rated at 1,000 cfm and the Goodman at 1,600 cfm. The test equipment was not the same as the test equipment used at the ATS lab, but results were similar. A flow grid was used to measure airflow and a handheld watt meter to measure fan power. Airflow was measured at static pressures of 0.5, 0.6, and 0.7 inch w.c. and at two speed settings. Results, provided in Figure 13, show both furnaces would comply with the proposed 0.45 W/cfm maximum.



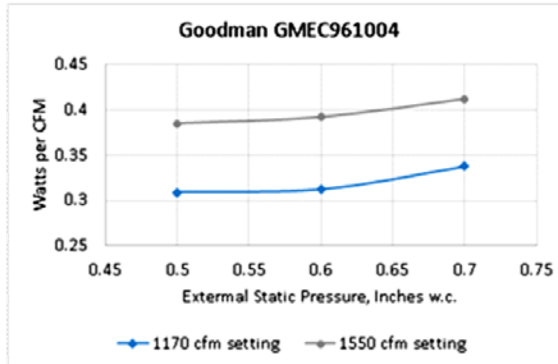




**Figure 13: Preliminary lab test results for two ECM furnaces**

# Test Objectives

## *Efficacy Testing and Test Criteria*

The primary objective of the tests is to determine whether, using industry standard methods of installation and good practice, market rate furnaces that meet the federal FER requirement[12] will also comply with the proposed 2019 Title 24, Part 6 efficacy requirement of 0.45 W/cfm. The underlying assumption is that all furnaces equipped with ECMs will pass the FER test. As it is not possible to infer the fan efficacy in cooling operation from the federal FER rating, it was necessary to evaluate this supposition by completing laboratory tests of furnaces at a variety of speed settings and external static pressures. Consistent with the proposal to include heat pumps in the 0.45W/cfm requirement, they were also tested.

Preliminary testing of two ECM-equipped furnaces completed at the Frontier Energy lab confirmed that they could meet the proposed 0.45 W/cfm Title 24, Part 6 efficacy requirement at an external static pressure of 0.7 inch w.c. (D. Springer 2017). In response to industry and Energy Commission concerns that additional data was needed to support the supposition that all or most furnaces with ECM-powered fans will be able to comply and to avoid preemption risks, the Statewide CASE Team prepared a laboratory test plan, presented below, and compiled representative lists of market rate furnaces and heat pumps. PG&E’s ATS lab, which is located in San Ramon, acquired the representative products and completed testing on ten furnaces, each equipped with ECM-powered fans, and seven heat pump air handlers with both ECMs and lower efficiency permanent split capacitor fan motors.

Fan laws dictate that fan motor brake horsepower is proportional to total static pressure as well as volume flow rate. It is therefore necessary to define a static pressure at which fan efficacy is measured. Current provisions in the Title 24 standards, including the 350 cfm per ton Home Energy Rating System (HERS) verification (or application of Tables 150.0-B and -C) in Part 6, and the requirement for duct sizing using industry standards in Part 11 (e.g., ACCA Manual D) encourage better design. Filter labeling, which will be enforced under California Appliance Efficiency Regulations (Title 20) in 2019, will also facilitate improved designs. The medians of 0.80 to 0.88 W/cfm found in prior field studies are higher than desirable. Ducts, and particularly coils and filters, can be easily sized to yield lower static pressures. The maximum total external static pressure (ESP) recommended by the Statewide CASE Team for furnace systems is 0.70 inch w.c., which is the criterion used for qualifying furnace fan efficacy in this report. Cooling coils, which typically add about 0.25 in. w.g static pressure, make up part of the 0.7 inch w.c. ESP. Since heat pump air handlers were tested with cooling coils installed, a

[12] Based on the assumption that furnaces that meet the FER standard will incorporate ECM fans.

lower threshold of 0.5 inch w.c. was selected, which accounts for 0.25 inch w.c. less internal static pressure and an additional 0.05 inch w.c. that might be added by an auxiliary electric resistance heat strip. Tests were completed up to an external static pressure of 1.0 inch w.c.

### *Compliance with Title 24, Part 6 Airflow Requirements*

In addition to measuring W/cfm over a range of airflows, the test plan calls for calculating cfm per ton and applying the federal FER test procedure to furnaces that do not meet the 350 cfm/ton airflow test. Failure of the FER test would indicate that manufacturers would make improvements or withdraw the product from the market following adoption of the 2019 DOE standard. If furnaces pass the FER tests but fail the efficacy test, manufacturers may have grounds for opposing the lower efficacy requirement.

Not all furnace manufacturers specify the cooling system sizes that can be paired with their furnace models, whereas heat pumps always have nominal cooling capacity ratings. A technical advisor to the Statewide CASE Team recommended the following method to determine furnace cooling capacity:

*Furnace Cooling Capacity (tons) = Integer (maximum cooling airflow at 0.5 inch w.c. ÷ 200 + 0.5) ÷ 2*

For example, a furnace that can deliver 1,300 cfm at 0.5 inch w.c.[13] would be suitable to be paired with a 3.5-ton air conditioner. This approach assumes that air conditioners have rated cooling capacities that are close to their nominal tonnage ratings, which is often not the case. For example, a nominal 4-ton Amana ASZC160481A condenser with an MBVC2000 coil has a rated total capacity of 38,800 Btuh (3.23 tons) at AHRI conditions. At the rated evaporator airflow of 1,356 cfm it has a delivery of 339 cfm per nominal ton and 419 cfm per rated ton.[14] It may not be useful to rate a furnace based on cfm per ton without knowing the air conditioner to which it is paired, particularly because of the multitude of speed settings available with ECM furnaces.

## Overview of Test Procedures

### *Test Location and Staff*

All tests were completed at PG&E's ATS lab in San Ramon, California by ATS test engineers Edwin Huestis and Robert Davis. Testing was completed in October 2017.

### *Lab Description*

Furnaces and heat pumps were tested in an environmental chamber that was used to control temperature and relative humidity in accordance with the referenced test standards. As shown in Figure 1 of the attached test plan, air was discharged through calibrated nozzles for precisely measuring airflow. The nozzles, aided by a booster blower, were used to establish a range of external static pressures at each speed setting. Test sequences were automated with the aid of a LabView program that modified external static pressures. It was necessary to manually change nozzles to obtain accurate measurements across the full range of speed settings.

[13] With no filter.

[14] This discrepancy was pointed out by Rob Penrod of Villara in a 2019 Title 24, Part 6 docket posting. The example provided is for an Amana ASZC160481A condenser with an MBVC2000 coil.

### *Furnaces Tested*

Furnace and heat pump model numbers and their specifications are listed in Table 1 of the attached Laboratory Test Plan. Fan speed settings were selected as being representative; not all possible speed settings were tested.

### *Test Plan Implementation*

The test plan is provided below. The following notes describe difficulties encountered and minor adjustments made to the test plan:

- Initially, sub-metering of the blower motors was to be done by passing power through a 20 amp Yokogawa power meter. When starting the first test unit (Rheem R80), the furnace returned an error code that indicated a communication failure between the board and blower. The solution was to wire the power line through a current transformer (CT) with several turns to increase its signal. The CT was a 50:5 unit, with 4 turns of the wire through it, so the current and power reading had to be scaled up by a factor of 2.5.
- All furnaces and heat pumps were tested in a horizontal position with the access panel facing upwards to enable changes to control settings. This position kept the axis of the blower in the same orientation as it would be in either upflow or downflow installations, that is, horizontal. No tests were completed with access panels facing to the side, as it would be in typical horizontal installations, so airflow and power differences that may be related to the position of the blower were not identified. It is likely the position does not affect overall findings as there is little difference in airflow listed in manufacturer specifications.
- Two furnaces required repeat testing because a leaking flange caused airflow measurement errors. Subsequently, a leak inspection was conducted at the start of each test, with the blower on and operating against a high resistance. Seams that showed signs of leakage were taped.
- The test plan called for matching the supplied voltage to the nameplate voltage. All furnace units were labeled as 115V except the two Lennox units, which had a nameplate voltage of 120V, so a voltage regulator was used to increase the voltage for these two units. The voltage regulators did not maintain a steady voltage, so some adjustments were necessary. All heat pump air handlers were connected to single phase 230V power.
- External static pressure was controlled by the selection of the nozzles in the flow measurement chamber and by adjusting the speed of a booster blower rather than using a damper. At low fan speeds, high static pressures could not be achieved even when using only the smallest nozzle size. Some test sequences required multiple nozzle changes to achieve the required pressures. Different nozzle combinations were used to verify that the same airflow/pressure measurements were obtained at specific speed settings.
- For the furnaces, the burner heat exchanger was downstream of the blower, whereas with the heat pump air handlers, the refrigerant coil was upstream of the blower. The measured external resistance was always the pressure in the duct downstream of the test unit referenced to the test unit intake.

## Test Results

Table 36 and 37 summarize complete test results in tabulated form for the furnaces and heat pumps, respectively, including the measured W/cfm as a function of flow resistance for each furnace/speed setting combination tested. Values below the proposed 0.45 W/cfm limit are highlighted in green, while results above the proposed 0.45 W/cfm limit are highlighted in red. Cells that are highlighted in red but blank represent extrapolations of test data that indicate the test condition would result in an efficacy greater than 0.45 W/cfm.

Two salient points from the furnace results presented in Table 36 include:

- All furnaces except one met the proposed 0.45 W/cfm limit at 0.7 inch w.c. flow resistance. The one furnace that exceeded the efficacy limit did so at its “Hi” and “Lo” speed settings, but was below 0.45 W/cfm at other speed settings.
- The multiple speed settings available on the ECM furnaces allow significant flexibility for matching air conditioner capacities while still meeting the proposed fan efficacy requirement, though a few furnaces would not meet the 350 cfm per ton delivery requirement at 0.7 inch w.c. when air conditioner tons were calculated as described above.

Key findings from the heat pump results presented in Table 37 are:

- All heat pump air handlers except one met the proposed 0.45 W/cfm limit at 0.5 inch w.c. flow resistance, which was one of three that utilize a PSC motor.
- In all cases the high-speed setting produced the highest efficacy value.
- All air handlers comply with the 350 cfm per nominal ton requirement at 0.5 inch w.c.

Figure 14 presents a typical fan efficacy test result. This plot shows the results from the Lennox SL280UH090XV48B model. The x-axis shows the total external static pressure (representing pressure losses from grilles, ducts, filter, and coil) in inch w.c., and the y-axis shows the fan efficacy in W/cfm of airflow. This unit was tested seven times, once for each of seven representative speed settings. Several of the furnaces include incremental adjustments to increase or decrease speed settings by some percentage. In this and other plots the adjusted speeds are represented by dashed lines.

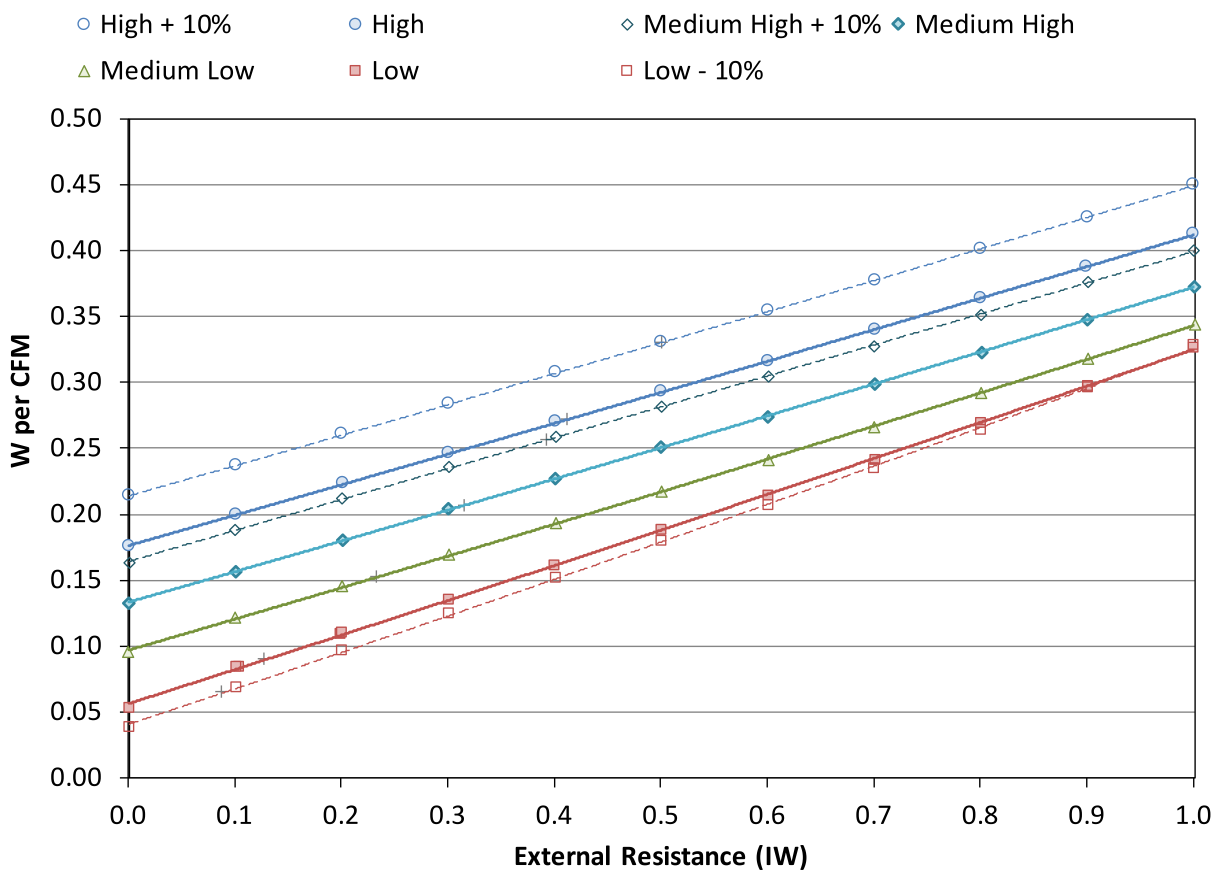



**Figure 14: Typical furnace fan efficacy test results – Lennox SL28OUH090XV48B**

The response to increasing static pressure seen in Figure 14 is typical of most of the furnaces tested. The power required to move air increases with increases in flow and static pressure, as expected. At 0.7 inch w.c. the fan efficacy at the highest speed setting is 0.375 W/cfm for this furnace, considerably below the proposed limit of 0.45 W/cfm. Even at 1.0 inch w.c., a resistance far above what is expected in typical system designs, the fan efficacy for this furnace remains below 0.45 W/cfm.

Figure 15 shows the results from the Carrier 59TP6A060E171214, which was the worst performing furnace tested in terms of fan efficacy. This was the only unit that exceeded the proposed 0.45 W/cfm fan efficacy requirement at the highest speed setting, surpassing the efficacy limit even at zero inch w.c. At the "M-Hi" and lower settings it was under the 0.45 W/cfm limit at 0.7 inch w.c, but at this setting the furnace delivered less than 350 cfm/ton (based on calculated tons). At this setting, the furnace delivered 1,104 cfm against a static pressure of 0.7 inch w.c. so it should not be used with an air conditioner larger than 3-tons (based on 350 cfm per ton).

As seen in Figure 15, the "Lo" setting produced extremely high W/cfm at relatively low static pressures. Furnaces commonly use low speed settings for recirculating air, for example when the thermostat switch is set to "fan". When ducts are designed for high airflows, pressure losses are negligible when very low fan speeds are applied, so the poor efficacy at the "Lo" setting can be disregarded.

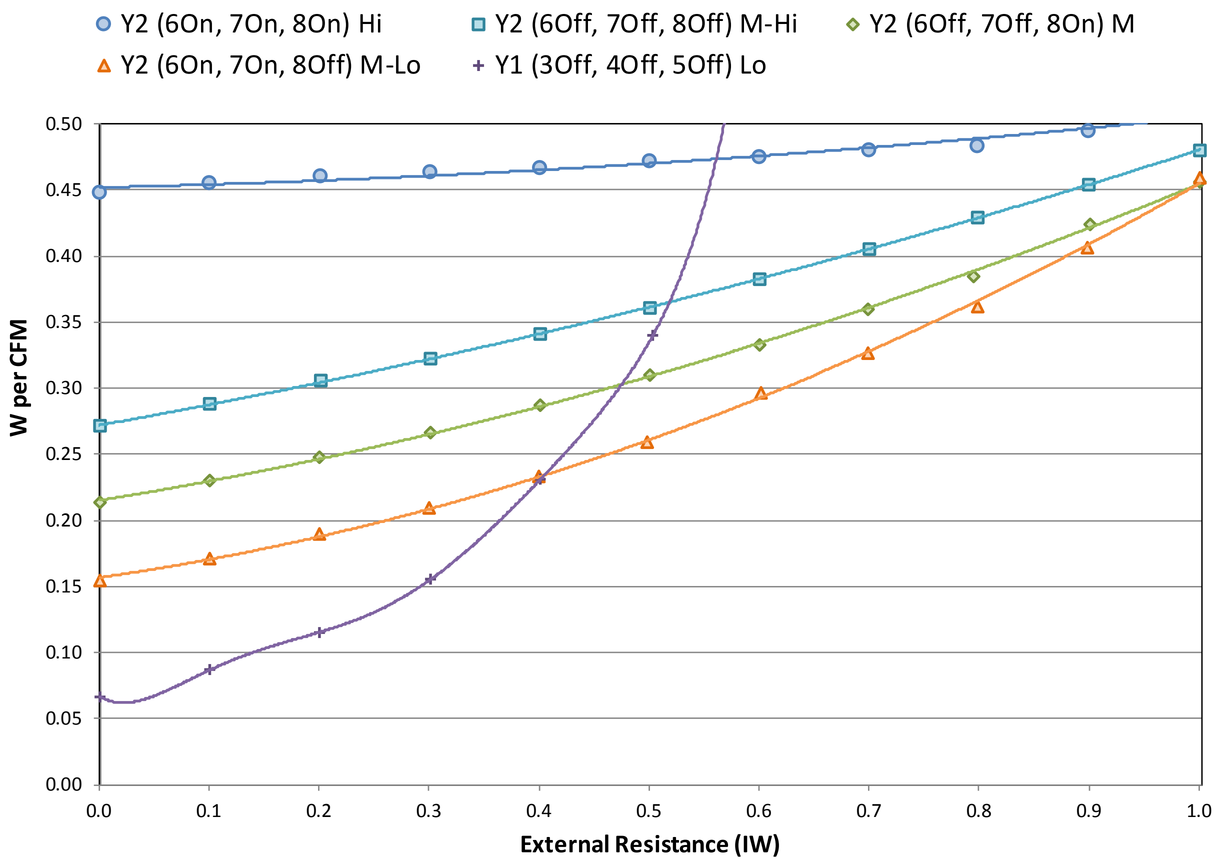



**Figure 15: Furnace fan efficacy test results – Carrier 59TP6A060E171214**

Figure 16 presents fan efficacy test results for the Trane XT95TDH1B04A9H21BA, the best performing of the tested units in terms of fan efficacy. The plot shows that the unit has five speed settings, providing options for "High", "Medium-High", "Medium", "Medium-Low", and "Low". In this unit, all four speed settings resulted in fan efficacies below 0.45 W/cfm across the entire range of flow resistances. Only the "Hi" setting also met the 350 cfm/nominal ton minimum. The highest measured fan efficacy was 0.340 W/cfm when using the "High" setting at 1.0 inch w.c.

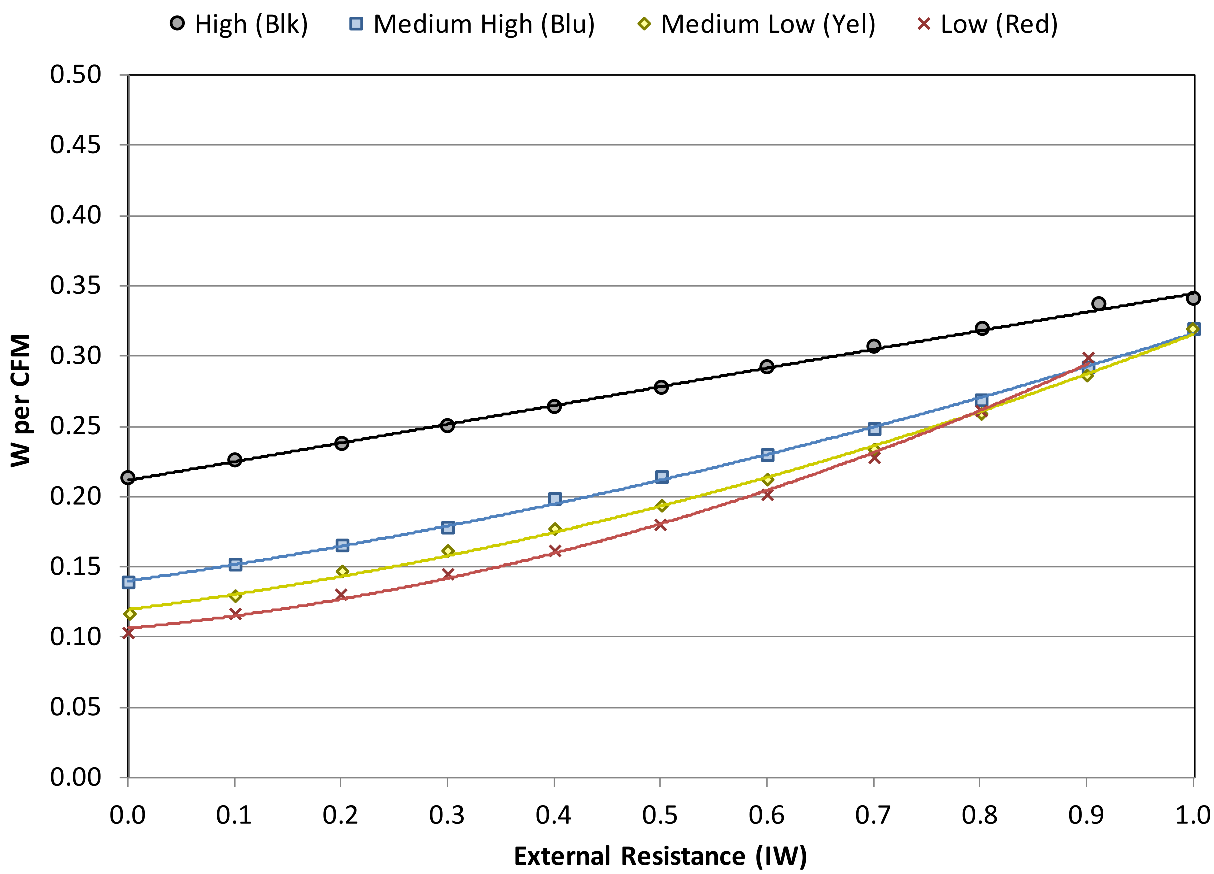



**Figure 16: Furnace fan efficacy results – Trane XT95 TDH1B04A9H21BA**

### *Furnace Test Observations*

Except for the Carrier 59TP6A060E171214, all furnace/speed setting combinations were below 0.45 W/cfm at 0.7 inch w.c. at all speed settings. The Carrier unit exceeded 0.45 W/CFM at 0.7 inch w.c. when using the "Hi" and "Lo" speed settings. This does not cause an issue for the proposed 0.45 W/cfm requirement, as the Carrier unit had several other speed settings which do meet the proposed requirement. Seventy-five percent of the furnace/speed setting combinations met the proposed 0.45 W/cfm requirements even at 1.0 inch w.c. flow resistance.

Test results were used to calculate the FER of the Carrier furnace to determine if it would pass the federal standard.[15] Applying Equation 1 and the operating hours in Table 32 produced the results listed in Table 35, which shows the unit would not meet the required FER standard. In completing the tests to determine fan energy at the settings required for the FER test it was challenging to determine what settings to use for each of the three operating modes. There appear to be 24 different cooling speed settings that can be applied on this unit, six primary speeds times four adjustments that can be applied to each primary setting. There are also two heating speeds and one unspecified continuous fan speed.

[15] The FER test procedure requires that the burner be activated, which was not done in these tests.

**Table 35: Results of FER Calculation for Carrier 59TP6A060E171214 Furnace**

| Qmax at 0.5 inch w.c. | High Heating Capacity | Low Heating Capacity | Heating Capacity Ratio | Heating Operating Hours (HH) | Cooling Operating Hours (CH) | Constant Circulation Operating Hours (CCH) | |
|---|---|---|---|---|---|---|---|
| 1,475 | 58,000 | 38,000 | 0.655 | 1,267 | 640 | 400 | |
| **Heating Speed** | **Flow at Maximum Speed** | **ESP at Maximum Speed** | **Emax** | **Eheat** | **Ecirc** | **Maximum Fan Efficacy Rating (FER)** | **Tested Fan Efficacy Rating (FER)** |
| High at 0.70 | 1,336 | 0.70 | 632 | 228 | 55 | 247 | 287 |
| High at 0.65 | 1,370 | 0.65 | 644 | 225 | 54 | 247 | 281 |

Two of the furnace fans, the Rheem 802VA075421MXA and the Lennox SL28OUH0-90XV48B displayed characteristics of near-constant airflow. The Rheem furnace airflow fell from 1,652 cfm at 0 inch w.c. to 1,553 cfm at 0.7 inch w.c. and the Lennox airflow fell from 1,551 cfm at 0 inch w.c. to only 1,528 cfm at 0.7 inch w.c. The remaining eight furnaces behaved as regulated torque fans, with airflow declining with increasing static pressure. The slopes of the efficacy curves (W/cfm versus external static pressure) for these two constant airflow furnaces appeared little different than for the others. It would be of interest to conduct a study to compare overall system performance of constant airflow versus constant torque fans as dirt accumulates on filters, and static pressure builds.

To aid in understanding how the test data relates to the federal test procedure, it is useful to quote from the federal test procedure that states "For products with multi-stage heating or modulating heating, the airflow-control settings to be tested are: The default constant-circulation setting; the default low heating setting; and the absolute maximum setting. The absolute lowest airflow-control setting is used to represent constant circulation if a default constant-circulation setting is not specified," and "In instances where a manufacturer specifies multiple airflow-control settings for a given function to account for varying installation scenarios, the highest airflow-control setting specified for the given function shall be used for the DOE test procedure."

With all of the setting combinations it can be challenging to navigate the sometimes-confusing instructions on how to select fan speeds for heating, cooling, and fan only. The range of setting options available with some furnaces also might introduce uncertainty about which should be applied when FER ratings are developed by testing labs. For some, heating, cooling, and fan speeds can be set individually and on others it appears that only the cooling speed can be set and other speeds are based on some reduction from the cooling speed.

**Table 36: Tabulated Furnace Fan Efficacy Results**

| Furnace | Speed Setting | External Static Pressure | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** | **1** |
| Rheem R802VA075421MXA | Y1&Y2 (4 Off/5 Off) | 0.248 | 0.267 | 0.284 | 0.305 | 0.324 | 0.344 | 0.367 | 0.391 | 0.413 | 0.437 | 0.461 |
| | Y1 (4 Off/5 Off) | 0.143 | 0.155 | 0.180 | 0.202 | 0.23 | 0.2505 | 0.275 | 0.300 | 0.325 | 0.351 | 0.375 |
| | G (12 On) | 0.145 | 0.157 | 0.182 | 0.204 | 0.232 | 0.2525 | 0.277 | 0.320 | 0.327 | 0.353 | 0.377 |
| | Y1 (4 On/5 Off | 0.091 | 0.116 | 0.14 | 0.167 | 0.193 | 0.218 | 0.245 | 0.270 | 0.303 | 0.330 | 0.360 |
| | Y1 (4 Off/5 On) | 0.070 | 0.0900 | 0.115 | 0.140 | 0.107 | 0.218 | 0.225 | 0.250 | 0.280 | 0.320 | 0.360 |
| | G (12 Off) | 0.060 | 0.075 | 0.105 | 0.130 | 0.160 | 0.185 | 0.220 | 0.250 | 0.230 | 0.320 | 0.360 |
| | Y1 (4 On/5 On) | 0.060 | 0.075 | 0.105 | 0.130 | 0.160 | 0.190 | 0.225 | 0.260 | 0.300 | 0.330 | 0.375 |
| Rheem R95TC0851521MSA | High | 0.380 | 0.393 | 0.405 | 0.420 | 0.430 | 0.440 | 0.435 | 0.440 | 0.445 | 0.445 | 0.455 |
| | Medium High | 0.345 | 0.360 | 0.375 | 0.380 | 0.405 | 0.420 | 0.430 | 0.440 | 0.445 | 0.450 | 0.455 |
| | Medium | 0.291 | 0.304 | 0.307 | 0.330 | 0.345 | 0.361 | 0.378 | 0.396 | 0.415 | 0.433 | 0.453 |
| | Medium Low | 0.280 | 0.292 | 0.305 | 0.318 | 0.332 | 0.348 | 0.367 | 0.385 | 0.403 | 0.421 | 0.44 |
| | Y | 0.233 | 0.245 | 0.257 | 0.271 | 0.287 | 0.304 | 0.322 | 0.34 | 0.358 | 0.377 | 0.399 |
| Carrier 59TP6A060E171214 | Y2 (6On, 7On, 8On) Hi | 0.448 | 0.455 | 0.460 | 0.463 | 0.467 | 0.471 | 0.475 | 0.480 | 0.483 | 0.495 | |
| | Y2 (6Off, 7Off, 8Off) M-Hi | 0.272 | 0.288 | 0.305 | 0.322 | 0.341 | 0.361 | 0.382 | 0.405 | 0.429 | 0.454 | 0.480 |
| | Y2 (6Off, 7Off, 8On) M | 0.213 | 0.230 | 0.248 | 0.267 | 0.287 | 0.310 | 0.333 | 0.360 | 0.384 | 0.424 | 0.459 |
| | Y2 (6On, 7On, 8Off) M-Lo | 0.154 | 0.172 | 0.190 | 0.210 | 0.233 | 0.259 | 0.296 | 0.327 | 0.362 | 0.406 | 0.459 |
| | Y2 (6Off, 7Off, 8Off) Lo | 0.067 | 0.087 | 0.116 | 0.0155 | 0.233 | 0.340 | | | | | |
| Carrier 58PHY04510112 | High (Gra) | 0.220 | 0.236 | 0.251 | 0.269 | 0.285 | 0.302 | 0.320 | 0.348 | 0.387 | 0.396 | 0.425 |
| | Medium High (Yel) | 0.150 | 0.166 | 0.187 | 0.206 | 0.233 | 0.245 | 0.268 | 0.300 | 0.325 | 0.371 | 0.417 |
| | Medium (Orn) | 0.096 | 0.113 | 0.132 | 0.149 | 0.177 | 0.210 | 0.245 | 0.300 | 0.357 | 0.437 | |
| | Medium Low (Blu) | 0.089 | 0.100 | 0.124 | 0.149 | 0.177 | 0.218 | 0.266 | 0.316 | 0.387 | | |
| | Low (Red) | 0.089 | 0.091 | 0.110 | 0.140 | 0.177 | 0.238 | | | | | |
| Lennox SL280UH090XV48B | High + 10% | 0.214 | 0.236 | 0.260 | 0.284 | 0.307 | 0.331 | 0.354 | 0.377 | 0.401 | 0.425 | 0.450 |
| | High | 0.176 | 0.199 | 0.223 | 0.246 | 0.270 | 0.293 | 0.316 | 0.340 | 0.363 | 0.388 | 0.413 |
| | Medium High + 10% | 0.163 | 0.188 | 0.212 | 0.236 | 0.259 | 0.281 | 0.304 | 0.328 | 0.351 | 0.376 | 0.400 |
| | Medium High | 0.133 | 0.157 | 0.180 | 0.204 | 0.227 | 0.250 | 0.274 | 0.298 | 0.323 | 0.348 | 0.373 |
| | Medium Low | 0.095 | 0.121 | 0.146 | 0.169 | 0.193 | 0.217 | 0.214 | 0.266 | 0.292 | 0.318 | 0.344 |
| | Low | 0.053 | 0.084 | 0.110 | 0.135 | 0.162 | 0.188 | 0.214 | 0.242 | 0.269 | 0.296 | 0.328 |
| | Low + 10% | 0.038 | 0.069 | 0.097 | 0.124 | 0.152 | 0.179 | 0.210 | 0.239 | 0.268 | 0.296 | 0.328 |

| Furnace | Speed Setting | External Static Pressure | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** | **1** |
| Lennox EL195UH030XE24B | High(Blk) | 0.142 | 0.156 | 0.172 | 0.187 | 0.204 | 0.221 | 0.240 | 0.262 | 0.275 | 0.312 | 0.336 |
| | Medium High (Brn) | 0.124 | 0.141 | 0.155 | 0.172 | 0.188 | 0.209 | 0.229 | 0.255 | 0.280 | 0.304 | 0.331 |
| | Medium (Blu) | 0.107 | 0.120 | 0.138 | 0.155 | 0.175 | 0.199 | 0.224 | 0.250 | 0.276 | 0.304 | 0.336 |
| | Medium (Yel) | 0.100 | 0.103 | 0.115 | 0.137 | 0.162 | 0.189 | 0.218 | 0.250 | 0.297 | 0.346 | 0.399 |
| | Low (Red) | 0.092 | 0.095 | 0.101 | 0.122 | 0.151 | 0.199 | 0.249 | 0.318 | 0.401 | | |
| Trane XT95 TDH1B04A9H21BA | High | 0.213 | 0.225 | 0.238 | 0.250 | 0.264 | 0.275 | 0.292 | 0.307 | 0.319 | 0.337 | 0.340 |
| | Medium High | 0.139 | 0.152 | 0.165 | 0.178 | 0.198 | 0.214 | 0.230 | 0.248 | 0.268 | 0.290 | 0.319 |
| | Medium Low | 0.117 | 0.130 | 0.146 | 0.161 | 0.177 | 0.193 | 0.215 | 0.230 | 0.261 | 0.286 | 0.319 |
| | Low | 0.103 | 0.116 | 0.130 | 0.145 | 0.162 | 0.180 | 0.202 | 0.228 | 0.261 | 0.298 | |
| Trane XT80 TUD1C100A9H51BC | High | 0.366 | 0.379 | 0.391 | 0.403 | 0.416 | 0.428 | 0.436 | 0.440 | 0.442 | 0.444 | 0.445 |
| | Medium High | 0.307 | 0.320 | 0.333 | 0.347 | 0.36 | 0.374 | 0.388 | 0.400 | 0.413 | 0.425 | 0.432 |
| | Medium Low | 0.253 | 0.267 | 0.281 | 0.294 | 0.308 | 0.322 | 0.337 | 0.352 | 0.367 | 0.384 | 0.401 |
| | Low | 0.202 | 0.215 | 0.229 | 0.242 | 0.257 | 0.272 | 0.287 | 0.303 | 0.321 | 0.339 | 0.360 |
| Goodman GME80603BXBB | High | 0.252 | 0.267 | 0.282 | 0.290 | 0.299 | 0.320 | 0.330 | 0.349 | 0.364 | 0.381 | 0.400 |
| | Medium High | 0.194 | 0.209 | 0.222 | 0.230 | 0.245 | 0.261 | 0.278 | 0.296 | 0.315 | 0.334 | 0.355 |
| | Medium | 0.146 | 0.160 | 0.17 | 0.186 | 0.202 | 0.219 | 0.237 | 0.255 | 0.278 | 0.305 | 0.327 |
| | Medium Low | 0.110 | 0.124 | 0.138 | 0.154 | 0.172 | 0.192 | 0.213 | 0.237 | 0.265 | 0.305 | 0.346 |
| | Low | 0.075 | 0.088 | 0.104 | 0.122 | 0.146 | 0.171 | 0.208 | 0.255 | 0.313 | 0.441 | |
| Goodman GCEC961005CNAA | Y&Off/Off/Off (High) | 0.336 | 0.35 | 0.361 | 0.374 | 0.387 | 0.405 | 0.414 | 0.420 | 0.422 | 0.310 | 0.434 |
| | Y%Off/Off/On (Medium High) | 0.271 | 0.284 | 0.296 | 0.309 | 0.322 | 0.336 | 0.351 | 0.368 | 0.388 | 0.408 | 0.427 |
| | Y&On/Off/Off/Off (Medium) | 0.205 | 0.218 | 0.230 | 0.244 | 0.258 | 0.274 | 0.294 | 0.313 | 0.333 | 0.355 | |
| | Y&On/On/On (Medium Low) | 0.171 | 0.184 | 0.196 | 0.211 | 0.227 | 0.246 | 0.265 | 0.286 | 0.308 | 0.336 | 0.368 |
| | Y&Off/On/Off (Low) | 0.143 | 0.155 | 0.169 | 0.183 | 0.202 | 0.223 | 0.245 | 0.269 | 0.300 | 0.336 | 0.374 |

Notes:

1. Cells are colored green where the efficacy falls below 0.45 W/cfm.
2. Cells are colored red where the efficacy is above 0.45 W/cfm.
3. Where cells are blank measurements could not be obtained because static pressure could not be reached.

Figure 17 compares the efficacy test results for all seven heat pump air handlers measured at their high-speed settings, which in all cases resulted in the highest efficacy, measured in W/cfm. To distinguish those air handlers that use PSC fan motors their plots include lines. The remainder use ECMs.

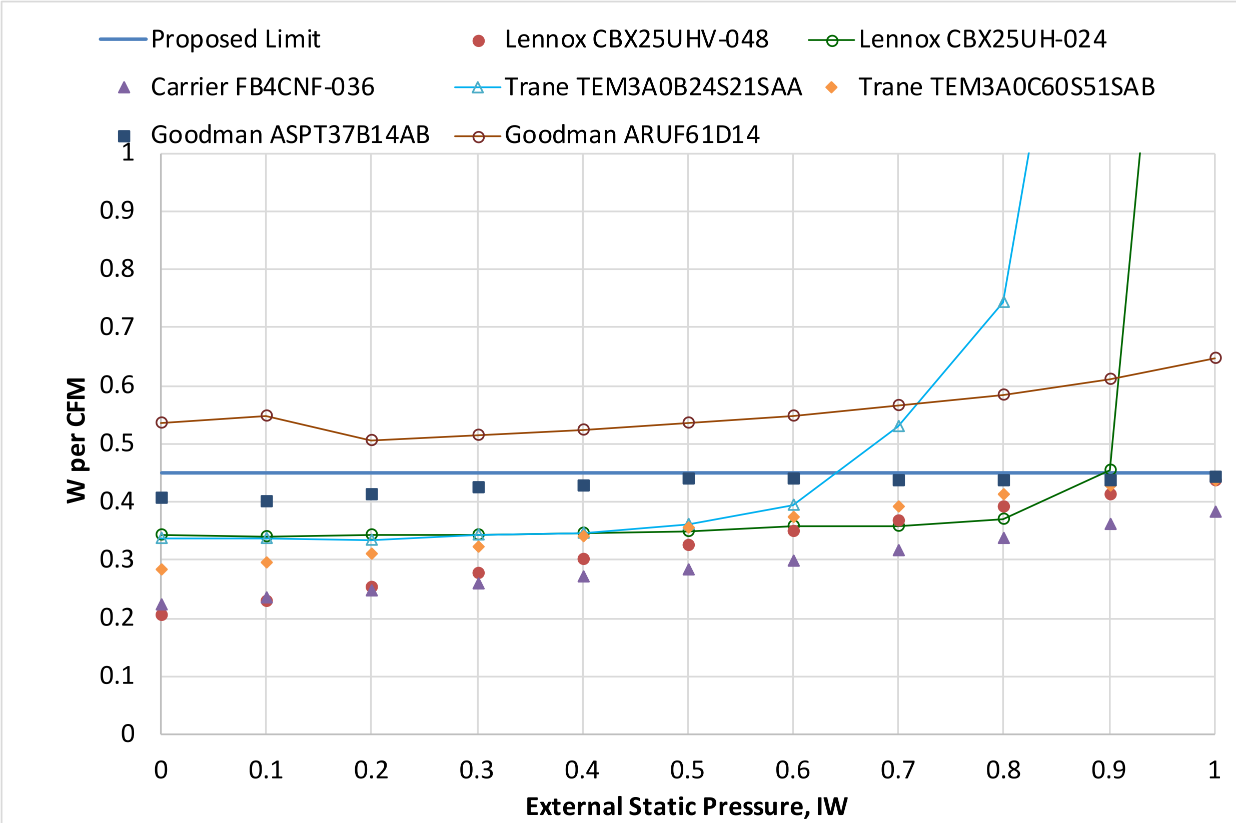



**Figure 17: Heat pump air handler efficacy comparison at highest speed settings**

### *Heat Pump Test Observations*

As shown by Figure 17 above and Table 37 that follows, all heat pump air handlers but one Goodman unit met the 0.45 W/cfm at 0.5 inch w.c. criteria, and that unit utilizes a PSC motor. Poor efficacy cannot be solely attributed to the motor type, since two of the air handlers with PSC motors showed efficacies that were comparable to or lower than two of the ECM powered air handlers. Cabinet and blower design can have a large effect on internal resistance to airflow.

All air handlers tested are capable of delivering more than 350 cfm per ton at their nominally rated capacity. The high airflow capacity of some suggests they are designed for larger heat pump outdoor units than their ratings indicate.

**Table 37: Tabulated Heat Pump Air Handler Fan Efficacy Results**

| Heat Pump | Speed Setting | External Static Pressure | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 |
| Goodman ARUF61D14AB | Black (High) | 0.485 | 0.495 | 0.505 | 0.513 | 0.524 | 0.535 | 0.548 | 0.564 | 0.584 | 0.61 | 0.647 |
| | Blue (Medium) | 0.429 | 0.438 | 0.445 | 0.452 | 0.46 | 0.468 | 0.477 | 0.49 | 0.505 | 0.524 | 0.552 |
| | Red (Low) | 0.373 | 0.383 | 0.391 | 0.399 | 0.408 | 0.42 | 0.429 | 0.444 | 0.458 | 0.509 | 0.554 |
| Goodman ASPT37B14AB | Tap 5 (High) | 0.388 | 0.401 | 0.407 | 0.401 | 0.413 | 0.426 | 0.44 | 0.436 | 0.438 | 0.437 | 0.443 |
| | Tap 4 (Medium High) | 0.352 | 0.364 | 0.366 | 0.366 | 0.379 | 0.393 | 0.408 | 0.423 | 0.438 | 0.436 | 0.441 |
| | Tap 3 (Medium) | 0.271 | 0.279 | 0.283 | 0.296 | 0.31 | 0.326 | 0.342 | 0.361 | 0.38 | 0.404 | 0.43 |
| | Tap 2 (Medium Low) | 0.235 | 0.237 | 0.247 | 0.264 | 0.278 | 0.298 | 0.315 | 0.336 | 0.359 | 0.4 | 0.43 |
| | Tap 1 (Low) | 0.197 | 0.2 | 0.215 | 0.232 | 0.25 | 0.266 | 0.287 | 0.311 | 0.34 | 0.384 | 0.43 |
| Trane TEM3A0C60S51SAB | Tap 5 (High) | 0.282 | 0.295 | 0.309 | 0.323 | 0.339 | 0.355 | 0.372 | 0.391 | 0.412 | 0.426 | 0.438 |
| | Tap 4 (Medium) | 0.254 | 0.267 | 0.282 | 0.297 | 0.312 | 0.328 | 0.345 | 0.365 | 0.386 | 0.407 | 0.425 |
| | Tap 3 (Low) | 0.229 | 0.243 | 0.255 | 0.27 | 0.312 | 0.304 | 0.324 | 0.346 | 0.368 | 0.39 | 0.42 |
| Trane TEM3A0B24S21SAA | G & Black (High) | 0.315 | 0.327 | 0.337 | 0.336 | 0.346 | 0.362 | 0.394 | 0.53 | 0.743 | 1.089 | 2.318 |
| | G & Blue (Medium) | 0.298 | 0.309 | 0.309 | 0.308 | 0.319 | 0.326 | 0.363 | 0.499 | 1.089 | 1.379 | |
| | G & Red (Low) | 0.299 | 0.309 | 0.304 | 0.305 | 0.319 | 0.342 | 0.418 | 0.509 | 0.892 | 1.427 | 1.721 |
| Carrier FB4CNF-036 | Tap 5 (Max) | 0.223 | 0.223 | 0.235 | 0.247 | 0.259 | 0.272 | 0.284 | 0.299 | 0.314 | 0.36 | 0.382 |
| | Tap 4 (E Heat) | 0.207 | 0.22 | 0.239 | 0.252 | 0.267 | 0.28 | 0.283 | 0.302 | 0.326 | 0.348 | 0.37 |
| | Tap 3 (High) | 0.214 | 0.229 | 0.239 | 0.252 | 0.253 | 0.28 | 0.296 | 3.14 | 0.34 | 0.364 | 0.387 |
| | Tap 2 (Medium) | 0.166 | 0.18 | 0.191 | 0.205 | 0.218 | 0.233 | 0.255 | 0.279 | 0.299 | 0.324 | 0.35 |
| | Tap 1 (Low) | 0.15 | 0.164 | 0.177 | 0.189 | 0.204 | 0.223 | 0.242 | 0.264 | 0.289 | 0.312 | 0.341 |
| Lennox CBX25UH-024 | G & Black (High) | 0.331 | 0.338 | 0.34 | 0.341 | 0.343 | 0.348 | 0.357 | 0.371 | 0.453 | 2.355 | |
| | G & Blue (Medium) | 0.34 | 0.34 | 0.337 | 0.331 | 0.332 | 0.33 | 0.332 | 0.342 | 0.409 | 1.784 | |
| | G & Red (Low) | 0.356 | 0.356 | 0.349 | 0.341 | 0.333 | 0.329 | 0.331 | 0.359 | 0.688 | 1.448 | |
| Lennox CBX25UHV-048 | Cool:, Adj: + | 0.249 | 0.274 | 0.299 | 0.324 | 0.348 | 0.372 | 0.396 | 0.419 | 0.425 | 0.435 | 0.446 |
| | Cool: 4, Adj: Norm | 0.209 | 0.233 | 0.255 | 0.278 | 0.302 | 0.325 | 0.347 | 0.368 | 0.39 | 0.414 | 0.434 |
| | Cool: 4: Adj: - | 0.165 | 0.188 | 0.211 | 0.234 | 0.256 | 0.278 | 0.299 | 0.321 | 0.343 | 0.364 | 0.386 |
| | Cool:3, Adj: Norm | 0.132 | 0.156 | 0.179 | 0.202 | 0.222 | 0.244 | 0.265 | 0.286 | 0.307 | 0.328 | 0.349 |
| | Cool: 2, Adj:Norm | 0.099 | 0.123 | 0.145 | 0.167 | 0.189 | 0.209 | 0.229 | 0.25 | 0.271 | 0.293 | 0.292 |
| | Cool:1, Adj: Norm | 0.073 | 0.096 | 0.118 | 0.14 | 0.161 | 0.181 | 0.203 | 0.224 | 0.245 | 0.268 | 0 |
| | Cool: 1, Adj: - | 0.061 | 0.086 | 0.108 | 0.127 | 0.151 | 0.172 | 0.194 | 0.217 | 0.24 | 0.266 | 0.292 |
| | Cont. Fan (4,4, N) | 0.052 | 0.072 | 0.094 | 0.127 | 0.137 | 0.159 | 0.182 | 0.206 | 0.232 | 0.26 | 0.288 |

Notes:

1. Cells are colored green where the efficacy is at or below 0.45 W/cfm.
2. Cells are colored red where the efficacy is above 0.45 W/cfm.
3. Where cells are blank measurements could not be obtained because static pressure could not be reached.

# Conclusions

## *Furnaces*

All furnaces except for the Carrier 59TP6A060E171214 using the “Hi” speed setting meet the proposed 0.45 W/cfm requirement at 0.75 inch w.c. Based on the FER test results, this furnace would likely not meet the 2019 federal furnace standard. This Carrier unit provides other speed settings that produce better fan efficacies, and if it can meet the 350 cfm/ton requirement in Title 24, Part 6, it would be able to meet an efficacy of 0.45 W/cfm or less

Typically, systems are designed to have a flow resistance of 0.7 inch w.c. or less. Since all the tested units provide ample opportunities to meet the proposed requirement at 0.7 inch w.c., these test results support the recommendations presented in the main body of this CASE Report.

Additionally, 75 percent of tested furnace/flow combinations would meet the proposed 0.45 W/cfm requirement even at 1.0 inch w.c. flow resistance, but not the 350 cfm/ton requirement. This indicates that many furnaces will still meet the requirement even in installations with poorly designed ducting systems and high flow resistances.

As previously noted, it is not relevant to rate furnaces based on cfm per ton before they are paired with air conditioners and before particular speed settings are field-selected. The Statewide CASE Team recommends that the Energy Commission consider changing the cfm per nominal ton rating to cfm per ton at rated AHRI conditions. This change will correct for the wide variations in nominal vs. rated capacity, and will more accurately reflect air conditioner performance as it is affected by airflow.

## *Heat Pumps*

All heat pump air handlers except the 5-ton Goodman ARUF61D14 produced efficacies well below 0.45 W/cfm at 0.5 inch w.c., which is deemed a reasonable external static pressure for heat pump air handlers with integral coils.

Given the test results and clear market availability of heat pumps capable of meeting the 0.45 W/cfm standard, the Statewide CASE Team continues to recommend that heat pumps be included in the lower efficacy requirement as proposed. This change may prevent use of certain products in California, which raises the question of whether the measure qualifies as being preemptive of federal standards. However, the existing 0.58 W/cfm limit could also limit use of some heat pump air handlers. For example, as seen in Figure 17, if the Goodman ARUF61D14 were installed in a system having an external static pressure greater than 0.7 inch w.c., it would not meet the current 0.58 W/cfm requirement.

# Laboratory Test Plan

## *Introduction*

The purpose of these tests is to determine whether a representative sample of non-weatherized furnaces with ECM-powered blowers and heat pump air handlers with either ECM or PSC motor types can meet the proposed Title 24, Part 6 requirement of delivering at least 350 cfm/ton of air using 0.45 W/cfm or less, at reasonable levels of duct static pressure. This is accomplished by testing each fan's performance at different speed settings and outlet static pressures, in order to create performance curves for each fan.

In addition, if any tested furnace fans cannot meet the proposed Title 24 requirements, more testing will be done to see if non-compliant fans meet the maximum federal Fan Efficiency Ratio (FER) of 0.44 × $Q_{max}$ + 182 (for non-weatherized, non-condensing furnaces). This FER standard is mandated for all furnace fans manufactured in or imported to the U.S., and goes into effect on July 3, 2019. The mandate is part of the Code of Federal Regulations, which refers to a ruling by the U.S. DOE.

## *Tested Equipment*

Ten furnaces with ECM-powered blowers were selected for testing, and are listed in Table 38. The furnaces come from five different manufacturers, range between 40,000 to 100,000 Btuh in heating capacity, and are designed to be combined with cooling coils ranging from two to five tons of cooling capacity. They have Annual Fuel Utilization Efficiency (AFUE) ratings between 80 and 96. All of these furnaces have ECM-powered blowers. Two of the ECMs can be set to four different speeds, six have five operating speeds, and two are variable speed. The ECMs are also controlled in two different ways: A) by holding torque constant overall operating conditions, or B) by holding flow constant overall operating conditions.

**Table 38: List of Tested Furnaces**

| Manufacturer | Model | Configurations | 2nd Config. *priority for testing | AFUE | Motor Descriptor | Motor HP | Speeds | Heating Stages | Heating Capacity (Btuh) | Cooling Capacity (Tons) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Lennox** | SL280UH090XV48B | upflow & horiz | up* | 80 | variable speed | 1/2 | var | 2 | 88,000 | 4 |
| **Lennox** | EL195UH030XE24B | upflow & horiz | up | 95 | constant torque | 1/2 | 5 | 1 | 30,000 | 2 |
| **Goodman** | GME800603BXB | upflow & horiz | up* | 80 | multi-speed | 1/2 | 5 | 2 | 60,000 | 3 |
| **Goodman** | GCEC961005CNA | down & horiz | down | 96 | multi-speed | 1 | 5 | 2 | 100,000 | 5 |
| **Carrier** | 58PHY04510012 | up, down, horiz | down | 80 | none given | 1/3 | 5 | 1 | 42,000 | 3 |
| **Carrier** | 59TP6A060E141114 | up, down, horiz | down* | 96 | variable speed | 1/2 | var | 2 | 60,000 | 3 |
| **Trane** | XT80 TUD1C100A9H51B | up, down, horiz | down | 80 | constant torque | 1 | 4 | 2 | 100,000 | 5 |
| **Trane** | XT95 TDH1B040A9H21A | up, down, horiz | down* | 95 | constant torque | 1/2 | 4 | 1 | 40,000 | 2 |
| **Rheem** | R802VA075421MXB | upflow & horiz | up | 80 | variable speed | 3/4 | 5 | 2 | 75,000 | 4 |
| **Rheem** | R92TA0851521MSA | upflow & horiz | up | 92 | constant torque | 1 | 5 | 1 | 84,000 | 5 |

Table 39 lists the heat pump air handlers that were chosen for testing. They represent a mix of motor types (four ECM and three PSC) and cooling capacities ranging from two to five tons. Originally, ten units were selected but due to delays in delivery, the field was narrowed to these seven representative units. None were tested with electric resistance strip heat coils installed.

**Table 39: List of Tested Heat Pumps**

| Manufacturer | Model | Configurations | Motor Type | Motor Descriptor | Motor HP | Speeds | Cooling Capacity (Tons) |
|---|---|---|---|---|---|---|---|
| **Lennox** | CBX25UHV-048-230-01 | upflow, horizontal | ECM | variable speed | 1 | 12 | 4 |
| **Lennox** | CBX25UH-024-230-01 | upflow, horizontal | PSC | multi-speed | 1/3 | 3 | 2 |
| **Goodman** | ASPT37B14AB | multi-position | ECM | multi-speed | 3/4 | 5 | 3 |
| **Goodman** | ARUF61D14 | multi-position | PSC | multi-speed | 3/4 | 3 | 5 |
| **Carrier** | FB4CNF036 | multi-position | ECM | multi-tap | 1/2 | 3 | 3 |
| **Trane** | TEM3A0C60S51SA | multi-position | ECM | none given | 3/4 | 3 | 5 |
| **Trane** | TEM3A0B24S21SA | multi-position | PSC | none given | 1/4 | 3 | 2 |

### *Experimental Setup*

Using the ATS HVAC test facility, ATS staff shall conduct testing of ten residential furnaces for blower performance, in terms of cfm per watt at different levels of external resistance. The test apparatus will utilize existing systems in the ATS HVAC lab to provide measurement of airflow at different levels of backpressure. Due to equipment crowding in the “Indoor Room” of the lab, the test furnaces will be placed in the “Outdoor Room” with their discharge ducted to the Indoor Room airflow measurement apparatus. Backpressure at the furnace discharge will be set and maintained through a combination of changing the number of open nozzles in the airflow apparatus and adjusting the speed of the booster blower downstream of the apparatus.

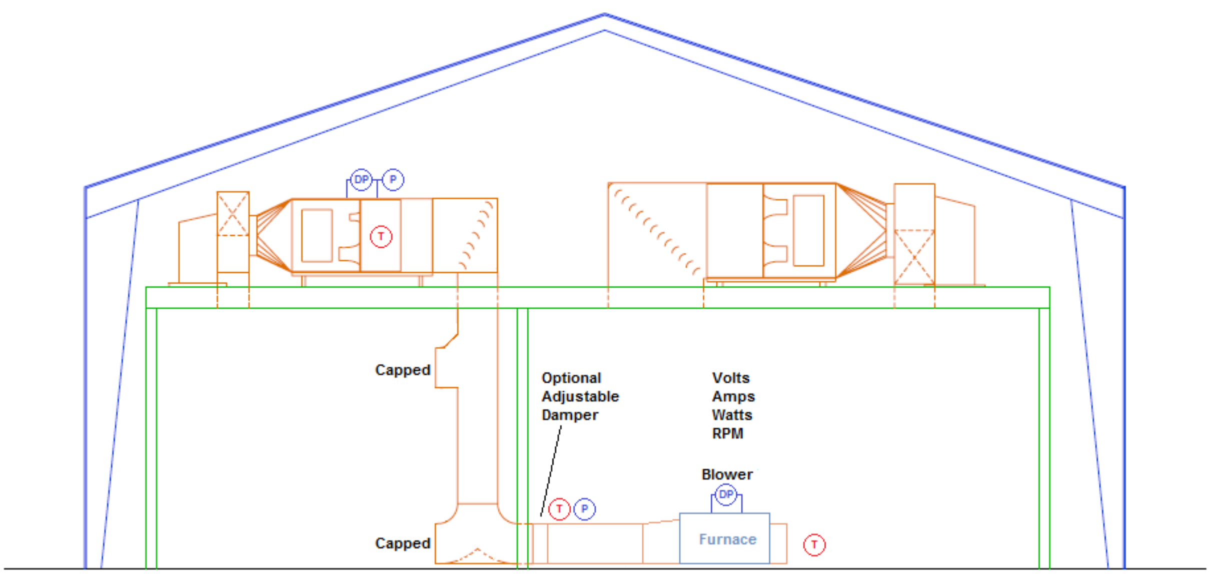



**Figure 18: HVAC lab setup for furnace and heat pump tests**

Optionally, a damper may be placed downstream of the pressure measurement to provide additional resistance if not enough flexibility is possible using the selected nozzle combinations and by keeping the air velocity through the nozzles within the range recommended by standards (3,000 to 7,000 fpm). This may not be advisable as it may create more potential for duct leakage.

All testing is performed with a free or short ducted inlet (less than 12 inches) and a ducted outlet. The location of the pressure measurement for backpressure shall be done in accordance with ASHRAE Standard 37-2009. There are two ASHRAE Standards that specify minimum straight duct length and use of flow straighteners and settling means to ensure reliable pressure measurements. The 2012 DOE procedure for furnace blower testing references AMCA 210/ASHRAE 51-1999, while the current draft of the procedure revision references ASHRAE 37-2009. The main difference is that ASHRAE 51-1999 requires a flow straightener, as well as a longer length of duct than ASHRAE 37-2009 (see Figure 20). The preference is to use ASHRAE 37-2009 to save space and to reduce errors from duct friction.

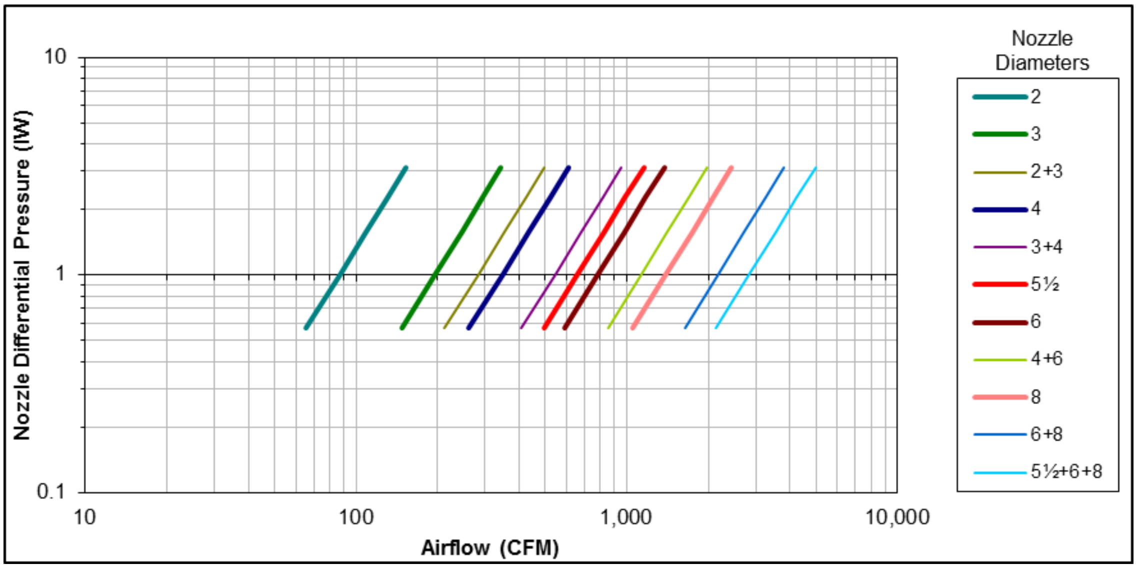



**Figure 19: Airflow apparatus operating range**

Pressure measurement setup per ASHRAE 37-2009:
(DOE e-CFR document references this method.)

Test setup per AMCA 210/ASHRAE 51-2009:
(DOE 2012 PDF document references this method – longer duct plus straightener.)

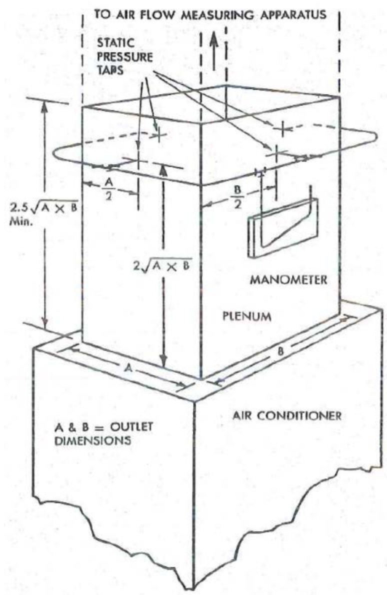
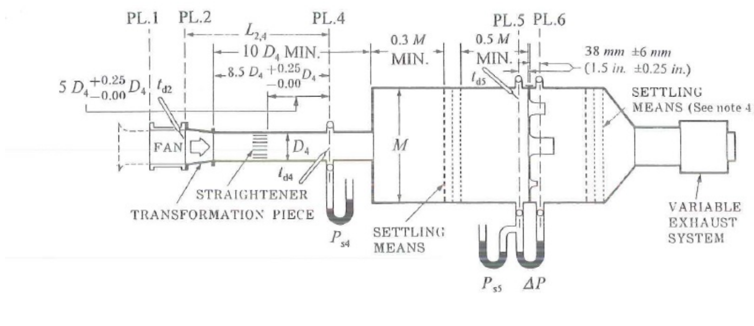



Figure 7a External static pressure measurement.




NOTES

1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Additional ductwork of any size, including elbows, may be used to connect between the chamber and the exit of the 10 *D* minimum test duct.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
5. Minimum *M* is determined by the requirements of 6.3.1 for this figure.

FLOW AND PRESSURE FORMULAE

$$*Q_5 = \sqrt{2}\ Y\sqrt{\Delta P / \rho_5}\ \Sigma(CA_6)$$

$$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$$

$$V_4 = \left(\frac{Q}{A_4}\right)\left(\frac{\rho}{\rho_4}\right)$$

$$*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2 \rho_4$$

$$P_{v2} = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$$

$$P_{t1} = 0$$

$$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} + \frac{L_e}{D_{h4}}\right) P_{v4}$$

$$P_t = P_{t2} - P_{t1}$$

$$P_s = P_t - P_v$$

*The formulae given above are the same in both the SI and the I-P systems, except for $Q_5$ and $P_{v4}$: In the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.

Figure 10 Outlet Duct Setup-Multiple Nozzles in Chamber

ANSI/AMCA STANDARD 210 ANSI/ASHRAE STANDARD 51 29

**Figure 20: Standard pressure measurement options**

From recent testing of a split system heat pump using the ASHRAE 37-2009 outlet duct configuration, 10 second pressure measurements over at least a half hour were found to vary by less than 0.0062 inch w.c. at a static pressure of 0.1 inch w.c., and by less than 0.0048 at a static pressure of 0.45 inch w.c. We aim to set static pressure for this furnace fan test to within ±1 percent of the highest static pressure test value of 0.9 inch w.c., or to within ±0.009 inch w.c.. Even though the furnaces tested will not have a cooling coil to help settle the flow, we feel confident that the shorter ASHRAE 37-2009 outlet duct configuration can meet this level of accuracy.

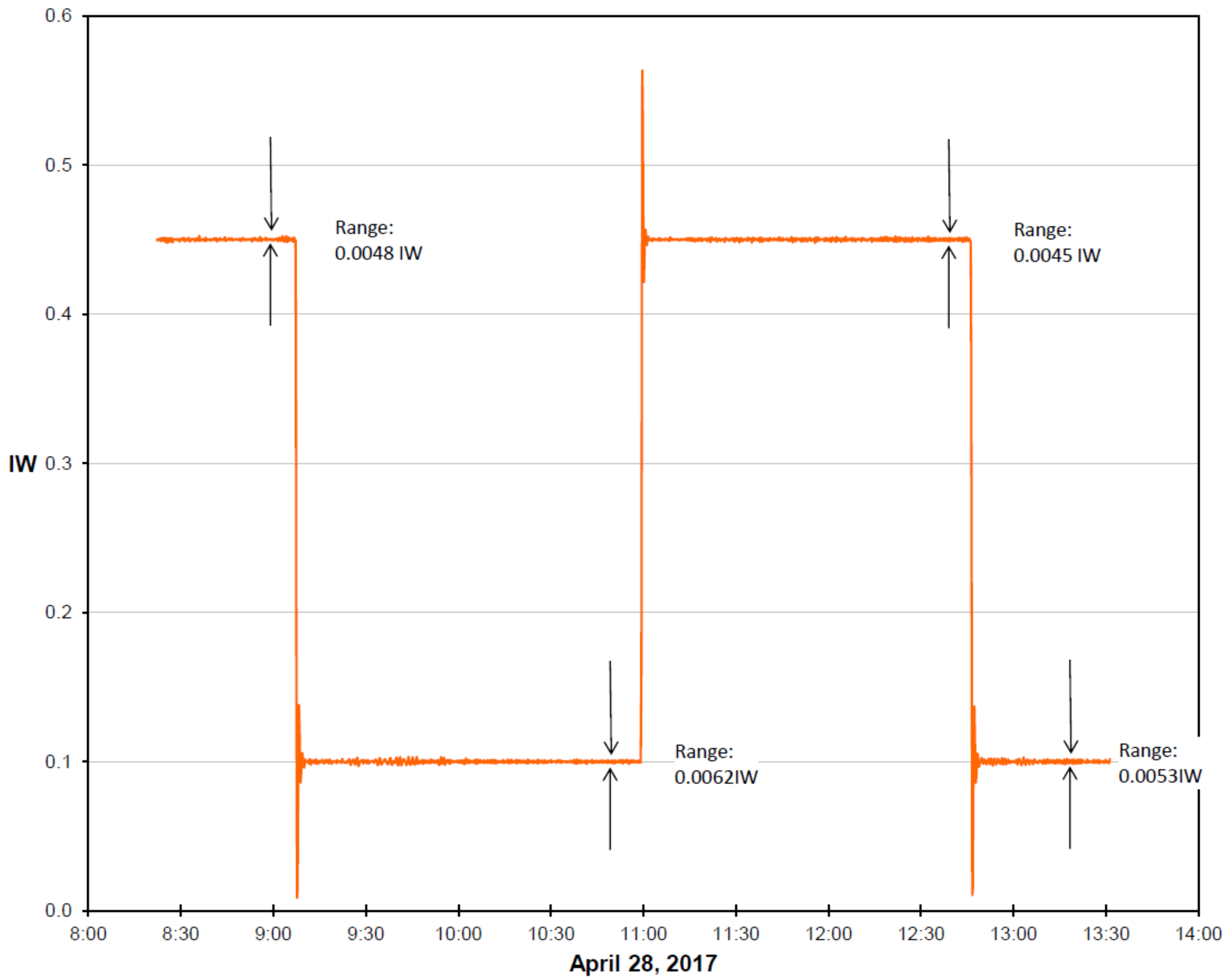



**Figure 21: Recent test holding fixed backpressure**

The length of the transformation piece (from the furnace outlet, which varies in size with each furnace, to the length of duct where outlet static pressure is measured) will vary to accommodate the requirements of Section 6.2.5 and Figure 5 of ASHRAE Standard 51-1999 for the maximum angle of convergence or divergence of the duct wall.

Great care must be taken to keep duct leakage to a minimum, since no leakage corrections are made to the test results. Use mastic or foil tape to seal the transformation piece at the furnace outlet and outlet duct connections. Look, listen, and feel for any air leaks at all duct connections in the test apparatus after each new furnace has been installed, and reseal leaks with mastic or foil tape as needed.

All furnaces are to be initially positioned for horizontal airflow. A subset of four to six furnaces are to be tested again in up-flow or down-flow position with additional ducting. Due to height restrictions, an elbow may be needed in either up- or down-flow orientation at the test unit discharge prior to the pressure measurement.

The temperature rise across the blower (with or without the burner in operation) will be measured as the difference between two thermocouple arrays. A short duct (12 inches) may be attached to the intake side of the furnace to provide a structure to hold the thermocouples in place. If used, the backpressure measurement will be a differential static pressure measurement between the manifold on the discharge side, and a manifold attached to the short intake duct. The temperature rise is of interest even with the burner off as an indication of how much heating the motor actually contributes. No filters will be used.

The furnace burner will not be fired for any performance curve testing, but may need to be fired if any FER testing (described later in this test plan) is performed. The downstream temperature array will be installed such that when the burner on the furnace is activated, the temperature sensors will not “see” the hot surfaces in the furnace. This generally means the array is placed downstream of an elbow and/or a mixing device. Figure 22 shows the recommended locations from ASHRAE 103.

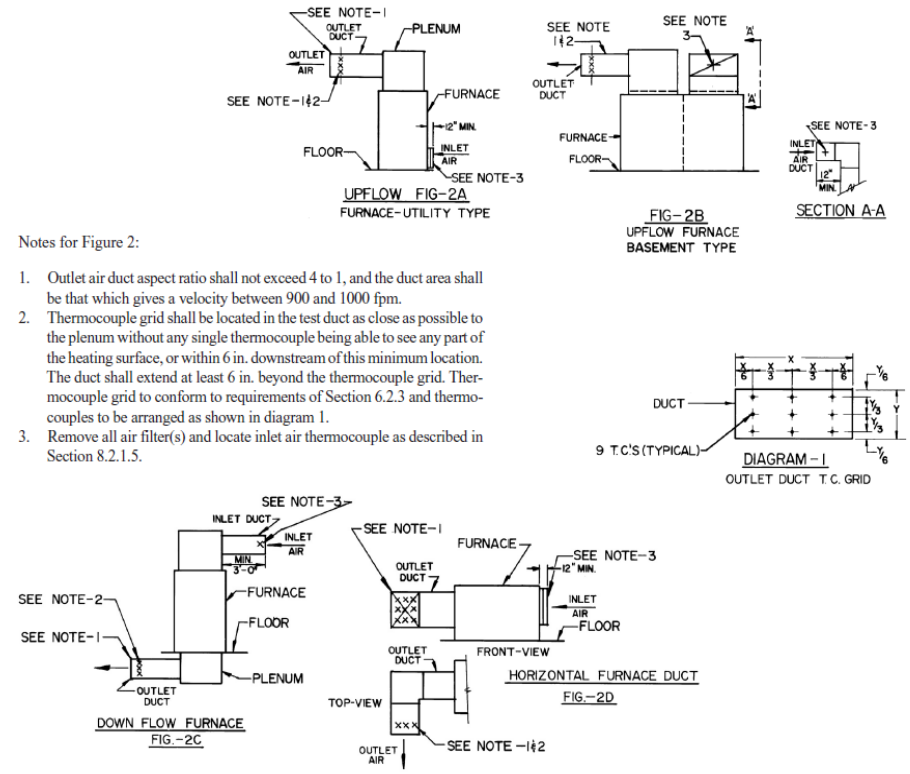



Figure 2 Duct and plenum arrangement for gas, oil, and electric forced-air central furnaces (including direct vent).

**Figure 22: Temperature measurement setup per ASHRAE 103**

## *Instrumentation*

The controllable parameters of the test include:

- Blower speed setting
- Furnace external resistance (or differential pressure)
- Return air temperature or density
- Supplied voltage (within 1 percent of nameplate voltage; held via a voltage regulator)

The dependent variables to be measured include:

- Airflow rate (cfm, referenced to return air density)
- Power consumption (watts), and power quality, of furnace input and blower only
- Blower rotational speed (revolutions per minute (rpm))
- Blower pressure rise
- Blower temperature rise

Table 40 lists the instrumentation already installed in the HVAC test lab that will be used for these tests.

**Table 40: Instrumentation List**

| Measurement | Instrument | Manufacturer/Model | Accuracy |
|---|---|---|---|
| Barometric Pressure | Multi-function weather station on roof of building | Vaisala WTX520 | ±0.007 PSIA (±50 Pa) |
| Return air dry-bulb temperature | Average of 4 Type-T thermocouples arrayed in a 2×2 grid across the intake duct, or 4 RTDs. | Therm-X<br><br>Burns Engineering | ±0.5°F<br><br>±0.2°F |
| Return air dew-point temperature and/or wet bulb temperature | Chilled mirror dew point sensor<br><br>Paired wet and dry bulb RTDs | General Electric Optica<br>Burns Engineering | ±0.36°F<br><br>±0.2°F |
| Supply air dry-bulb temperature | Average of 9 Type-T thermocouples arrayed in a 3×3 grid across the supply duct and downstream of the static pressure measurement taps, and not "visible" to the heated burner surfaces if it needs to be activated. | Therm-X | ±0.5°F |
| Supply-return differential pressure | Pressure transmitter attached to manifolded pressure taps at center of each side of duct entering and leaving the unit | Rosemount 3051C | ±0.04% of span (-0.5 to 1.5 IW) |
| Blower differential pressure | Pressure transmitter connected between the taps on either side of the blower (i.e. across the furnace partition). | Rosemount 3051C | ±0.04% of span (-1 to 3 IW) |
| Supply airflow station upstream static pressure | Pressure transmitter attached to manifolded pressure taps at center of each side of the flow box upstream of the nozzle partition | Rosemount 3051C | ±0.04% of span (-1 to 3 IW) |
| Supply airflow station differential pressure | Pressure transmitter attached to manifolded pressure taps at center of each side of the flow box on both sides of the nozzle partition | Rosemount 3051C | ±0.04% of span (0 to 4 IW) |
| Supply airflow station dry bulb temperature | Single fast-response RTD upstream of nozzles | Burns Engineering | ±0.2°F |
| Unit Supply Power, Voltage and Current | Two elements of a 3-element true-RMS power meter with outputs for total power, voltage and current. One element is for the input to the furnace and the other is just for the blower. | Yokogawa WT330 | ±(0.1% of reading +0.1% of range) |
| Blower Speed | Optical tachometer reading reflective tape on indoor blower impeller. | Monarch ACT-1B | ±1 RPM or 0.005% of reading |
| Gas Quantity (if needed) | Diaphragm meter with pulse output (2000 counts per cubic foot) | American Meter AC-250 with IMAC pulse head | |
| Gas Flow Rate (if needed) | Thermal mass flow meter | Sierra SmartTrak 100 | ±1.0% of full scale |
| Gas Heating Value (if needed) | Natural gas chromatograph | Rosemount 370XA | ±0.025% repeatability |

a. All pressure and temperature instruments will be calibrated against laboratory standards prior to testing.

# Test Procedures

Various operating conditions are simulated by controlling static pressure at the furnace outlet. Static pressure control is done by adjusting flow nozzle combinations and/or adjusting the speed of an auxiliary exhaust fan, according to Section 6.4 of ASHRAE 51-1999.

The test facility has the ability to control inlet conditions by adjusting temperature and humidity levels in the inlet chamber. For the fan curve performance tests, air density should be held within ± 0.5 percent of 0.075 pounds mass per cubic foot (lbm/ft$^3$). This is the density designated as "Standard Air" in Section 3.2.7 of ASHRAE 51-1999.

In addition, adjustments may be made to the static pressure at the furnace outlet in order to keep the value of "k" constant to within ± 1 percent for each fan. The value of k is calculated as:

$$k = P / (\rho \times N^2)$$

where P is the outlet total pressure found by adding the static pressure in the outlet duct to the barometric pressure at the fan inlet, and N is the fan rotational speed. The duct air density, ρ, is calculated using equations 8.1 through 8.4 from ASHRAE 51-1999, based on barometric pressure, inlet dry and dew point or wet bulb temperatures, and the static pressure and dry bulb temperature in the outlet duct.

Voltage supplied to the unit under test will be held to within 1 percent of the nameplate voltage via a voltage regulator.

### *Fan Performance Curve Testing Procedure*

Once each furnace has been installed, and all ducts have been carefully sealed, adjust the inlet conditions to reach an air density of 0.075 lbm/ft$^3$ ± 0.5 percent.

Adjust the fan motor speed taps for the highest airflow setting. Adjust exhaust fan and throttling valves until an outlet duct static pressure of 0.1 ainch w.c. has been reached. Allow the system to come to steady state, then record the measurements listed in Table 40. Data recording will be done at a rate of every ten seconds and averaged over ten minutes, subject to the test tolerances specified in ASHRAE 36-2009. Keep adjusting exhaust fan and nozzles to reach successive outlet static pressures of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 inch w.c., and take steady state readings at each static pressure. Using information about the flow nozzle areas, calculate fan airflow based on the dry-bulb and differential pressure measurements taken across the nozzle or chamber and using the appropriate equations from Section 8.3 of ASHRAE 51-1999.

Note that the static pressure for each test can be within a tolerance of ±1 percent of the highest static pressure reading to be made during these tests, which is within ±0.9×1 percent = ±0.009 inch w.c. The static pressures to aim for (0.1, 0.2, 0.3 inch w.c., etc.) may also be adjusted slightly to keep the value of "k" constant, as described above.

### *Fan Energy Rating (FER) Testing*

FER testing will only be needed for fans that cannot supply at least 350 cfm per ton of nominal cooling capacity at top speed and a static pressure of 0.5 inch w.c., while using 0.45 W/cfm or less. The FER test procedure for furnace fans without an adding cooling coil in place has three basic steps:

1. At the maximum (cooling) fan speed setting and a fan outlet static pressure between 0.65 and 0.70 inch w.c., and measure fan energy and flow characteristics.
2. Keeping the throttle position and exhaust fan settings as they are, adjust the fan to its fan-only/continuous fan setting, usually the lowest fan speed setting and measure all energy and flow characteristics.

3. Again, keeping the throttle position and exhaust fan settings as they were in step 1, adjust the fan to its **maximum** heating speed setting, fire up the furnace burner to its **lowest** heat rate setting (equal to its maximum setting for single stage furnaces), make sure the inlet air is heated by at least 18 degrees Fahrenheit, and measure energy and flow characteristics once equilibrium has been reached.

The same test apparatus from the Fan Performance Curve testing can be used as long as the furnace can also be supplied with natural gas, is hooked up to an appropriate flue, and is fired according to specifications, all as laid out in ASHRAE Standard 103-2007.

Based on these three measurements, FER is calculated as follows:

$$FER = \frac{(CH \times E_{Max}) + (HH \times E_{Heat}) + (CCH \times E_{Circ})}{(CH + 830 + CCH) \times Q_{Max}} \times 1000$$

The values of E represent the power use of the fan in watts at each fan setting, Q max is the maximum nameplate fan flow in cubic feet per minute (cfm), and the operating hours are defined as CH = annual cooling hours (640), CCH = annual constant circulation hours (400), and HH = annual heating hours (830/HCR). HCR is the heating capacity ratio defined as the flowrate at the maximum heating speed divided by the maximum nameplate flow rate of the unit (usually the maximum cooling speed). More information about the FER test procedure can be found in the DOE Uniform Test Method for Measuring the Energy Efficiency of Residential Furnace Fans.

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