eTRM
OFFICIAL SOURCE
CA Energy Efficiency Measure Data

MEASURE CHARACTERIZATION

Smart Fan Controller, Residential

https://www.caetrm.com/measure/SWHC059/01/

USE CATEGORY
HC - HVAC

COMMITTED
August 1, 2023 5:47 AM

STATUS
CPUC Approved

EFFECTIVE START DATE
August 1, 2023

VERSION
SWHC059-01

DOWNLOADED
September 20, 2023 1:41 PM

Technology Summary

Heating, ventilating, air conditioning (HVAC) systems inadvertently waste cooling or heating energy by providing zero or sub-optimal fixed fan-off delays which do not deliver all available energy to a conditioned space at the end of thermostat calls for cooling or heating. The smart fan controller (SFC) operates the HVAC fan for extended variable fan-off delays at the end of thermostat calls for cooling or heating to save energy and increase thermal comfort.

The air conditioning (AC) evaporator cools the conditioned space by removing sensible and latent heat from the return air which reduces the supply air temperature and humidity to satisfy the thermostat call for cooling and maintain comfortable space conditions. Latent heat is removed as water vapor is condensed out of the air due to the temperature of the evaporator coil being less than the return air dew point temperature. Latent heat is the quantity of heat absorbed or released by air undergoing a change of state, such as water vapor condensing out of the air as water onto a cold evaporator coil or cold water evaporating to water vapor which will cool the air. Most evaporators are cold and wet (below 40 to 50°F) after the compressor turns off. Cold water condensed on the evaporator coil after the compressor turns off is generally wasted. The evaporator coil is still partially flooded with the liquid refrigerant and this residual liquid refrigerant can be used to provide space cooling to optimize and improve system efficiency. With zero or sub-optimal fan off delays, the evaporator absorbs heat from outside the HVAC system, and cold water on the coil evaporates or falls off the coil and flows down the condensate drain. After the AC compressor turns off, the SFC continues operating the HVAC fan to circulate return air across the evaporator coil and provide additional sensible cooling. Additional sensible cooling provided during the fan delay period reduces the conditioned space temperature enough to lengthen the AC compressor off cycle and postpone the start of the next cooling cycle. Longer AC compressor off cycles increase energy savings, outweighing energy use associated with extended variable fan-off delays.

Southern California Edison (SCE) funded an Emerging Technologies (ET) program study to evaluate the potential energy efficiency benefits associated with the SFC extended variable fan-off delay for cooling only. R972 Third party laboratory tests were also performed on split- and packaged HVAC systems to evaluate energy savings for the SFC extended variable fan-off delay for Direct Expansion (DX) cooling and gas furnace heating, heat pump heating, hydronic heating, and electric resistance heating systems. R3126 R3127 The SFC extended variable fan-off delays recover cooling energy from evaporator coils after the compressor turns off to evaporatively cool the conditioned space which increases comfort and saves 10 to 21% on cooling energy based on the SCE ET program study and 10 to 32% based on third party laboratory tests. R972 R3126

Emerging Technologies

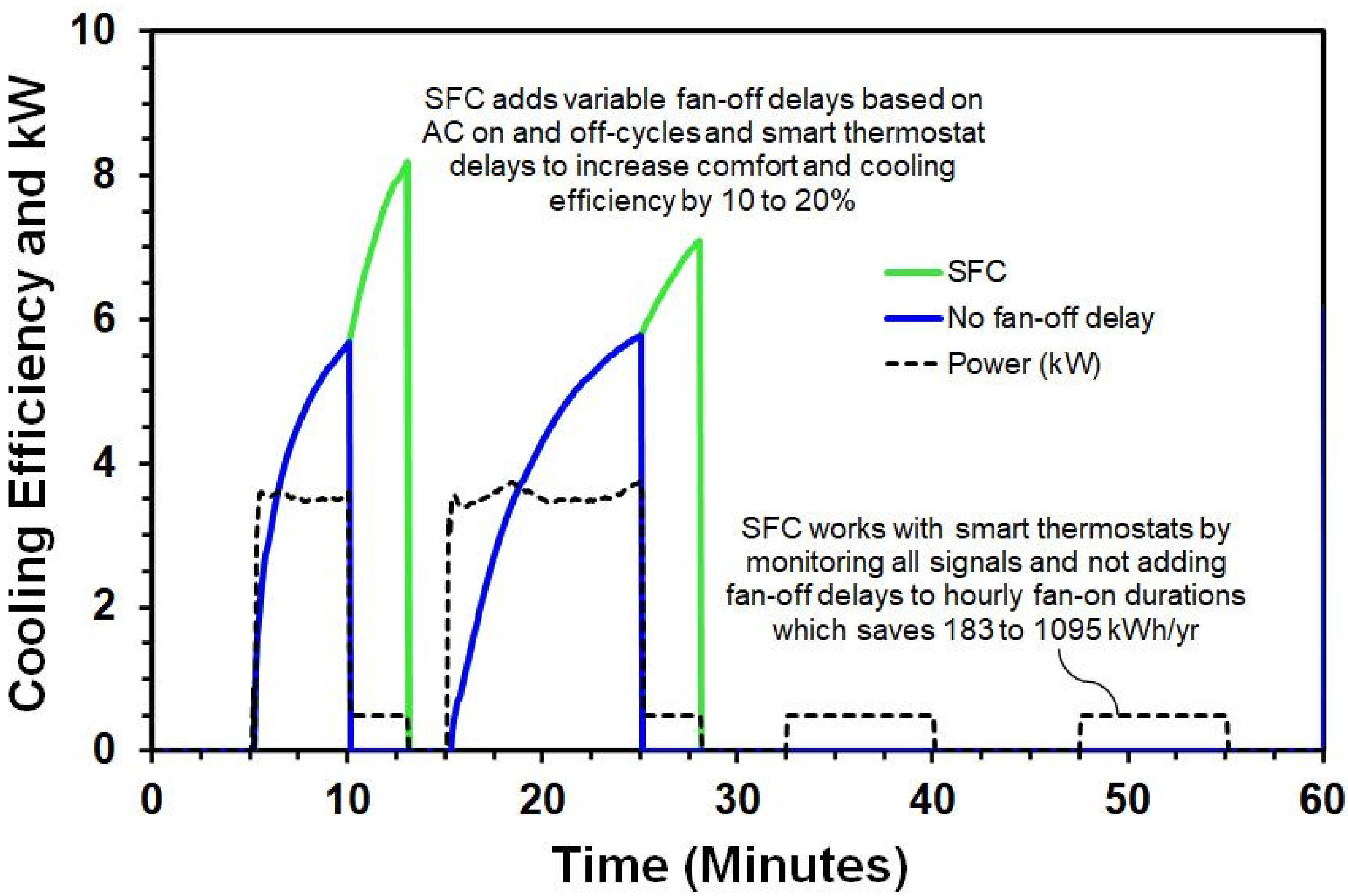
ETP FLAG (PROJECT NUMBER) (TEXT) R972	PROGRAM FUNDING YEAR (TEXT)
ET11SCE1130	**2010-2012**

Gas furnaces heat conditioned spaces by delivering warm air at low or medium fan speeds with Heat Exchanger (HX) operating temperatures of 325 to 400 degrees Fahrenheit (°F). On older furnaces, the SFC energizes the fan to a higher fan speed after the heat exchanger reaches operating temperatures to satisfy the thermostat call for heating sooner and save gas energy. On newer furnaces the fan speed is controlled at low or medium speed, and the SFC variable fan-off delay fan speed is set to the circulation fan speed which is typically low or medium. After a 2-minute base fan-off delay the HX temperature is about 220 to 280°F with a 40 to 50°F air temperature rise indicating significant undelivered heating energy based on field tests of a base gas furnace. R3141 (See tab F23) After the SFC variable fan-off delay of 3 to 6-minutes, the average HX temperature is 120 to 190°F and the conditioned space temperature is 1 to 2 °F above the base conditioned space temperature which increases thermal comfort and off-cycle time and provides 10 to 25% gas savings based on field tests of the same furnace with SFC extended variable fan-off delays. R3141 (See tab F23) Please refer to figure titled "Tests of base gas furnace with 2-minute fan-off delays and SFC extended variable fan-off delays" in Gas Savings (therms) section. R3141 (See tab F23)

Heat pumps and hydronic heating systems deliver warm air with average HX operating temperatures of 110 to 160°F. After zero to 60-second base fan-off delays the air temperature rise is 20 to 30 indicating more heating energy is available. R3127 After the SFC variable fan-off delay of 2 to 3.5-minutes, the average temperature rise is 7 to 10°F and the conditioned space temperature is 0.5 to 1°F above the upper thermostat differential which increases thermal comfort and off-cycle time and provides 10 to 15% savings based on third party laboratory tests. R3127

Measure Case Description

The measure case is defined as a smart fan controller (SFC) installed to operate the HVAC fan for extended variable fan-off delays on systems with or without a smart communicating thermostat (SCT). The Smart Fan Controller (SFC) saves energy and reduces peak electricity demand by providing variable fan-off delays after the thermostat call for cooling or heating to deliver additional sensible cooling or heating energy to the conditioned space which improves energy efficiency, thermal comfort, and extends off cycle times. The SFC fan-off delays vary from a minimum of 0 to 2 minutes to a maximum of 3.5 to 6 minutes for cooling or heating depending on system type and is adjusted based on the cooling or heating on and off times. The SFC can also control a gas furnace heating fan from a default fan speed to a higher fan speed after the heat exchanger has reached operating temperature (for enabled systems). The higher fan speed reduces time required to satisfy the thermostat call for heating and reduces on-cycle times. The SFC works with smart thermostats by monitoring the Air Conditioning (AC) compressor Y signal, fan G signal, and heat W signal to avoid adding fan-off delays to short cycles or to intermittent fan-on durations selected by smart thermostat users. Research studies indicate 9 to 31% of users select continuous or hourly fan-on controls increasing electricity use by 1054 to 3520 kWh/yr. R3121 R3122 R3123 R3124 Monitoring all thermostat signals and not adding fan-off delays to fan-on durations can save 183 to 730 kWh per year as shown in the following figure . The 183 kWh/yr savings are based on adding 2.5 minutes to 5-minute fan-on durations per hour with 0.5 kW fan and the 730 kWh/yr savings are based on two 10-minute fan-on durations per hour.



SFC works with smart thermostats to increase energy savings

The SFC detects smart thermostat fan-off delays and adjusts SFC variable fan-off delays to not interfere with savings opportunities from smart thermostats. The SFC monitors on- and off-cycles to determine whether variable fan-off delays are providing cooling or heating energy savings and Fault Detection Diagnostic (FDD) algorithms dynamically adjust fan-off delays based on the duration of the on- and off-cycles. Ecobee provides a default 30-second fan-off delay which is ineffective for HVAC systems with fixed fan-off delays of 30 to 120-seconds for cooling or heating (insert ecobee reference). Google smart thermostat Airwave option works with early AC compressor turn-off (EACT) when indoor relative humidity is less than a certain level (e.g., 29%) and provides a short fan-off delay after shorter and more frequent cooling cycles (enter Google nest reference). Google Nest help says "compressor coils stay cold and can generate cold air for 5-10 minutes after the compressor has been turned off." (enter Google nest reference) Field tests indicate Airwave provides an average cooling fan-off delay of 1.05 +/- 0.16 minutes for 94 of 114 AC cycles over 33.3 hours which is slightly longer than 1-minute fixed fan-off delays provided by new HVAC systems. R2130

Offering ID

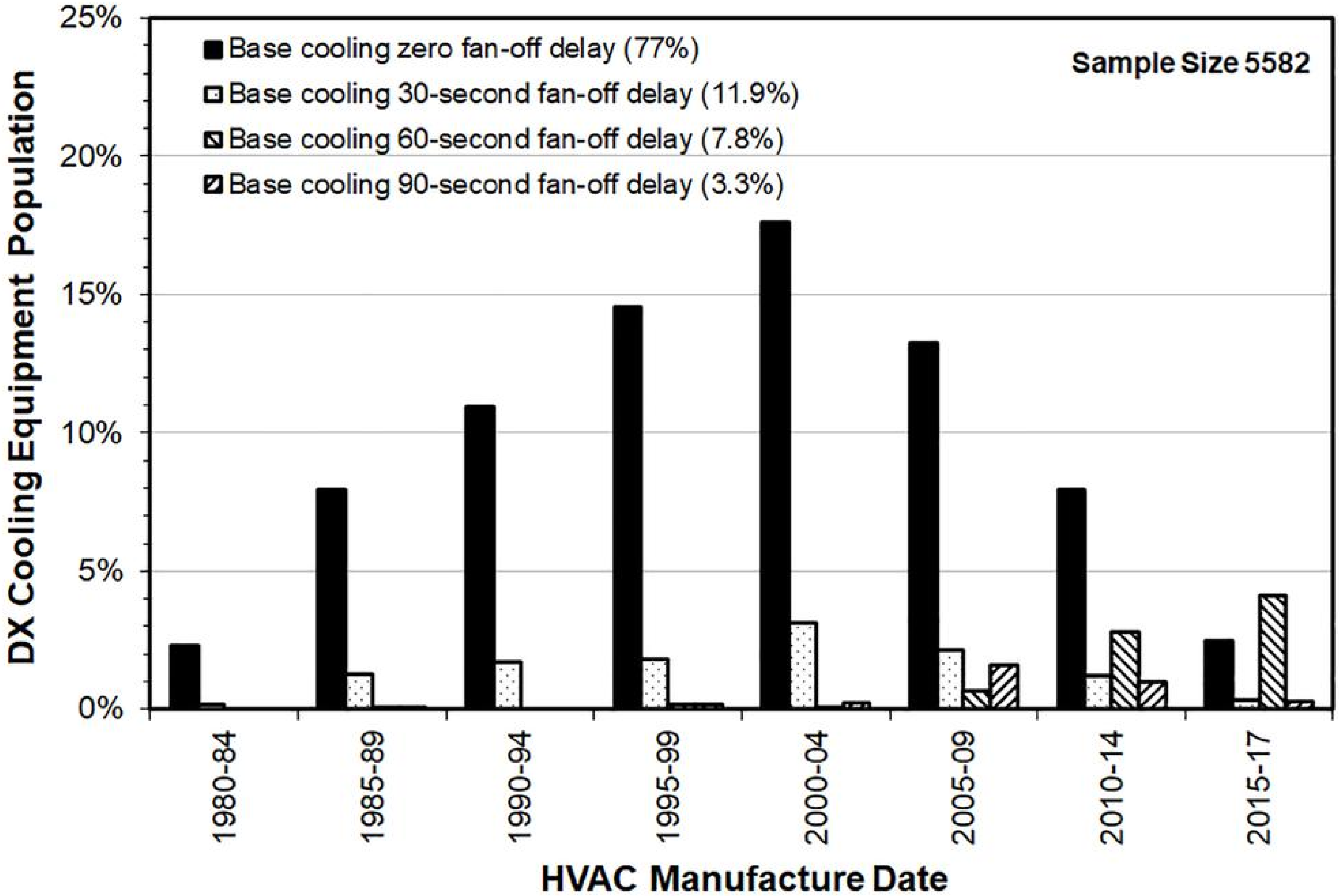
MEASURE CASE EQUIPMENT	MEASURE APPLICATION TYPE	STATEWIDE MEASURE OFFERING ID (TEXT)	MEASURE OFFERING DESCRIPTION (TEXT)
SFC	AOE	**A**	**Smart fan controller (SFC), AOE**
SFC	NR	**B**	**Smart fan controller (SFC), NR**
SFC with SCT	AOE	**C**	**Smart fan controller (SFC) with smart communicating thermostat (SCT), AOE**
SFC with SCT	NR	**D**	**Smart fan controller (SFC) with smart communicating thermostat (SCT), NR**

.

Base Case Description

The base case is defined as a residential central package or split HVAC system with or without a smart communicating thermostat (SCT). The base case may also include an HVAC system with a previously installed non-smart "legacy" fan controller that only monitors the fan "G" signal and provides fan-off delays after every fan-on duration which will increase energy use and interfere with smart thermostat savings (see discussion below). R1587 R3048 To avoid double-counting savings when replacing a "legacy" fan controller, the SFC measure will only be installed to replace a "legacy" fan controller with installation date earlier than 5 years prior to installing the SFC (e.g., for 2024 the installation date would be 2019, etc.). The manufacturing date on the UL label will be collected to identify when the "legacy" fan controller was installed.

There is no code regarding fan-off delays. The base case HVAC system has either a zero fan-off delay or a fixed fan-off delay after the compressor or furnace turn off which wastes cooling and heating energy that is not delivered to the conditioned space. Most fans turn off when compressor turns off and about 23% continue to operate the fan for a fixed fan-off time delay of 30 to 90 seconds after the compressor turns off as shown in the following figure . Systems with gas furnaces operating in heating mode have a fixed 30 to 120 second fan-off time delay. Most heat pumps, hydronic and electric heating systems have zero fan-off time delay and 38% have fixed 30 to 65 second time delay. The direct-expansion cooling base case fan-off delay varies from 0 to 90 seconds. The average cooling fixed fan-off delay is 49-seconds based on 1284 units with non-zero delays in a sample of 5582 AC units where 4298 or 77% had no fan-off delay as shown in the following figure. R3139



Distribution of DX Cooling Equipment Age and Base Cooling Fan-Off Delay

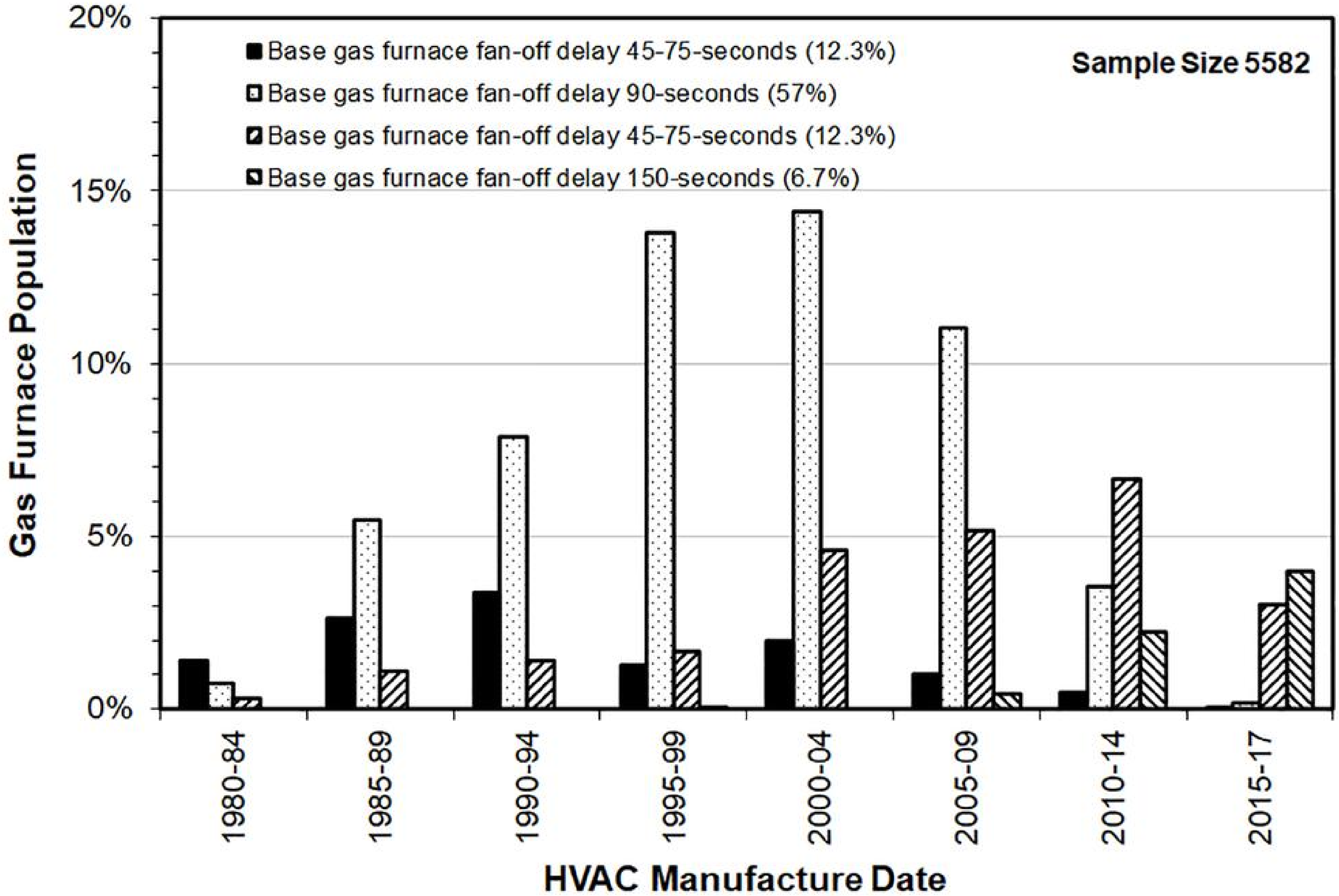
This measure applies to all fully functional residential central package or split HVAC systems equipped with cooling evaporator Direct Expansion (DX) coils and heating gas furnace, heat pump (air or water source), hydronic, or electric resistance heating systems. The measure also applies to residential central package or split HVAC systems with gas-only heating without cooling evaporator (DX) coils. Manual set fan-off time delay fan controllers are not eligible.

HVAC systems manufactured in 2010 and thereafter will include some level of fan-off control delay capability as indicated by a high-level of Industry Standard Practice (ISP) effort supported as part of this measure package update. R3046 However, only 48.5% of newer units manufactured from 2010 to the present have 30 to 90-second cooling fan-off delays while 51.5% still have no cooling fan-off delays, and 77% of new and existing units have zero fan-off delays based on data shown in the following table. R3139

DX Cooling Manufacturing Date versus Base Cooling Fan-Off Delay

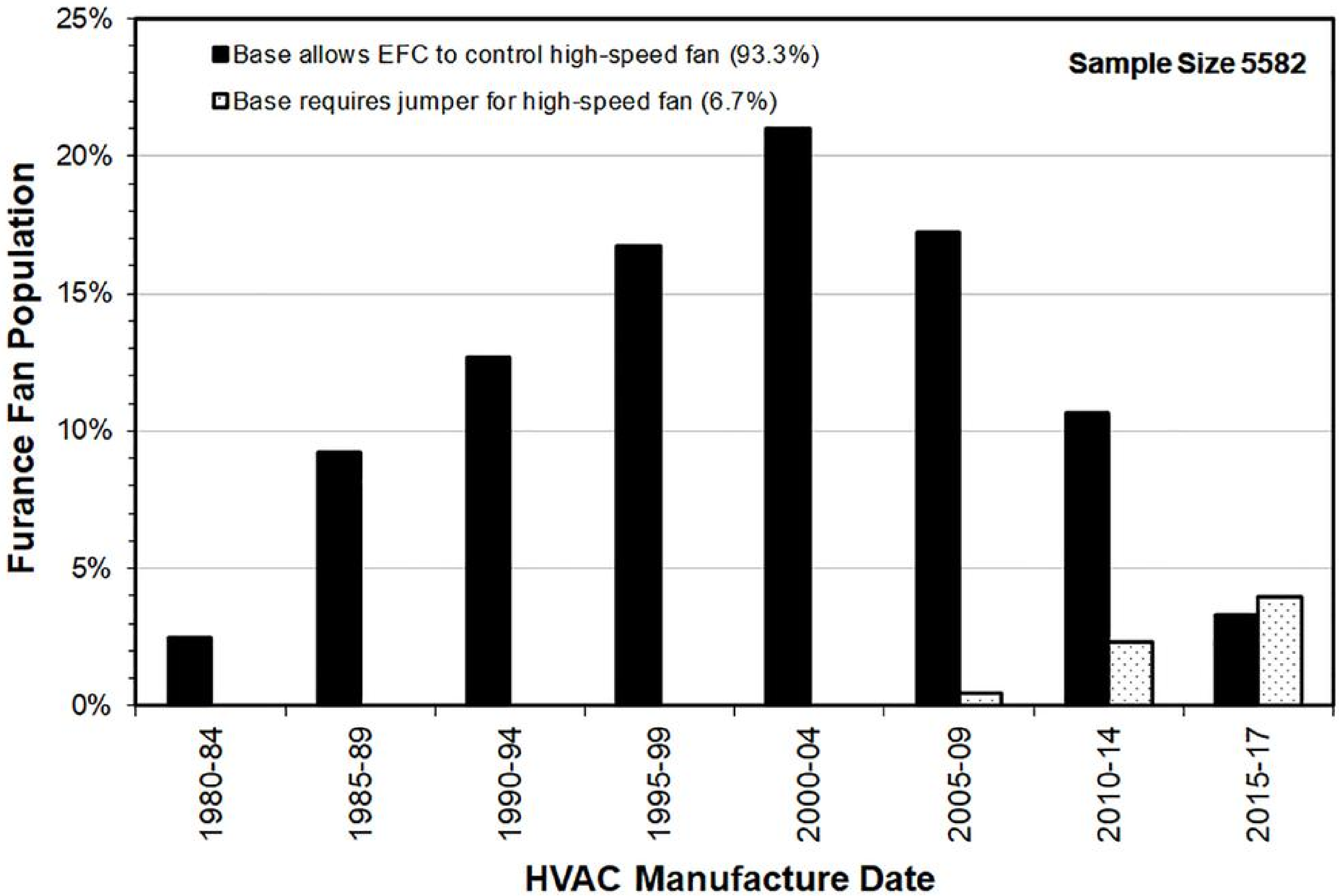
DX COOLING MANUFACTURE DATE	BASE DX COOLING POPULATION	BASE ZERO COOLNG FAN-OFF DELAY	BASE NON-ZERO FAN-OFF DELAY	30-SEC. FAN-OFF DELAY	60-SEC. FAN-OFF DELAY	90-SEC. FAN-OFF DELAY
1980-84	139	128	11	11	0	0
1985-89	516	443	73	71	1	1
1990-94	706	611	95	95	0	0
1995-99	935	814	121	102	9	10
2000-04	1172	982	190	175	3	12
2005-09	986	740	246	119	37	90
2010-14	773	442	281	69	157	55
2015-17	405	138	267	20	231	16
Total	5582	4298	1284	662	438	184
Weighting Factors	**1.00**	**0.770**	**0.230**	**0.119**	**0.078**	**0.033**

The weighted average gas furnace fixed fan-off delay is 97.4 seconds based on a database of 5582 gas furnaces as shown in the following figure. R3139



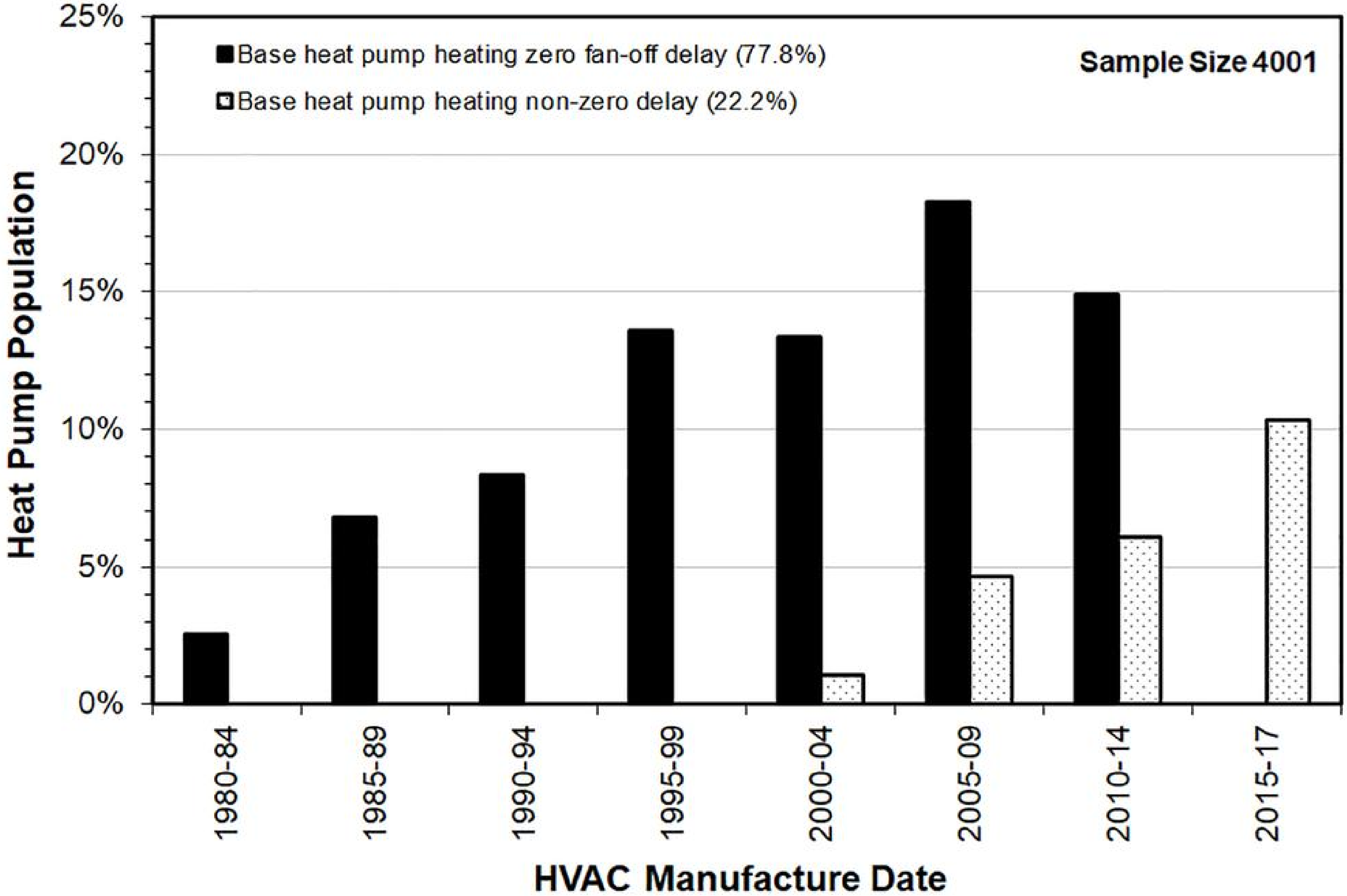
Distribution of Gas Furnace Equipment Age and Base Fan-Off Delay

About 93% of gas furnaces allow high speed fan control in heating mode from the thermostat fan G signal based on a database of 5582 gas furnaces as shown in the following figure. R3139



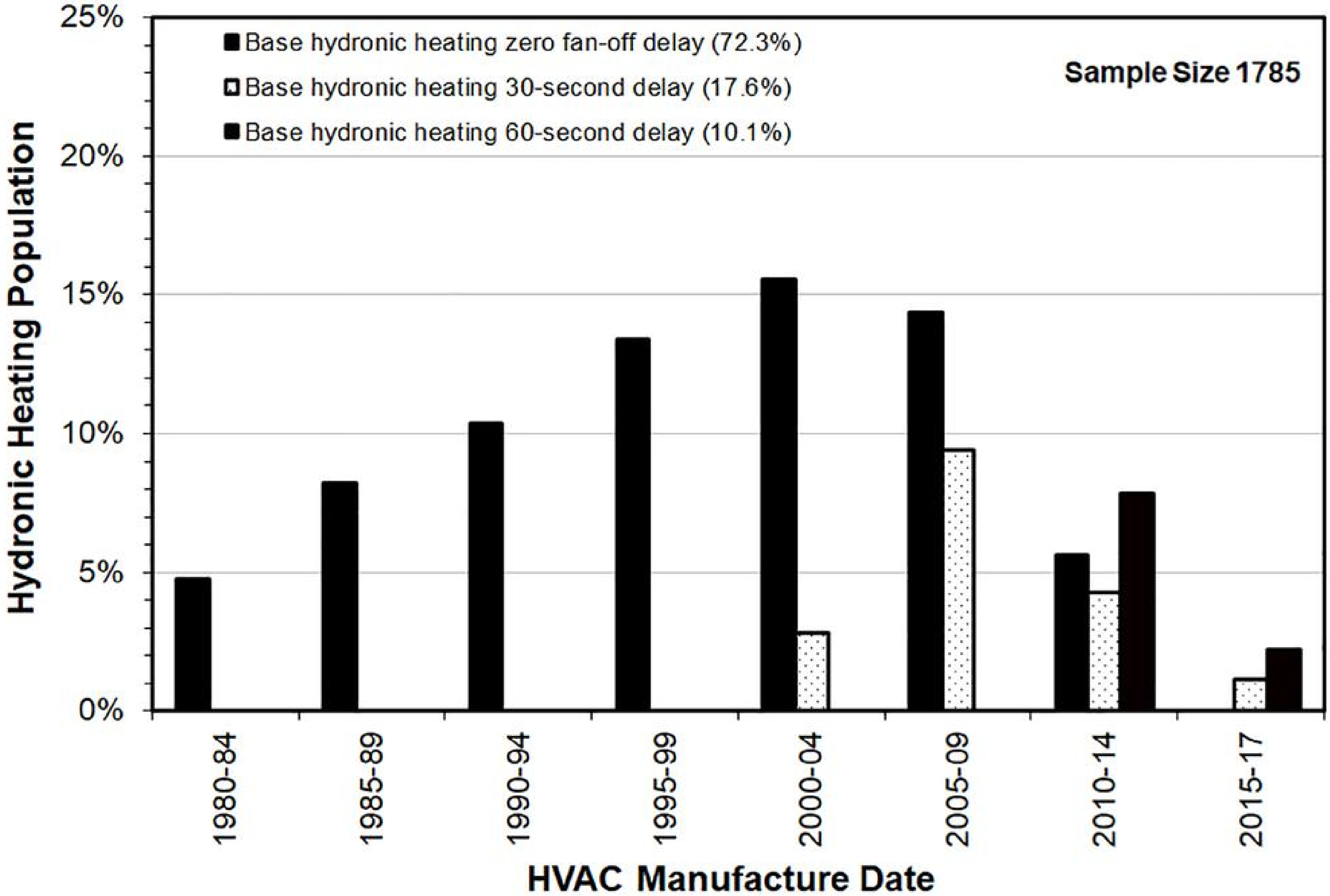
Distribution of Gas Furnace Equipment Age and Base Fan Speed Control

About 78% of heat pumps (3114 in a sample of 4001) have no heating fan-off delay and 22% of heat pumps have a weighted average fixed fan-off delay of 65 seconds based on 887 units in a sample of 4001 heat pumps as shown in the following figure. R3139



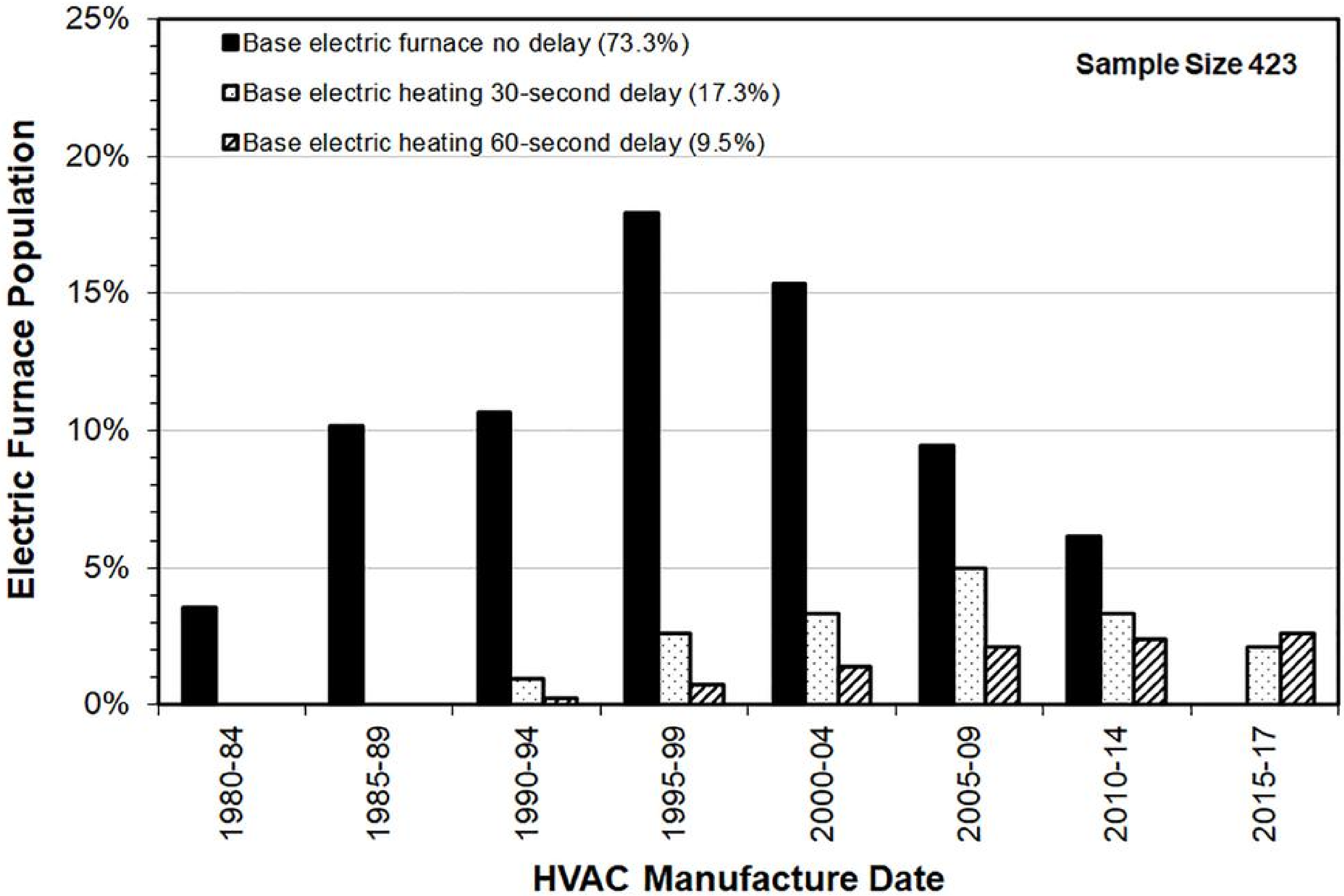
Distribution of Heat Pump Equipment Age and Base Heating Fan-Off Delay

About 62% of hydronic heating systems have no fan-off delay (787 in a sample of 1291), and 38% have a fixed fan-off delay of 41 seconds based on 494 units in a sample of 1785 hydronic heating systems. R3139



Distribution of Hydronic Heating Equipment Age and Base Heating Fan-Off Delay

About 73% of electric heating systems have no fan off delay (310 in a sample of 423), and 27% have a weighted average fixed fan-off delay of 39 seconds based on 113 units in a sample of 423 electric heating systems. R3139



Distribution of Electric Furnace Heating Equipment Age and Base Fan-Off Delay

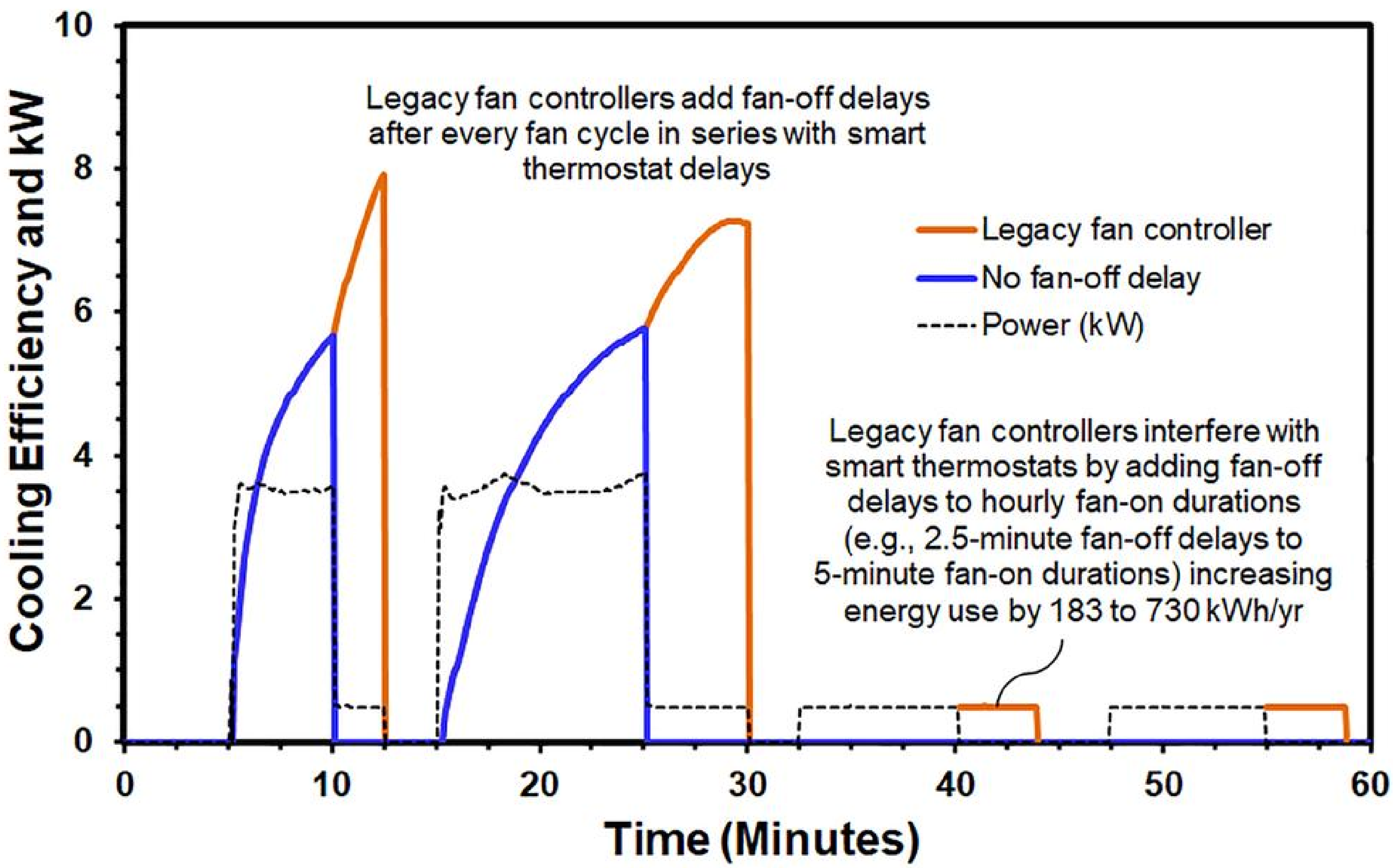
The energy savings power function regression equations include a weighted average of the existing fan-off time delay options compared to the SFC variable fan-off time delay based on independent laboratory tests.

Base Case Descriptions

MEASURE CASE EQUIPMENT	MEASURE APPLICATION TYPE	STATEWIDE MEASURE OFFERING ID (TEXT)	EXISTING DESCRIPTION (TEXT)	STANDARD DESCRIPTION (TEXT)
SFC	AOE	**A**	**No smart fan controller (SFC)**	**No smart fan controller (SFC)**
SFC	NR	**B**	**No smart fan controller (SFC)**	**No smart fan controller (SFC)**
SFC with SCT	AOE	**C**	**No smart fan controller (SFC) with smart communicating thermostat (SCT)**	**No smart fan controller (SFC) with smart communicating thermostat (SCT)**

MEASURE CASE EQUIPMENT	MEASURE APPLICATION TYPE	STATEWIDE MEASURE OFFERING ID (TEXT)	EXISTING DESCRIPTION (TEXT)	STANDARD DESCRIPTION (TEXT)
SFC with SCT	NR	**D**	**No smart fan controller (SFC) with smart communicating thermostat (SCT)**	**No smart fan controller (SFC) with smart communicating thermostat (SCT)**

The base case also includes previously installed add-on retrofit "legacy" fan controllers that only monitor the fan "G" signal and provide fan-off delays after fan-on durations and interfere with smart thermostat savings. R1587 R3048 Legacy fan controllers add increasing fan-off delays up to 5 minutes after every fan-on cycle as shown in the following figure. The third and fourth orange curves show a legacy fan controller adding 3.75-minute fan-off delays to 7.5-minute fan-on durations. This can increase fan energy by 183 to 730 kWh/year for a Permanent Split-Capacitance (PSC) fan motor. The 183 kWh/yr is based on adding 2.5 minute fan-off delays after every 5-minute fan-on duration per hour with a 0.5 kW fan. The 730 kWh/yr is based on adding two 5-minute fan-off delays after two 10-minute fan-on durations per hour based on "circulate" controls and 0.5 kW fan.



Why legacy fan controllers interfere with smart thermostat savings

Code Requirements

This measure is not governed by either state or federal codes and standards.

Applicable State and Federal Codes and Standards

CODE	APPLICABLE CODE REFERENCE	EFFECTIVE DATE
CA Appliance Efficiency Regulations – Title 20	None.	n/a
CA Building Energy Efficiency Standards – Title 24	None.	n/a
Federal Standards – Code of Federal Regulations	None.	n/a

Program Requirements

MEASURE IMPLEMENTATION ELIGIBILITY

All measure application type, delivery type, and sector combinations that are established for this measure are specified below. Measure application type is a categorization based on the circumstances and timing of the measure installation; each measure application type is distinguished by its baseline determination, cost basis, eligibility, and documentation requirements. Delivery type is the broad categorization of the delivery channel through which the market intervention strategy (financial incentives or other services) is targeted. This table also designates the broad market sector(s) that are applicable for this measure.

Note that some of the implementation combinations below may not be allowed for some measure offerings by all program administrators.

Implementation Eligibility

MEASURE APPLICATION TYPE	SECTOR	DELIVERY TYPE
AOE	Res	DnDeemDI
AOE	Res	DnDeemed
NR	Res	DnDeemDI
NR	Res	DnDeemed

The baseline air conditioning system can be equipped with a previously installed "legacy" fan controller that only monitors thermostat fan G signals and provides fan-off delays after each fan-on duration. Legacy fan controllers were identified in two CPUC-sponsored evaluation studies as potentially interfering with savings opportunities from Smart Communicating Thermostats (SCTs) by increasing fan and HVAC energy use and overwhelming cooling energy savings. R1587 R3048 CPUC evaluators reviewed research conducted on the interactive effect between SCTs and previously installed legacy fan controllers and indicated the research met the threshold of the recommendation, and should not preclude submitting this and other evidence to CalTF for stakeholder review and comment in support of developing the Smart Fan Controller (SFC) measure package. R2130 As noted above, the SFC works with smart thermostats by monitoring all thermostat signals and only provides extended variable fan-off delays after thermostat calls for cooling (AC Y signal) or thermostat calls for heating (heat W signal) to save 10 to 20% more energy than smart thermostat delays. The base case also includes previously installed add-on retrofit "legacy" fan controllers that only monitor the fan "G" signal and provide fan-off delays after fan-on durations and interfere with smart thermostat savings. R1587 R3048

The SFC can also be installed with HVAC equipment having any manufacturing date including new equipment. The SFC may be installed at DMo, SFm. and MFm building types to optimize and improve the cooling or heating efficiency of the following building HVAC systems : a) central air conditioner (AC) with direct expansion (DX) cooling and gas furnace heating (rDXGF), b) central AC and heat pump (HP) heating (rDXHP), and c) no cooling (NC) with gas furnace (GF) heating (rNCGF). The SFC may also be installed at MFm building types with the following building HVAC systems: d), central AC and hydronic heating (rDXWH), e) central AC and electric furnace (rDXEF), and f) central AC with water-source-heat pump cooling and heating (rDXWP).

ELIGIBLE PRODUCTS

Eligible products must work with smart thermostats and monitor all thermostat signals including: a cooling AC "Y" signal, a heat "W" signal, and a fan "G" signal. Eligible products must not provide a fan-off delay after fan-only durations to avoid increasing fan-only energy use. Research studies indicate 9 to 31% of users select continuous or hourly fan-on controls increasing electricity use by 1054 to 3520 kWh/yr. R3121 R3122 R3123 R3124 Monitoring all thermostat signals and not adding fan-off delays to fan-on durations can save 183 to 730 kWh per year as shown in the figure in the Measure Case Description section titled "Why legacy fan controllers interfere with smart thermostat savings." The 183 kWh/yr savings are based on adding 2.5-minute fan-off delays to 5-minute fan-on durations with 0.5 kW fan. The 730 kWh/yr savings are based on adding two 5-minute fan-off delays per hour when users select "circulate" which enables two 10-minute fan-only durations per hour or turns on the fan for 30% every hour.

All installations shall comply with all current applicable regulations, code, and standards including (but not limited to) the California Building Energy Efficiency Standards (Title 24), the California Appliance Efficiency Regulations (Title 20), and the National Electrical Code (NEC).

ELIGIBLE BUILDING TYPES AND VINTAGES

This measure is applicable for all residential building types and vintages including single-family (SFm), multifamily (MFm), and mobile homes (DMo).

ELIGIBLE CLIMATE ZONES

This measure is applicable in all California climate zones.

Program Exclusions

There are no program exclusions for the Smart Fan Controller (SFC).

Data Collection Requirements

For downstream direct installation delivery programs, the smart fan controller requires site data collection of make, model, serial number, and manufacturing date of the host HVAC system and estimated floor area (square feet) of the conditioned space as shown in the following table. To avoid double-counting savings when replacing a "legacy" fan controller, the SFC measure will only be installed to replace a "legacy" fan controller with installation date earlier than 5 years prior to installing the SFC (e.g., for 2024 the installation date would be 2019, etc.). The manufacturing date on the UL label will be collected to identify when the "legacy" fan controller was installed.

DATA COLLECTION REQUIREMENTS
HVAC Make
HVAC Model
HVAC Serial Number
HVAC Equipment Manufacturing Date
Conditioned Floor Area (ft2)
Legacy fan controller installation date (if applicable)

Electric Savings (kWh)

The annual electric unit energy savings (UES) of this measure are derived as the difference between base and measure case annual unit energy consumption (UEC). This measure applies to all fully functional residential central or packaged HVAC systems equipped with cooling evaporator direct expansion (DX) coils and heating gas furnace, heat pump (air or water source), hydronic, or electric resistance heating systems. The methodology used to derive the calculations for each central or packaged HVAC system are provided in the sections below.

Annual Unit Energy Savings - Electric

EQUATION (KWH / YR)
$UEC\_YrkWhBase - UEC\_YrkWhMeas$

UEC_YrkWhBase = Annual unit energy consumption - electric, baseline (kWh/yr)
UEC_YrkWhMeas = Annual unit energy consumption - electric, measure case (kWh/yr)

Annual Unit Energy Consumption - Electric, Measure Case

BUILDING HVAC	EQUATION (KWH / YR)
rDXEF	$UEC\_YrkWhBase - ((1 - coolEIRAdj\_\_YrkWh) \bullet UEC\_YrkWhBase\_cool) - (1 - heatEIRAdj\_\_YrkWh) \bullet UEC\_YrkWhBase\_heat$
rDXGF	$UEC\_YrkWhBase - ((1 - coolEIRAdj\_\_YrkWh) \bullet UEC\_YrkWhBase) - (-IE\_hvac\_\_kWh\_therm \bullet (UEC\_YrThermBase - UEC\_YrThermMeas))$
rDXHP	$UEC\_YrkWhBase - ((1 - coolEIRAdj\_\_YrkWh) \bullet UEC\_YrkWhBase\_cool) - (1 - heatEIRAdj\_\_YrkWh) \bullet UEC\_YrkWhBase\_heat$
rDXHW	$UEC\_YrkWhBase - ((1 - coolEIRAdj\_\_YrkWh) \bullet UEC\_YrkWhBase) - (-IE\_hvac\_\_kWh\_therm \bullet (UEC\_YrThermBase - UEC\_YrThermMeas))$
rDXWP	$UEC\_YrkWhBase - ((1 - coolEIRAdj\_\_YrkWh) \bullet UEC\_YrkWhBase\_cool) - (1 - heatEIRAdj\_\_YrkWh) \bullet UEC\_YrkWhBase\_heat$
rNCGF	$UEC\_YrkWhBase - ((1 - coolEIRAdj\_\_YrkWh) \bullet UEC\_YrkWhBase) - (-IE\_hvac\_\_kWh\_therm \bullet (UEC\_YrThermBase - UEC\_YrThermMeas))$

UEC_YrkWhBase = Annual unit energy consumption (total) - electric, baseline (kWh/yr)
coolEIRAdj__YrkWh = Cooling energy input ratio adjustment - electric (dimensionless)
UEC_YrkWhBase_cool = Annual cooling unit energy consumption - electric, baseline (kWh/yr)
heatEIRAdj_YrkWh = Heating energy input ratio adjustment - electric (dimensionless)
UEC_YrkWhBase_heat = Annual heating unit energy consumption - electric, baseline (kWh/yr)
IE_hvac__kWh_therm = Interactive effects fan energy for variable fan-off delay heating (kWh/therm)
heatEIRAdj__YrTherm = Heating energy input ratio adjustment - therm (dimensionless)
UEC_YrThermBase = Annual unit energy consumption - gas, baseline (therm/yr)
UEC_YrThermMeas = Annual unit energy consumption - gas, measure case (therm/yr)

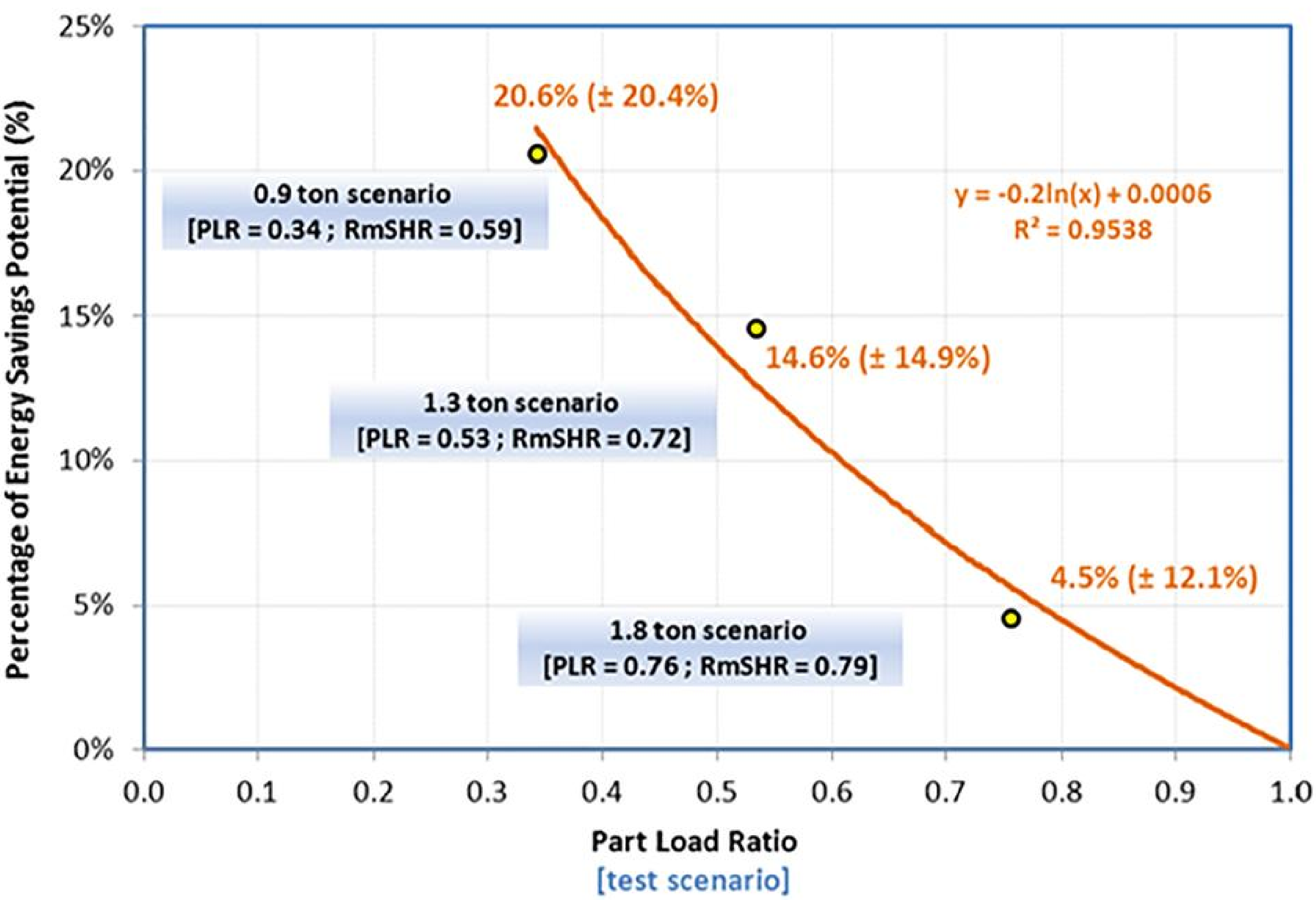
ELECTRIC UNIT ENERGY SAVINGS - DIRECT EXPANSION (DX) COOLING (KWH)

The SFC DX cooling UES are calculated using baseline UEC values from the DEER2024 EnergyPlus prototypes times the average percentage savings (or cooling EIR adjustment) based on the statewide Fan Controller, Residential (SWHC029-03) measure package. R3130 R3174 Energy impacts are taken directly from DEER2024 (version source: D24_E+_Res_v4). The MeasureID and EnergyImpactID are RE-ResAC-FanCtrls. The UES is calculated as a function of the baseline energy use and the part load ratio (PLR). The functional relationship is determined based on an Emerging Technologies (ET) Program study conducted by Southern California Edison (SCE) in 2012 ("SCE ET Study") and laboratory tests performed by Intertek, an Air-Conditioning, Heating, and Refrigeration Institute (AHRI) certified independent testing laboratory. R972 R3126 R3127

The Part Load Ratio (PLR) for each hour is calculated as follows based on EnergyPlus simulations performed for SWHC029-03. R3046

```
PLR = Cooling Load (Btu/hr) / AC Cooling Capacity (Btu/hr)
```

The following figure from the SCE ET Study plots the percentage of energy savings versus the PLR. R972 The logarithmic curve fit relation is listed on the top right of the figure below.



Cooling Energy Savings Potential as a Function of Part Load Ratios (PLR)

Once the PLR is calculated, the equation below applies the logarithmic curve fit of percentage of energy savings versus PLR determined from laboratory testing. The value of the logarithmic curve fit is capped at 20.6% to avoid applying test results outside the range from SCE ET Study.

```
AC Cooling Energy Savings (kWh) = Total Baseline AC Unit Energy Consumption (UEC) (kWh) ×
                          MIN(0.206,−0.21ln(PLR) + 0.0006))
```

The result from the equation above represents the AC energy savings for each hour. This number is summed for all hours of the year to obtain the total annual energy savings. Each zone has a separate AC-system based on how the DEER prototypes are modeled and results are obtained for each zone. The EnergyPlus model has two systems (N-S, E-W orientations) in double-wide mobile (DMo) homes, four systems in single-family (SFm) homes (single-story, two-story, two orientations), and 24 systems in multifamily (MFm) homes (two-story buildings with 14 units, two orientations). The results obtained for each of the building units are averaged to obtain one representative savings number per building type. This averaged savings value is the kWh/year cooling savings per unit for each respective building type and climate zone. Energy savings are normalized per square foot of building floor area.

The SWHC029-03 cooling energy savings based on EnergyPlus are provided in the following for each building prototype and climate zone based on SCE laboratory tests of cooling system performance capped at 20.6% maximum cooling savings and EnergyPlus simulations performed for the statewide Fan Controller for Air Conditioner, Residential (SWHC029-03) measure package. R3046 Average cooling savings for all building types and climate zones is 19% indicating an average Electric Input Ratio (EIR) efficiency adjustment or 0.81 (e.g., 0.81 = 1-0.19).

SFC average % cooling savings for DMo, SFm, and MFm prototypes

CLIMATE ZONE	DMO CAPPED COOLING SAVINGS (%)	SFM CAPPED COOLING SAVINGS (%)	MFM CAPPED COOLING SAVINGS (%)	AVE. CAPPED COOLING SAVINGS (%)
CZ01	16.6%	17.1%	8.4%	14.0%
CZ02	15.8%	20.6%	16.8%	17.7%
CZ03	20.6%	20.6%	17.1%	19.4%
CZ04	17.3%	20.6%	16.6%	18.1%
CZ05	19.0%	20.6%	20.4%	20.0%
CZ06	19.7%	20.6%	20.2%	20.2%
CZ07	20.6%	20.6%	17.9%	19.7%
CZ08	20.6%	20.6%	20.2%	20.5%
CZ09	20.6%	20.6%	20.6%	20.6%
CZ10	14.9%	18.8%	20.0%	17.9%
CZ11	20.0%	18.7%	20.6%	19.8%

CLIMATE ZONE	DMO CAPPED COOLING SAVINGS (%)	SFM CAPPED COOLING SAVINGS (%)	MFM CAPPED COOLING SAVINGS (%)	AVE. CAPPED COOLING SAVINGS (%)
CZ12	20.6%	20.2%	20.0%	20.3%
CZ13	19.1%	16.6%	20.6%	18.8%
CZ14	16.8%	18.2%	20.6%	18.6%
CZ15	20.6%	17.5%	20.6%	19.6%
CZ16	20.6%	17.2%	20.6%	19.5%
Average	**19.0%**	**19.3%**	**18.8%**	**19.0%**

The Electric savings are calculated based on the average improvement in the electric input ratio (EIR) for cooling or heating from the base case to the measure case. The EIR for cooling or heating is defined as the energy input divided by the energy output or one divided by the coefficient of performance (COP). The following table provides the cooling and heating EIR adjustments based on cooling or heating savings and the extra fan heating energy based on therm savings (kWh/therm). Average cooling energy savings (i.e., EIR adjustments) are based on SCE laboratory tests of cooling system performance and EnergyPlus simulations performed for the statewide Fan Controller for Air Conditioning, Residential (SWHC029-03) measure package. R972 R3046 The average cooling energy savings are 19% representing an average cooling EIR adjustment of 0.81 for all prototypes and climate zones. Heating energy savings for each HVAC system are provided in the following table based on third-party laboratory tests (see Intertek test data Appendix A and B), DEER 2020 MASControl3 simulations (Appendix C and D). R3126 R3127 R3140 R3128 R3129 R3136 R3142 R3137 R3138 Laboratory test data supporting heating savings are provided in the Gas Savings section. Energy savings are multiplied times calibrated UEC values from EnergyPlus (E+) prototype simulations of DMo, SFm, and MFm building types for residential direct expansion (DX) cooling, gas furnace (GF) heating (rDXGF), heat pump (HP) heating (rDXHP), hydronic heating (rDXHW), electric furnace heating (rDXEF), and water source heat pump heating (rDXWP) systems. R3130 Space cooling (kWh/year) and space heating (therm/year) UEC data for the 16 California climate zones (CZ) are used to calculate energy savings based on average percentage savings for each building HVAC system for residential double-wide mobile homes (DMo), single family (SFm) and multifamily (MFm) building types. R3174 As noted above, energy savings are normalized per square foot of building floor area. Average cooling EIR, cooling savings, heating EIR, extra fan heating, and heating savings are provided in the following table. These values are actually calculated based on each building type, HVAC type, and climate zone.

SFC average cooling EIR, cooling savings, heating EIR, extra fan heating energy, and heating savings

BLDG HVAC	COOLING EIR ADJUSTMENT	COOLING SAVINGS	HEATING EIR ADJUSTMENT	EXTRA FAN HEATING	HEATING SAVINGS
rDXGF	0.81 * base cool EIR	19.0%	0.835 * base furn. EIR	1.08 kWh/therm savings	16.5%
rDXHP heat pump (HP)	0.81 * base cool EIR	19.0%	0.895 * base heat EIR	Included in savings	10.5%
rDXHW hydronic	0.81 * base cool EIR	19.0%	0.808 * base heat EIR	1.26 kWh/therm savings	19.2%
rDXEF elec. furnace	0.81 * base cool EIR	19.0%	0.818 * base heat EIR	Included in savings	18.2%

BLDG HVAC	COOLING EIR ADJUSTMENT	COOLING SAVINGS	HEATING EIR ADJUSTMENT	EXTRA FAN HEATING	HEATING SAVINGS
rDXWP water source HP	0.81 * base cool EIR	19.0%	0.895 * base heat EIR	Included in savings	10.5%

The cooling UES are calculated using the following equations and baseline UEC values for cooling and gas furnace heating (rDXGF).

```
UES_cooling_kWh/y = (1-0.81)*UECkWhBase1-1.09*(1-0.835)*UECThermBase1_gf
```

UECkWhBase1 = Cooling UEC, baseline (kWh/yr)
UECThermBase1_gf = Gas furnace UEC, baseline (therm/yr)

The above equation includes interactive effects (kWh) regarding extra fan heating energy for the gas furnace heating fan-off delay (see Interactive Effects section below).

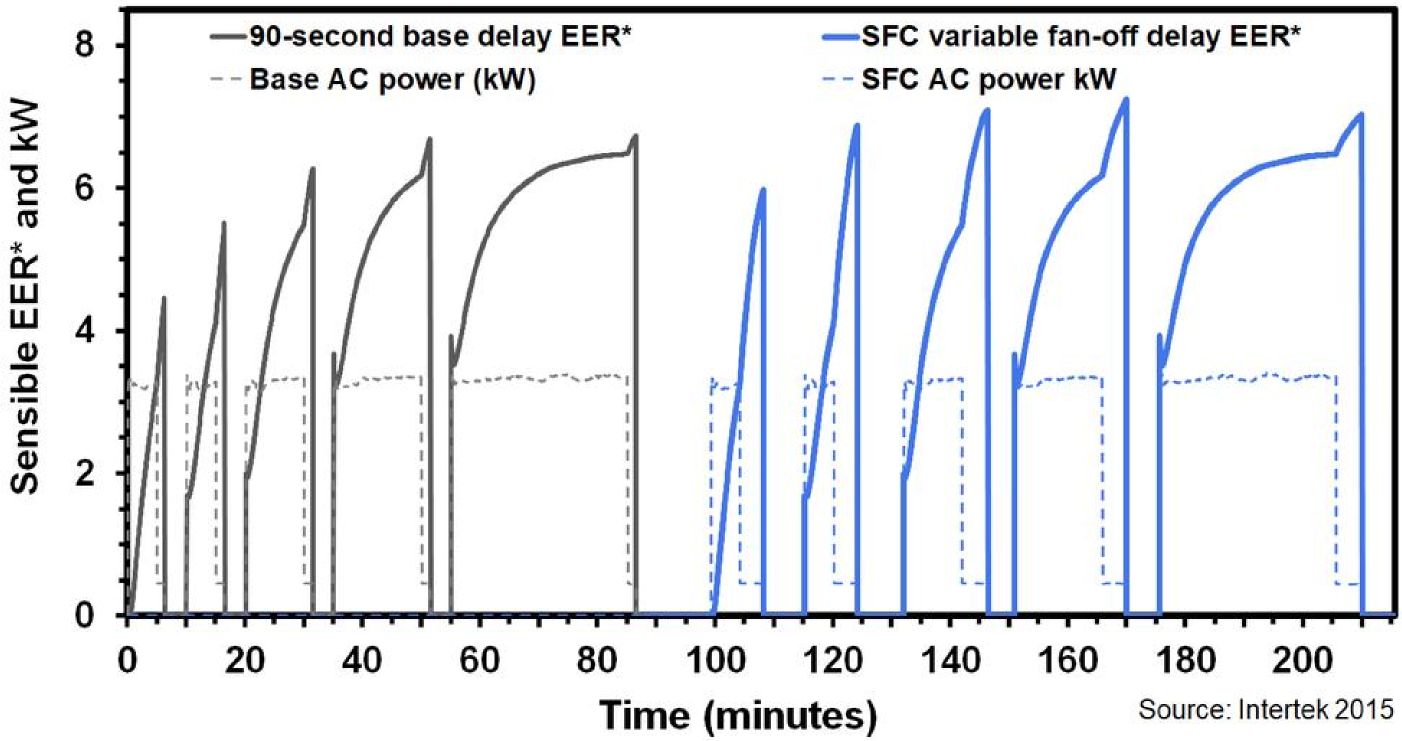
The cooling UES with hydronic heating are calculated using the following equations and baseline UEC values for cooling and hydronic heating (rDXHW). R3174

```
UES_cooling_kWh/y = (1-0.81)*UECkWhBase1-1.26*(1-0.808)*UECThermBase1_hyd
```

UECkWhBase1 = Cooling UEC, baseline (kWh/yr)
UECThermBase1_hyd = Hydronic heating UEC, baseline (therm/yr)

The above equation includes interactive effects (kWh) regarding extra fan heating energy for the hydronic heating fan-off delay (see Interactive Effects section below).

The following figure provides independent laboratory test data for a new HVAC system with a base 90-second base delay for cooling versus the SFC variable fan-off delay with average savings of 15%. R3126 R3127 Only 3.3% of air conditioners have a 90-second fan-off delay, 7.8% have a 60-second delay, 11.9% have a 30-second, and 77% have no fan-off delay. R3139 Average cooling savings are 19% based on the statewide Fan Controller for Air Conditioner, Residential (SWHC029-03) measure package (see above). The SFC adds 0.5 to 4.0 minutes to the 90-second base delay depending on the AC operating time. SFC cooling savings will be greater for 0, 30, 45, or 60-second base delays. Independent laboratory tests of the SFC versus 0, 60, and 90-second base fan-off delays are shown in the following table.



SFC variable cooling fan-off delay versus 90-second base delay for 3-ton unit

SFC Variable Cooling Delay versus 0, 60, and 90-second base delay for 3-ton unit

DESCRIPTION	TEST 6	TEST 7	TEST 8	TEST 9	TEST 10	AVERAGE
Compressor On Time (minutes)	5	5	10	15	30	8
No Delay AC Energy (kWh) [a]	0.265	0.271	0.544	0.828	1.673	0.435
No Delay Sensible Cooling (Btu) [b]	1,006	1,396	3,264	5,381	10,995	2,517
No Delay Sensible Efficiency [c=b/a/1000]	3.79	5.14	6.00	6.49	6.57	5.78
No Delay PLR [d=b/22144]	0.05	0.06	0.15	0.24	0.50	0.11
60-Second Delay AC Energy (kWh) [e]	0.274	0.280	0.551	0.834	1.675	0.442
60-Second Delay Sensible Cooling (Btu) [f]	1,241	1,488	3,395	5,527	11,216	2,632
60-Second Delay Sensible Efficiency [g=e/f/1000]	4.52	5.32	6.16	6.62	6.70	5.95
60-Second Delay PLR [h=b/22144]	0.06	0.07	0.15	0.25	0.51	0.12
90-Second Delay AC Energy (kWh) [i]	0.276	0.281	0.553	0.836	1.677	0.444

DESCRIPTION	TEST 6	TEST 7	TEST 8	TEST 9	TEST 10	AVERAGE
90-Second Delay Sensible Cooling (Btu) [j]	1,283	1,553	3,465	5,598	11,285	2,700
90-Second Delay Sensible Efficiency [k=j/i/1000]	4.65	5.52	6.27	6.69	6.73	6.08
90-Second PLR [l=j/22144]	0.06	0.07	0.16	0.25	0.51	0.12
SFC AC Energy (kWh) [m]	0.295	0.300	0.575	0.859	1.703	0.465
SFC Sensible Cooling (Btu) [n]	1,755	2,067	4,146	6,293	12,065	3,315
SFC Sensible Efficiency [o=m/n/1000]	5.96	6.88	7.22	7.33	7.08	7.13
90-Sec. input to match EFC (kWh) [p=n/k/1000]	0.377	0.375	0.661	0.940	1.793	0.545
SFC Savings (kWh) [q=p-i or q=(n-j)/k/1000+j-m]	0.083	0.074	0.087	0.081	0.090	0.080
SFC savings vs no delay [r=1-c/o]	**45.6%**	**40.3%**	**24.1%**	**15.7%**	**8.6%**	**28.0%**
SFC savings vs 60-sec. base delay [s=1-g/o]	**24.2%**	**22.7%**	**14.6%**	**9.7%**	**5.4%**	**16.5%**
SFC savings vs 90-sec. base delay [t=1-k/o]	**21.9%**	**19.8%**	**13.1%**	**8.7%**	**5.0%**	**14.7%**

ELECTRIC UNIT ENERGY SAVINGS - HEAT PUMP HEATING (KWH)

Heat Pump (HP) heating unit energy savings (UES) are based on Intertek and field test studies for extended variable fan-off delays for residential heat pumps. R3127 Findings from these studies show HP heating energy savings (kWh) vary as a function of the HP heating Part Load Ratio (PLR). The PLR for each hour is calculated as follows and is an output from DEER2020 DOE-2.3 or EnergyPlus.

```
PLR = Heat Pump Heating Load (Btu/hr) / Heat Pump Heating Capacity (Btu/hr)
```

The SFC was installed and tested on a 1.5-ton split-system heat pump. Intertek performed tests at 70F return air drybulb and 47F, 17F, 35F, and 62F outdoor air temperature (OAT). Laboratory tests with and without the SFC in heating mode provide data to evaluate heat pump heating energy savings. The following tables provide Intertek test data at at 47F, 17F, 35F, and 62F OAT for the heat pump in heating mode with no fan-off delay (factory default) and optional 65-second fan-off delay versus the SFC variable fan-off delay.

Heat Pump Heating PLR and Energy Savings with the SFC at 47°F OAT

TESTS AT 47 °F OAT	BASE FAN-OFF DELAY (SEC)	PLR HEAT PUMP HEATIING	HP INPUT BASE KWH [A]	HP OUPUT BASE BTU [B]	BASE EFFICIENCY [C=B/A/3412]	HP INPUT WITH SFC KWH [D]	HP OUPUT WITH SFC BTU [E]	HP EFFICIENCY WITH SFC [F=E/D/3412]	HP ENERGY SAVINGS WITH SFC [G=1-C/F]
125	0	0.003	0.044	36	0.243	0.047	91	0.562	56.7%
126	0	0.021	0.110	256	0.680	0.117	437	1.097	38.0%
127	0	0.077	0.226	953	1.239	0.234	1,330	1.664	25.5%
128	0	0.241	0.466	2,974	1.872	0.476	3,531	2.173	13.9%
129	0	0.427	0.709	5,268	2.179	0.719	5,862	2.389	8.8%
130	0	0.799	1.198	9,863	2.413	1.208	10,481	2.542	5.1%
131	65	0.008	0.048	95	0.588	0.051	148	0.848	30.6%
132	65	0.030	0.114	366	0.942	0.121	513	1.248	24.6%
133	65	0.092	0.229	1,135	1.451	0.238	1,430	1.760	17.6%
134	65	0.260	0.469	3,212	2.005	0.480	3,642	2.224	9.8%
135	65	0.447	0.712	5,522	2.272	0.723	5,981	2.425	6.3%
136	65	0.821	1.202	10,126	2.470	1.212	10,605	2.564	3.7%

Heat Pump Heating PLR and Energy Savings with the SFC at 17°F OAT

TESTS AT 17°F OAT	BASE FAN-OFF DELAY (SEC)	PLR HEAT PUMP HEATIING	HP INPUT BASE KWH [A]	HP OUPUT BASE BTU [B]	BASE EFFICIENCY [C=B/A/3412]	HP INPUT WITH SFC KWH [D]	HP OUPUT WITH SFC BTU [E]	HP EFFICIENCY WITH SFC [F=E/D/3412]	HP ENERGY SAVINGS WITH SFC [G=1-C/F]
137	0	0.002	0.041	13	0.095	0.045	37	0.241	60.7%
138	0	0.012	0.106	104	0.288	0.113	187	0.487	40.9%
139	0	0.066	0.218	559	0.750	0.227	809	1.044	28.1%
140	0	0.215	0.444	1,824	1.205	0.454	2,221	1.434	15.9%
141	0	0.423	0.677	3,595	1.556	0.688	4,008	1.707	8.9%

TESTS AT 17°F OAT	BASE FAN-OFF DELAY (SEC)	PLR HEAT PUMP HEATIING	HP INPUT BASE KWH [A]	HP OUPUT BASE BTU [B]	BASE EFFICIENCY [C=B/A/3412]	HP INPUT WITH SFC KWH [D]	HP OUPUT WITH SFC BTU [E]	HP EFFICIENCY WITH SFC [F=E/D/3412]	HP ENERGY SAVINGS WITH SFC [G=1-C/F]
142	0	0.800	1.127	6,804	1.769	1.138	7,204	1.855	4.6%
143	65	0.005	0.046	39	0.253	0.050	60	0.357	29.0%
144	65	0.018	0.110	156	0.415	0.117	218	0.548	24.3%
145	65	0.080	0.222	680	0.897	0.231	873	1.107	19.0%
146	65	0.235	0.447	1,995	1.307	0.458	2,296	1.470	11.1%
147	65	0.444	0.681	3,773	1.624	0.693	4,086	1.729	6.1%
148	65	0.821	1.131	6,981	1.809	1.143	7,278	1.866	3.1%

Heat Pump Heating PLR and Energy Savings with the SFC at 35°F OAT

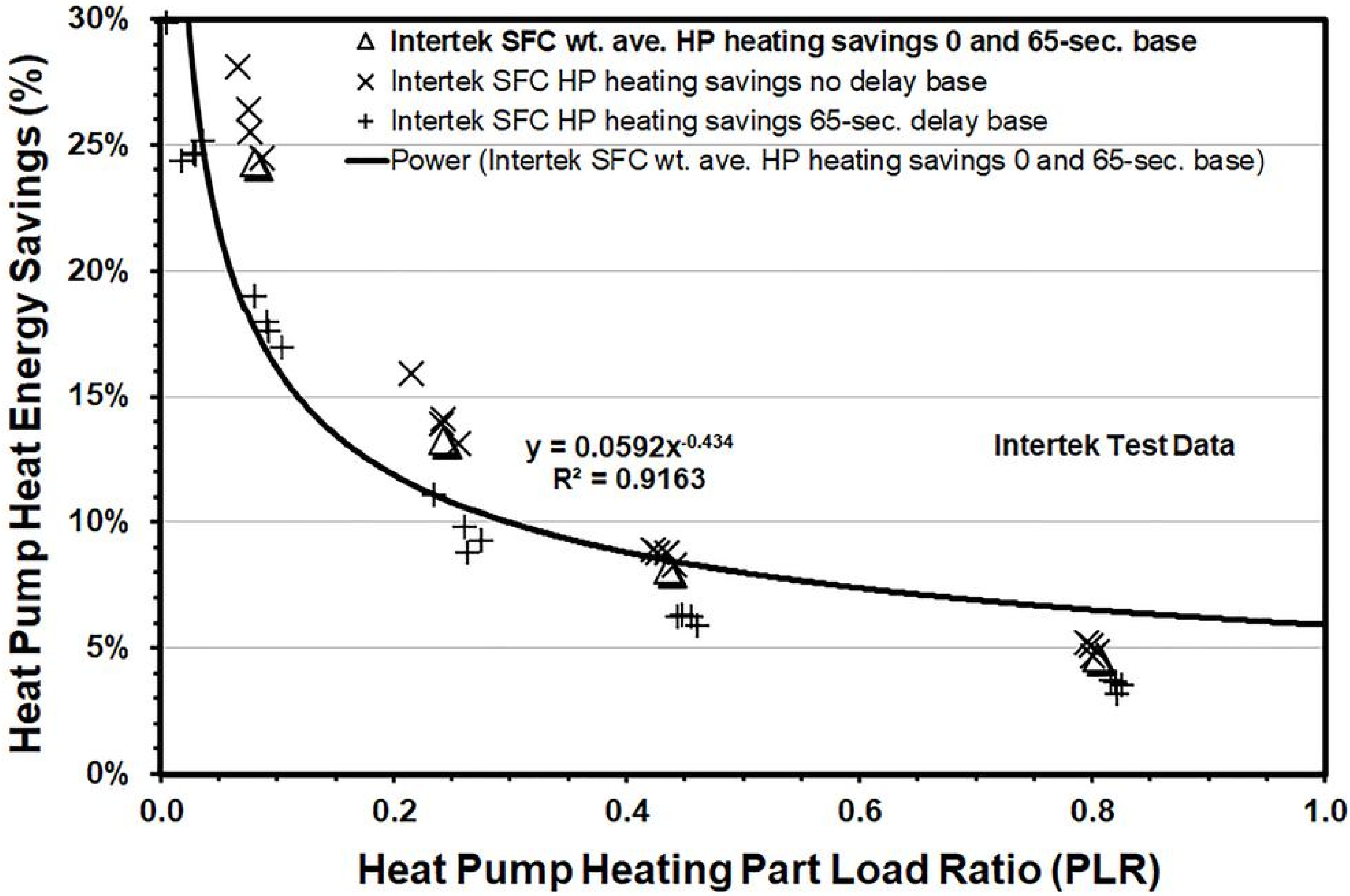
TESTS AT 35°F OAT	BASE FAN-OFF DELAY (SEC)	PLR HEAT PUMP HEATIING	HP INPUT BASE KWH [A]	HP OUPUT BASE BTU [B]	BASE EFFICIENCY [C=B/A/3412]	HP INPUT WITH SFC KWH [D]	HP OUPUT WITH SFC BTU [E]	HP EFFICIENCY WITH SFC [F=E/D/3412]	HP ENERGY SAVINGS WITH SFC [G=1-C/F]
149	0	0.002	0.043	25	0.174	0.046	66	0.422	58.8%
150	0	0.019	0.108	206	0.561	0.114	356	0.914	38.6%
151	0	0.076	0.222	810	1.071	0.230	1,144	1.456	26.4%
152	0	0.243	0.456	2,594	1.669	0.466	3,090	1.942	14.1%
153	0	0.434	0.692	4,636	1.962	0.703	5,159	2.151	8.8%
154	0	0.795	1.163	8,482	2.138	1.173	9,029	2.255	5.2%
155	65	0.007	0.046	70	0.442	0.050	109	0.638	30.7%
156	65	0.028	0.112	298	0.783	0.118	419	1.039	24.7%
157	65	0.091	0.225	971	1.264	0.234	1,230	1.540	17.9%
158	65	0.263	0.459	2,807	1.790	0.470	3,146	1.962	8.8%
159	65	0.455	0.696	4,860	2.046	0.707	5,261	2.182	6.2%

TESTS AT 35°F OAT	BASE FAN-OFF DELAY (SEC)	PLR HEAT PUMP HEATIING	HP INPUT BASE KWH [A]	HP OUPUT BASE BTU [B]	BASE EFFICIENCY [C=B/A/3412]	HP INPUT WITH SFC KWH [D]	HP OUPUT WITH SFC BTU [E]	HP EFFICIENCY WITH SFC [F=E/D/3412]	HP ENERGY SAVINGS WITH SFC [G=1-C/F]
160	65	0.817	1.167	8,716	2.190	1.177	9,133	2.274	3.7%

Heat Pump Heating PLR and Energy Savings with the SFC at 62°F OAT

TESTS AT 62°F OAT	BASE FAN-OFF DELAY (SEC)	PLR HEAT PUMP HEATIING	HP INPUT BASE KWH [A]	HP OUPUT BASE BTU [B]	BASE EFFICIENCY [C=B/A/3412]	HP INPUT WITH SFC KWH [D]	HP OUPUT WITH SFC BTU [E]	HP EFFICIENCY WITH SFC [F=E/D/3412]	HP ENERGY SAVINGS WITH SFC [G=1-C/F]
161	0	0.004	0.046	53	0.341	0.049	129	0.770	55.7%
162	0	0.025	0.114	348	0.893	0.121	596	1.450	38.4%
163	0	0.088	0.234	1,219	1.527	0.243	1,674	2.021	24.5%
164	0	0.256	0.483	3,563	2.163	0.493	4,191	2.491	13.1%
165	0	0.441	0.735	6,133	2.447	0.745	6,782	2.668	8.3%
166	0	0.805	1.238	11,190	2.649	1.249	11,865	2.785	4.9%
167	65	0.010	0.050	136	0.805	0.053	210	1.160	30.6%
168	65	0.036	0.118	500	1.243	0.124	704	1.660	25.2%
169	65	0.104	0.238	1,439	1.774	0.246	1,796	2.136	16.9%
170	65	0.276	0.486	3,831	2.308	0.497	4,314	2.544	9.3%
171	65	0.461	0.738	6,413	2.545	0.749	6,912	2.705	5.9%
172	65	0.826	1.242	11,478	2.708	1.253	12,002	2.808	3.6%

The following figure plots the percentage of energy savings versus the PLR based on Intertek laboratory tests. R972 The power function regression equation curve fit is shown on the figure below.



Heat Pump Energy Savings versus PLR

After the PLR is calculated, the equation below applies the heat pump heating energy savings versus PLR determined from laboratory tests to calculate energy savings based on the annual heat pump Unit Energy Consumption (UEC). R3174

$$\text{Heat Pump Heating Energy Savings (kWh)} = \text{Total Baseline Heat Pump UEC (kWh)} * 0.0592 * (\text{PLR})^{-0.434}$$

The result from the equation above represents the heat pump heating energy savings for each hour. This number is summed for all hours of the year to obtain the total annual heat pump heating energy savings. Measure analysis software control (MASControl3) is used to generate DEER2020 DOE-2.3 building energy simulation prototypes. R3129 Each zone has a separate heat pump system based on how the DEER prototypes are modeled and results are obtained for each zone. The post processor uses the above equation based on Intertek tests to calculate HP heating energy savings. The average HP heating energy savings for all building types and climate zones is provided in the following table. Average heat pump heating savings for all building types and climate zones is 10.5% indicating an average EIR heating efficiency adjustment of 0.895 (e.g., 0.895 = 1-0.105).

CLIMATE ZONE	DMO HEAT PUMP HEATING SAVINGS (%)	SFM HEAT PUMP HEATING SAVINGS (%)	MFM HEAT PUMP HEATING SAVINGS (%)	AVE. HEAT PUMP HEATING SAVINGS (%)

CLIMATE ZONE	DMO HEAT PUMP HEATING SAVINGS (%)	SFM HEAT PUMP HEATING SAVINGS (%)	MFM HEAT PUMP HEATING SAVINGS (%)	AVE. HEAT PUMP HEATING SAVINGS (%)
CZ01	9.9%	8.0%	9.6%	9.2%
CZ02	9.2%	9.1%	9.5%	9.3%
CZ03	11.6%	10.2%	10.9%	10.9%
CZ04	9.4%	8.5%	9.3%	9.1%
CZ05	10.4%	9.8%	10.6%	10.3%
CZ06	11.6%	11.3%	11.1%	11.3%
CZ07	13.8%	11.6%	12.7%	12.7%
CZ08	12.8%	11.6%	11.3%	11.9%
CZ09	11.7%	11.2%	11.2%	11.4%
CZ10	11.0%	11.1%	10.7%	10.9%
CZ11	9.6%	9.6%	10.4%	9.9%
CZ12	9.9%	9.5%	10.5%	10.0%
CZ13	10.2%	9.9%	10.7%	10.3%
CZ14	8.7%	9.7%	9.9%	9.4%
CZ15	11.3%	11.4%	10.9%	11.2%
CZ16	7.1%	6.7%	7.2%	7.0%
Average	**10.4%**	**10.3%**	**10.8%**	**10.5%**

The EnergyPlus model has two systems (N-S, E-W orientations) in double-wide mobile (DMo) homes, four systems in single-family (SFm) homes (single-story, two-story, two orientations), and 24 systems in multifamily (MFm) homes (two-story buildings with 14 units, two orientations). The heat pump heating results obtained for each of the EnergyPlus building types are averaged to obtain one representative savings number per building type. This averaged heat pump heating energy savings value is the kWh/year heating savings per unit for each respective building type and climate zone. Heat pump heating energy savings are normalized per square foot of building floor area.

ELECTRIC UNIT ENERGY SAVINGS - ELECTRIC FURNACE HEATING (KWH)

Electric furnace (EF) heating unit energy savings (UES) are based on laboratory test measurements of the heat pump which is conservative since the electric heating element temperature is comparable to the gas heat exchanger temperature (i.e., > 450°F). The additional heating capacity (and energy savings) provided by the SFC variable fan-off time delay which varies as a function of the heat-source operating time is compared to the baseline system with no time delay or a fixed fan-off time delay. The PLR for each hour is calculated as follows and is an output from DEER2020 DOE-2.3 or EnergyPlus.

```
PLR = Electric Furnace Heating Load (Btu/hr) / Electric Furnace Heating Capacity (Btu/hr)
```

After the PLR is calculated, the equation below applies the heating energy savings versus PLR determined from laboratory tests for the heat pump to calculate unit energy savings based on the UEC values. R3174

$$\text{Electric Furnace Heating Energy Savings (kWh)} = \text{Total Baseline Electric Furnace UEC (kWh)} \times 0.0592 \times (\text{PLR})^{-0.434}$$

Hourly data of multifamily (MFm) electric heating energy use from DEER2020 DOE-2.3 models were used to calculate hourly PLR and energy savings values and calculate annual PLR values and annual average energy savings shown in the following table . The average annual PLR values range from 0.057 to 0.111 depending on climate zone with an average of 0.075 ± 0.004. The average annual electric heating energy savings are 335 ± 43.0 kWh/yr or 18.2 ± 2.3% based on average savings and housing stock weights for each climate zone from READI. Electric furnace fan energy is included in the percentage savings calculations. Electric furnace heating energy savings are normalized per square foot of building floor area.

MFm Electric Heating Savings Based on Hourly PLR from DEER DOE-2.3

CLIMATE ZONE	AVE. HEATING PLR	BASE UEC (KWH/YR)	ENERGY SAVINGS (KWH/YR)	HOUSING STOCK WEIGHT	ENERGY SAVINGS (%)
1	0.094	2,285.9	369.2	0.008	16.2%
2	0.080	2,068.6	373.3	0.027	18.0%
3	0.082	2,441.5	441.6	0.369	18.1%
4	0.074	1,637.5	287.7	0.094	17.6%
5	0.072	2,376.0	434.9	0.012	18.3%
6	0.071	1,427.9	259.4	0.182	18.2%
7	0.057	1,016.4	198.0	0.130	19.5%
8	0.075	1,172.6	210.3	0.092	17.9%
9	0.076	1,930.7	349.6	0.039	18.1%

CLIMATE ZONE	AVE. HEATING PLR	BASE UEC (KWH/YR)	ENERGY SAVINGS (KWH/YR)	HOUSING STOCK WEIGHT	ENERGY SAVINGS (%)
10	0.081	2,220.7	402.6	0.016	18.1%
11	0.070	2,416.5	460.2	0.001	19.0%
12	0.071	2,408.3	464.3	0.023	19.3%
13	0.069	2,669.8	518.9	0.003	19.4%
14	0.078	3,067.1	548.4	0.000	17.9%
15	0.087	1,339.2	220.6	0.000	16.5%
16	0.111	3,889.5	586.5	0.003	15.1%
Average	**0.075 ± 0.004**	**1847 ± 243.8**	**335.3 ± 43**		**18.2 ± 2.3%**

ELECTRIC UNIT ENERGY SAVINGS - WATER SOURCE HEAT PUMP (WSHP) (KWH)

The Water Source Heat Pump (WSHP) heating UEC and electric savings for building HVAC type rDXWP are based on the DX cooling UEC and air-source heat pump (rDXHP) heating UEC values, hydronic heating (rDXHW) UEC values, and EER and COP values provided in ASHRAE 90.1 Table 6.8.1-2 Electrically Operated Unitary and Applied Heat Pumps—Minimum Efficiency Requirements. R1036 R3174 The rDXWP cooling UEC (kWh) values are calculated using the following equation.

```
Water Source Heat Pump Cooling UEC (kWh) = DX Cooling UEC (kWh) * 0.884
```

> *The rDXHP to rDXWP cooling cooling EIR adjustment of 0.889 is based on 11 EER for air-source and 12.3 EER for water-source (0.884 = 11/12.3).* R1036 The rDXWP cooling peak demand UEC (kW) values are calculated using the following equation and the 0.884 cooling EIR adjustment.

```
Water Source Heat Pump Cooling Peak Demand UEC (kW) = DX Cooling Peak Demand UEC (kW) * 0.884
```

The rDXWP electric heating UEC (kWh) values are calculated using the following equation.

```
Water Source Heat Pump Heating Electric UEC (kWh) = Heat Pump Heating UEC (kW) * 0.527
```

> *The rDXHP to rDXWP heating UEC ratio is 0.527 based on 7.7 HSPF for air-source and 14.6 HSPF for water source (0.527=7.7/14.6).* R1036

The DX cooling and HP heating percentage savings are used to calculate cooling and heating energy savings for the rDXWP building HVAC type. The rDXWP cooling Unit Energy Savings (UES) are based on Intertek and field test studies for extended variable fan-off delays for residential heat pumps. R3127 Findings from these studies show HP cooling energy savings (kWh) vary as a function of the HP cooling Part Load Ratio (PLR). The PLR for each hour is calculated as follows and is an output from DOE-2.3 or EnergyPlus.

```
PLR = Water Source Heat Pump Cooling Load (Btu/hr) / Water Source Heat Pump Cooling Capacity (Btu/hr)
```

After the PLR is calculated, the equation below applies the electric cooling energy savings versus PLR determined from SCE laboratory tests to calculate Unit Energy Savings for rDXWP based on the UEC values. R3174

```
WSHP (rDXWP) Cooling Energy Savings (kWh) = Total Baseline WSHP UEC (kWh) × MIN(0.206,−0.21n(PLR) +
0.0006))
```

Hourly data of multifamily (MFm) heat pump heating energy use from DEER2020 DOE-2.3 models are used to calculate hourly PLR and energy savings values and the calculate annual PLR. The rDXWP heating Unit Energy Savings (UES) are based on Intertek tests of variable fan-off delays for residential heat pumps (see Appendix B). R3127 Findings from these studies show WSHP heating energy savings (kWh) vary as a function of the WSHP heating Part Load Ratio (PLR). The PLR for each hour is calculated as follows and is an output from DOE-2.3 or EnergyPlus.

```
PLR = Water Source Heat Pump Heating Load (Btu/hr) / Water Source Heat Pump Heating Capacity (Btu/hr)
```

After the PLR is calculated, the equation below applies the electric heating energy savings versus PLR determined from laboratory tests of the heat pump to calculate Unit Energy Savings for rDXWP based on the UEC values. R3174

$$\text{WSHP (rDXWP) Heating Energy Savings (kWh)} = \text{Total Baseline WSHP UEC (kWh)} \times 0.0592 \times (\text{PLR})^{-0.434}$$

Hourly data of multifamily (MFm) heat pump heating energy use from DEER2020 MASControl3 DOE-2.3 models were used to calculate hourly PLR and energy savings values and calculate annual PLR values and annual average energy savings. The average annual PLR values vary depending on climate zone. The average annual electric heating energy savings are based on average savings and housing stock weights for each climate zone from READI. The WSHP electric fan heating and cooling energy are included in the percentage savings calculations. WSHP electric heating energy savings are normalized per square foot of building floor area. The WSHP gas heating savings (therms) for building HVAC type rDXWP are described in the Gas Savings section. The rDXWP savings will be updated when EnergyPlus models are available.

INTERACTIVE EFFECTS (KWH)

Interactive effects (kWh) for the fan heating energy for the variable fan-off delay for the gas furnace (rDXGF) are calculated using the following equation.

```
Interactive Effects rDXGF (kWh) = −1.08 × (1−0.835) × UECThermBase1_gf
```

UECThermBase1_gf = Gas furnace UEC, baseline (kWh)
The - 1.08 coefficient varies depending on building type and climate zone.

Interactive effects (kWh) for the fan heating energy for the variable fan-off delay for the hydronic heating (rDXHW) are calculated using the following equation.

```
Interactive Effects rDXHW (kWh) = −1.26 × (1−0.808) × UECThermBase1_hyd
```

UECThermBase1_hyd= Hydronic heating, baseline UEC (kWh)
The -1.26 coefficient varies depending on building type and climate zone.

The average interactive impacts are provided in the following table.

Interactive Effects - HVAC (kWh/therm)

BUILDING TYPE	BUILDING LOCATION	BUILDING HVAC	KWH_THERM (RATIO)
DMo	CZ01	rDXGF	**1.2050**
DMo	CZ01	rDXHP	**0.0000**
DMo	CZ01	rNCGF	**1.2050**
DMo	CZ02	rDXGF	**1.2020**
DMo	CZ02	rDXHP	**0.0000**
DMo	CZ02	rNCGF	**1.2020**
DMo	CZ03	rDXGF	**1.2260**
DMo	CZ03	rDXHP	**0.0000**
DMo	CZ03	rNCGF	**1.2260**
DMo	CZ04	rDXGF	**1.1870**
DMo	CZ04	rDXHP	**0.0000**
DMo	CZ04	rNCGF	**1.1870**
DMo	CZ05	rDXGF	**1.2160**
DMo	CZ05	rDXHP	**0.0000**
DMo	CZ05	rNCGF	**1.2160**
DMo	CZ06	rDXGF	**1.2060**
DMo	CZ06	rDXHP	**0.0000**
DMo	CZ06	rNCGF	**1.2060**

BUILDING TYPE	BUILDING LOCATION	BUILDING HVAC	KWH_THERM (RATIO)
DMo	CZ07	rDXGF	**1.1930**
DMo	CZ07	rDXHP	**0.0000**
DMo	CZ07	rNCGF	**1.1930**
DMo	CZ08	rDXGF	**1.2090**
DMo	CZ08	rDXHP	**0.0000**
DMo	CZ08	rNCGF	**1.2090**
DMo	CZ09	rDXGF	**1.1980**

(The complete table can be viewed in the Supporting Data tab)

Peak Electric Demand Reduction (kW)

Peak electric demand reduction (kW) impacts are based on peak kW from the statewide Fan Controller for Air Conditioner, Residential (SWHC029-03) measure package EnergyPlus update for DMo, SFm, and MFm prototypes. R3046 Demand savings are per each installed SFC unit. The DEER2022 peak demand periods shown in the following table are used to calculate the peak demand reduction for the California Title 24 Climate Zones (CZ) based on the DEER2020 peak demand definition, adopted by *Resolution E-5152*. R1503 These periods occur from June 1st through September 30th and provide the highest peak and average temperatures from 4:00 p.m. to 9:00 p.m. over three-day "heat wave" periods. Peak electric demand reduction savings are normalized per square foot of building floor area.

DEER Peak Demand Periods Adopted by Resolution E-5152

CLIMATE ZONE	START DATE	WEEKDAY	MAX PEAK TEMPERATURE (°F)	3-DAY AVERAGE TEMPERATURE (°F)
CZ01	Aug. 26	Wed.	86	60.2
CZ02	Aug. 26	Wed.	102	74.7
CZ03	Aug. 26	Wed.	87	71.3
CZ04	Aug. 26	Wed.	101	80.0
CZ05	Sep 16	Wed	93	68.3
CZ06	Sep 2	Wed	85	76.1

CLIMATE ZONE	START DATE	WEEKDAY	MAX PEAK TEMPERATURE (°F)	3-DAY AVERAGE TEMPERATURE (°F)
CZ07	Sep 2	Wed	83	74.4
CZ08	Sep 2	Wed	98	79.7
CZ09	Sep 1	Tue	100	82.9
CZ10	Jun 29	Mon	105	85.5
CZ11	Jun 29	Mon	110	90.2
CZ12	Jun 29	Mon	107	84.5
CZ13	Jun 29	Mon	109	90.6
CZ14	Jun 29	Mon	109	88.9
CZ15	Jun 29	Mon	120	100.8
CZ16	Aug. 12	Wed	88	77.7

The methodology used to derive the peak electric demand reduction (kW) calculations for each central or packaged HVAC system are provided per the following calculation based on climate zone and peak day per the above table.

Peak Demand Reduction

EQUATION (KW)
$UEC\_YrkWBase - UEC\_YrkWMeas$

UEC_YrkWBase = Average demand - baseline (kW)
UEC_YrkWMeas = Average demand - measure (kW)

Average Demand – Measure Case

EQUATION (KW)
$UEC\_YrkWBase \bullet coolEIRAdj\_\_YrkW$

coolEIRAdj__YrkW = Cooling energy input ratio adjustment - average demand (dimensionless)

Gas Savings (Therms)

The annual gas unit energy savings (UES) of this measure are derived as the difference between base and measure case annual unit energy consumption (UEC). The measure also applies to residential central or packaged gas only heating systems without cooling evaporator (DX) coils. The methodology used to derive the calculations for each central or packaged HVAC system are provided in the sections below.

Annual Unit Energy Savings - Gas

EQUATION (THERM / YR)
$UEC\_YrThermBase - UEC\_YrThermMeas$

UEC_YrThermBase = *Annual unit energy consumption - gas, baseline (therm/yr)*
UEC_YrThermMeas = *Annual unit energy consumption - gas, measure case (therm/yr)*

Annual Unit Energy Consumption - Gas, Measure Case

EQUATION (THERM / YR)
$UEC\_YrThermBase \bullet heatEIRAdj\_\_YrTherm$

heatEIRAdj__YrTherm = Heating energy input ratio adjustment - gas (dimensionless)

GAS UNIT ENERGY SAVINGS - FURNACE (THERMS)

Gas furnace (GF) heating EIR adjustment and energy savings are based on Intertek laboratory tests and field test studies of extended 2 to 4 minute variable fan-off delays for residential gas furnaces beyond the standard 1 to 2-minute fixed fan off delays provided by manufacturers . The SFC measure also provides low-to-high-speed fan operation after the heat exchanger (HX) reaches operating temperatures of 350 to 400 degrees Fahrenheit (F) for gas furnace systems so enabled. Findings from these studies show GF (therm) energy savings vary as a function of the heating part load ratio (PLR). The PLR for each hour is calculated as follows and is an output from DOE-2.3 or EnergyPlus.

```
PLR Gas Furnace Heating = Heating Load (Btu/hr) / Gas Furnace Heating Capacity (Btu/hr)
```

Laboratory tests with and without the SFC in heating mode provide data to evaluate heating energy savings. The following table provides Intertek test data for the SFC with low-to-high speed fan and variable fan-off delay versus the base gas furnace with low-speed fan and factory default 90-second delay and 120-second delay. R3126

Intertek gas furnace heating tests of SFC vs 90 and 120-second delay base

DESCRIPTION	TEST	TEST	TEST	TEST	AVERAGE
Furnace On Time (minutes)	7	8	15	30	15
Base 90-second delay tests	**Test 3**	**Test 5**	**Test 7**	**Test 9**	
90-sec. base Part Load Ratio (PLR) (w/o delay)	0.08	0.10	0.22	0.48	0.22
90-sec. base supply air temperature (°F)	102.4	103.4	110.7	116.3	108.2
90-sec. base Delivered heating energy (Btu) [a]	3,668	4,316	9,714	21,588	9,822
90-sec. base Energy use (Btu) [b]	7,375	8,559	16,511	33,407	16,463
90-sec. base heating efficiency (%) [c=a/b]	49.7%	50.4%	58.8%	64.6%	55.9%
90-sec. base electrical energy (kWh) [d]	0.052	0.059	0.109	0.213	0.11
90-sec. base gas input to match SFC (Btu) [e=a/j]	9,386	11,428	20,072	37,998	19,721
Base 120-second delay tests	**Test 11**	**Test 13**	**Test 15**	**Test 17**	
120-sec. base PLR (w/o delay)	0.09	0.10	0.23	0.49	0.23
120-sec. base supply air temperature (°F)	102.7	103.7	110.7	116.3	108.4
120-sec. base delivered heating energy (Btu) [f]	3,962	4,617	10,041	21,926	10,137
120-sec. base energy use (Btu) [g]	7,375	8,559	16,511	33,407	16,463
120-sec. base heating efficiency (%) [h=f/g]	53.7%	53.9%	60.8%	65.6%	58.5%
120-sec. base electrical energy (kWh) [i]	0.055	0.062	0.112	0.216	0.11
120-sec. base gas input to match SFC (Btu) [j=a/h]	8,690	10,684	19,419	37,412	19,051
SFC tests	**Test 12**	**Test 14**	**Test 16**	**Test 18**	
SFC supply air temperature (°F)	102.1	103.2	108.8	113.8	107.0
SFC vs 90-sec. supply air temp. diff. (°F)	-0.3	-0.3	-1.8	-2.5	-1.2
SFC vs 120-sec. supply air temp. diff. (°F)	-0.6	-0.5	-1.9	-2.5	-1.4
SFC Delivered heating energy (Btu) [k]	4,668	5,763	11,810	24,555	11,699
SFC Energy use (Btu) [l]	7,378	8,494	16,527	33,474	16,468

DESCRIPTION	TEST	TEST	TEST	TEST	AVERAGE
SFC Heating efficiency (%) [m=k/l]	63.3%	67.8%	71.5%	73.4%	69.0%
SFC electrical energy (kWh) [n]	0.063	0.074	0.127	0.231	0.12
SFC savings vs. 90-second base [o=1-c/m]	**21.4%**	**25.7%**	**17.7%**	**11.9%**	**19.2%**
SFC savings (Btu) [p=(k-a)/c+b-l]	2,008	2,934	3,545	4,525	3,253
SFC extra fan energy (kWh) [q=n-d]	0.011	0.015	0.019	0.018	0.016
SFC savings vs. 120-second base [r=1-c/m]	**15.1%**	**20.5%**	**14.9%**	**10.5%**	**15.3%**
SFC v. 120-sec savings (Btu) [s=(k-a)/c+g-1]	1,312	2,190	2,891	3,939	2,583
SFC extra fan energy (kWh) [t=n-i]	0.008	0.011	0.015	0.015	0.012
SFC weight ave. savings [u=0.933*o+0.067*r]	**19.5%**	**24.1%**	**16.8%**	**11.5%**	**18.0%**

Extra fan energy for the SFC ranges from 0.008 to 0.019 kWh with a weighted average of 0.015 kWh per test or 1.08 kWh/therm savings. R3126 The average SFC gas furnace heating energy savings range from 10.5 to 25.7% with a weighted average of 18 +/- 3.3%. The weighted average is based on 69.3% market share for 90-second or less base delay and 30.7% market share for 120-second or greater base per the following table. Field tests provide similar findings. Intertek gas furnace test data and summary Excel data are provided in the references. R3126

Gas Furnace Base Heating Equipment Age and Base Heating Fan-Off Delays

GAS FURNACE MANUFACTURING DATE	NON-ZERO DELAY BASE	45-SEC. DELAY	60-SEC. DELAY	65-SEC. DELAY	75-SEC. DELAY	90-SEC. DELAY	120-SEC. DELAY	150-SEC. DELAY
1980-84	139	2	59	15	3	42	18	0
1985-89	516	19	122	1	6	307	61	0
1990-94	706	16	148	18	7	439	78	0
1995-99	935	29	24	0	18	769	94	1
2000-04	1172	37	44	12	18	803	258	0
2005-09	986	32	14	0	10	615	289	26
2010-14	723	7	9	0	11	198	373	125
2015-17	405	1	1	0	2	11	168	222

GAS FURNACE MANUFACTURING DATE	NON-ZERO DELAY BASE	45-SEC. DELAY	60-SEC. DELAY	65-SEC. DELAY	75-SEC. DELAY	90-SEC. DELAY	120-SEC. DELAY	150-SEC. DELAY
Total	**5582**	**143**	**421**	**46**	**75**	**3184**	**1339**	**374**
Weight (all)		**0.026**	**0.075**	**0.008**	**0.013**	**0.570**	**0.240**	**0.067**
Weight (45-150 delay)		**0.026**	**0.097**			**0.570**	**0.240**	**0.067**
Weight (90 to 120-sec delay)						**0.693**	**0.307**	

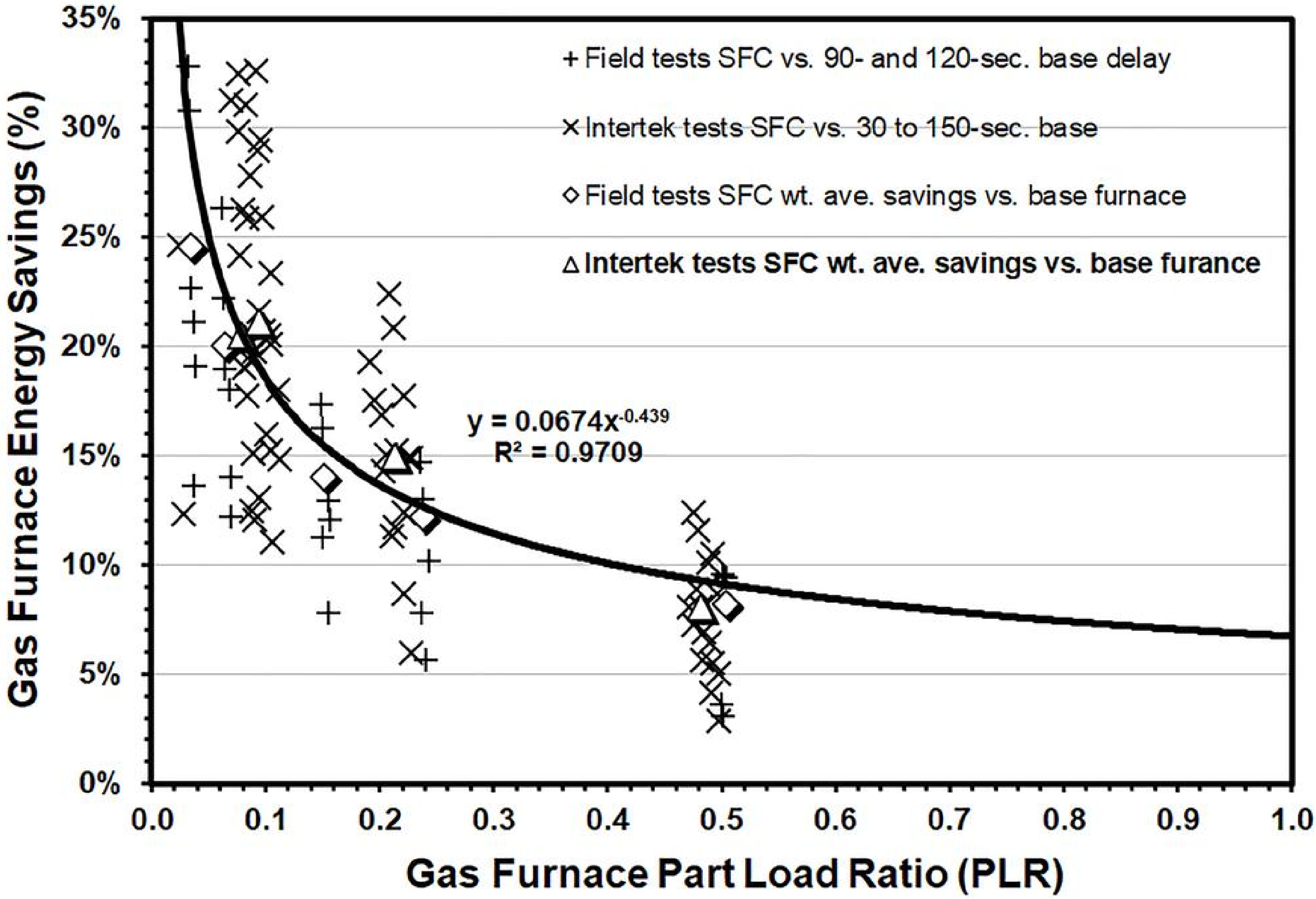
The following table summarizes field tests and Intertek tests of the SFC gas furnace heating savings. R3141 R3140 Field tests are used to verify the Intertek laboratory tests.

Gas Furnace Weighted Average Energy Savings vs. Base Delay and Fan Speed

GAS FURNACE RUN TIME (MINUTES)	FIELD TEST WEIGHTED AVE. PLR [A]	FIELD TEST WEIGHTED AVE. SAVINGS VS BASE [B]	INTERTEK TEST WEIGHTED AVE. PLR [C]	INTERKET TEST WEIGHTED AVE. SAVINGS VS BASE [D]
3	0.034	24.6%	0.019	35.3%
7	0.064	20.1%	0.079	20.5%
8	0.151	14.1%	0.095	21.1%
15	0.238	12.2%	0.214	15.0%
30	0.504	8.2%	0.482	8.1%

Laboratory and field test data and weighted average savings are plotted in the following figure which compares the SFC gas furnace heating energy savings versus PLR. The power function regression equation curve fit is also shown on the following figure.

$$\text{Gas Furnace Energy Savings (\%)} = 0.0674(\text{PLR})^{-0.439}$$



Gas Furnace Energy Savings as a Function of Part Load Ratio (PLR)

After the PLR is calculated using the EnergyPlus prototypes or MASControl3 DEER2020 DOE-2.3 prototypes, the equation below applies the gas furnace heating energy savings versus PLR determined from Intertek laboratory tests to calculate energy savings based on the annual gas furnace unit energy consumption (UEC). R3174

$$\text{Gas Furnace Heating Energy Savings (kWh)} = \text{Total Baseline Gas Furnace UEC (therm)} * (0.0674(PLR)^{-0.439})$$

The post processor uses the the above equation to calculate heating energy savings using a post processor based on the DEER2020 MASControl3 DOE-2.3 hourly output files (see Appendix C and D). R3128 R3129 The 16.5% average gas heating energy savings for all building types and climate zones is provided in the following table. The SWHC029-03 average PLR for heating is 0.099 based on EnergyPlus simulations, with 0.099 PLR, and the average gas furnace heating savings are 18.6% based on Intertek tests (see Appendix A). R3126

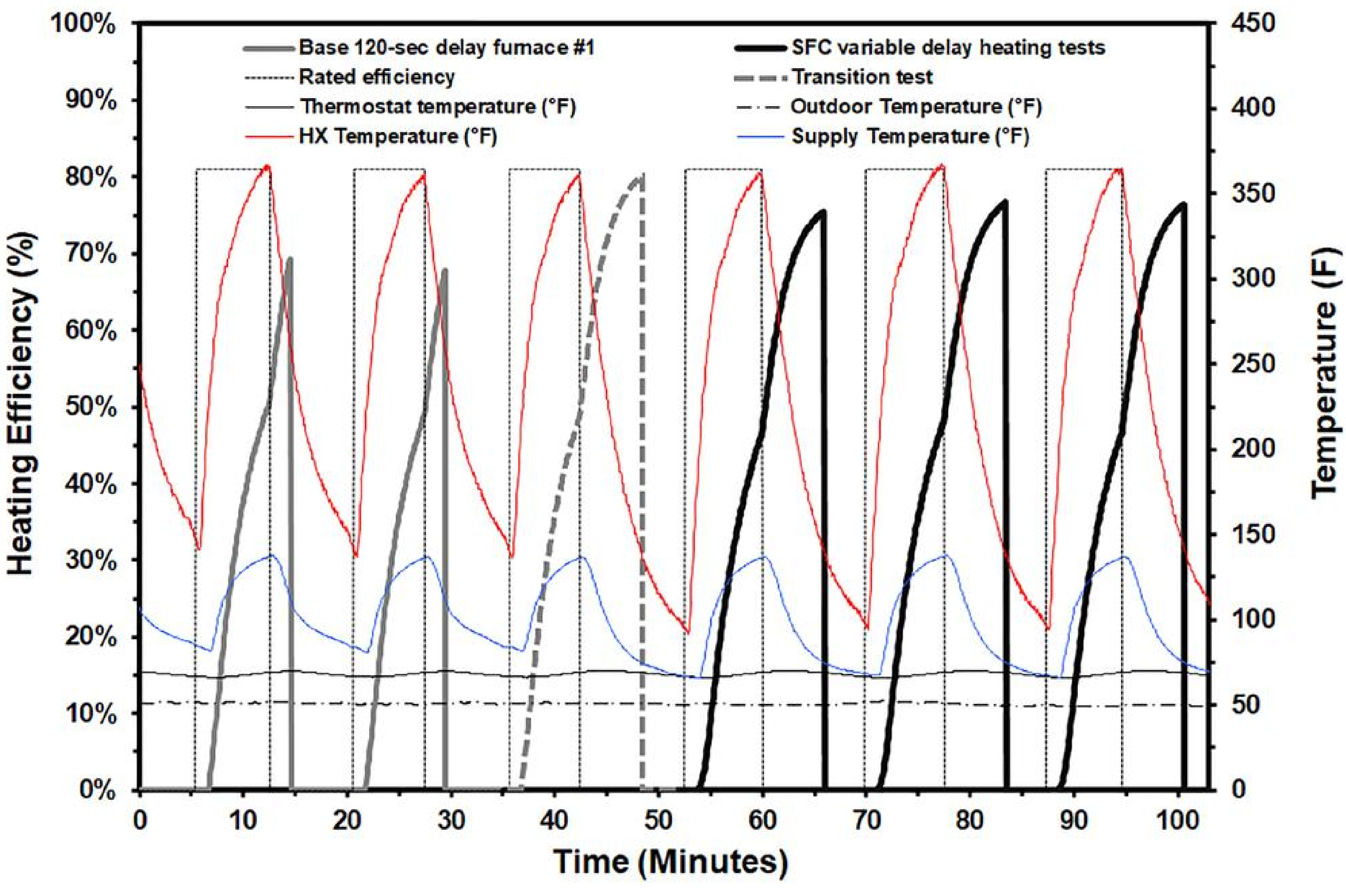
Gas Furnace Heating Savings for DMo, SFm, AND MFm Prototypes based on Hourly PLR from DEER2020 DOE-2.3

CLIMATE ZONE	DMO GAS FURNACE SAVINGS (%)	SFM GAS FURNACE SAVINGS (%)	MFM GAS FURNACE SAVINGS (%)	AVERAGE GAS FURNACE SAVINGS (%)
CZ01	15.2%	14.8%	16.2%	15.4%
CZ02	15.0%	16.7%	17.2%	16.3%
CZ03	16.0%	16.5%	17.3%	16.6%
CZ04	15.2%	15.7%	16.7%	15.9%
CZ05	15.4%	16.6%	17.1%	16.4%
CZ06	16.3%	17.6%	17.0%	17.0%
CZ07	17.3%	17.0%	17.2%	17.2%
CZ08	16.7%	17.5%	17.0%	17.1%
CZ09	15.3%	17.4%	17.2%	16.6%
CZ10	15.7%	17.7%	17.4%	16.9%
CZ11	14.8%	17.1%	17.6%	16.5%
CZ12	15.3%	17.1%	17.8%	16.7%
CZ13	15.8%	17.3%	17.8%	17.0%
CZ14	14.0%	17.3%	17.1%	16.1%
CZ15	14.2%	17.2%	15.7%	15.7%
CZ16	13.5%	15.4%	15.5%	14.8%
Average	**15.2%**	**17.1%**	**17.3%**	**16.5%**

Gas furnace heating unit energy savings (UES) are calculated using baseline unit energy consumption (UEC) values from the 2024 EnergyPlus prototype simulations of DMo, SFm, and MFm building types for residential direct expansion cooling and gas furnace heating (rDXGF) building HVAC systems. R3130 R3174 The gas UES values are calculated as a function of the base UEC values and the part load ratio (PLR). The functional relationship is determined based on Intertek heating test data and field test data. R3126 R3141 The gas savings are calculated based on the average improvement in the heating EIR adjustment from the base case to the measure case. Energy savings for each HVAC system are calculated based on Intertek tests of heating energy savings (see Appendix A) and DEER 2020 MASControl3 (Appendix C and D). R3126 R3128 R3129 R3136 R3137 R3138 R3142 Space heating UEC values (therm/year) for gas furnace heating for each of the 16 California climate zones (CZ) are used to calculate energy savings based on average percentage savings for each building HVAC system for residential double-wide mobile homes (DMo), single family (SFm) and multifamily (MFm) building types. Energy savings are normalized per square foot of building floor area.

```
Gas Furnace Unit Energy Savings (therm/y) = (1-0.835)*UEC (therm/y)
```

The following figure provides field tests of a gas furnace with base 120-second fan-off delays (left gray curve) and the SFC variable fan-off delays (right black curve). R3141 The figure shows heat exchanger (HX) temperature (red curve) reaching 364°F during the base and SFC tests. The HX temperature is 260°F after 2-minute fan-off delays indicating significant undelivered heating energy. The average HX temperature is 140°F after the SFC variable fan-off delays indicating more delivered heating to the space which improves thermal comfort and increases heating off-cycle times. SFC fan-off delays vary based on HVAC equipment type. Compared to fixed fan-off delays, the SFC provides 16.5% gas furnace heating savings based on Intertek tests (see Appendix A). R3126



Tests of base gas furnace with 2-minute fan-off delays and SFC extended variable fan-off delays

GAS UNIT ENERGY SAVINGS - HYDRONIC HEATING (THERMS)

Hydronic (HYD) heating Unit Energy Savings (UES) are based on Intertek tests for extended variable fan-off delays for residential hydronic (hot water coil forced air) heating systems (see Appendix B). R3127 Intertek performed tests on a 1.5-ton split-system hydronic heating system at 70F return air drybulb temperature and 47F OAT with and without SFC installed. Twelve (12) tests were performed with the water heater set at 130F and eight (8) tests were performed with the water heater set at 140F. The following table provides heating part load ratios and energy savings with the SFC based on 20 heating tests. The average hydronic heating energy savings are 19.2% based on Intertek laboratory tests. R3127

Hydronic Heating PLR and Energy Savings with the SFC

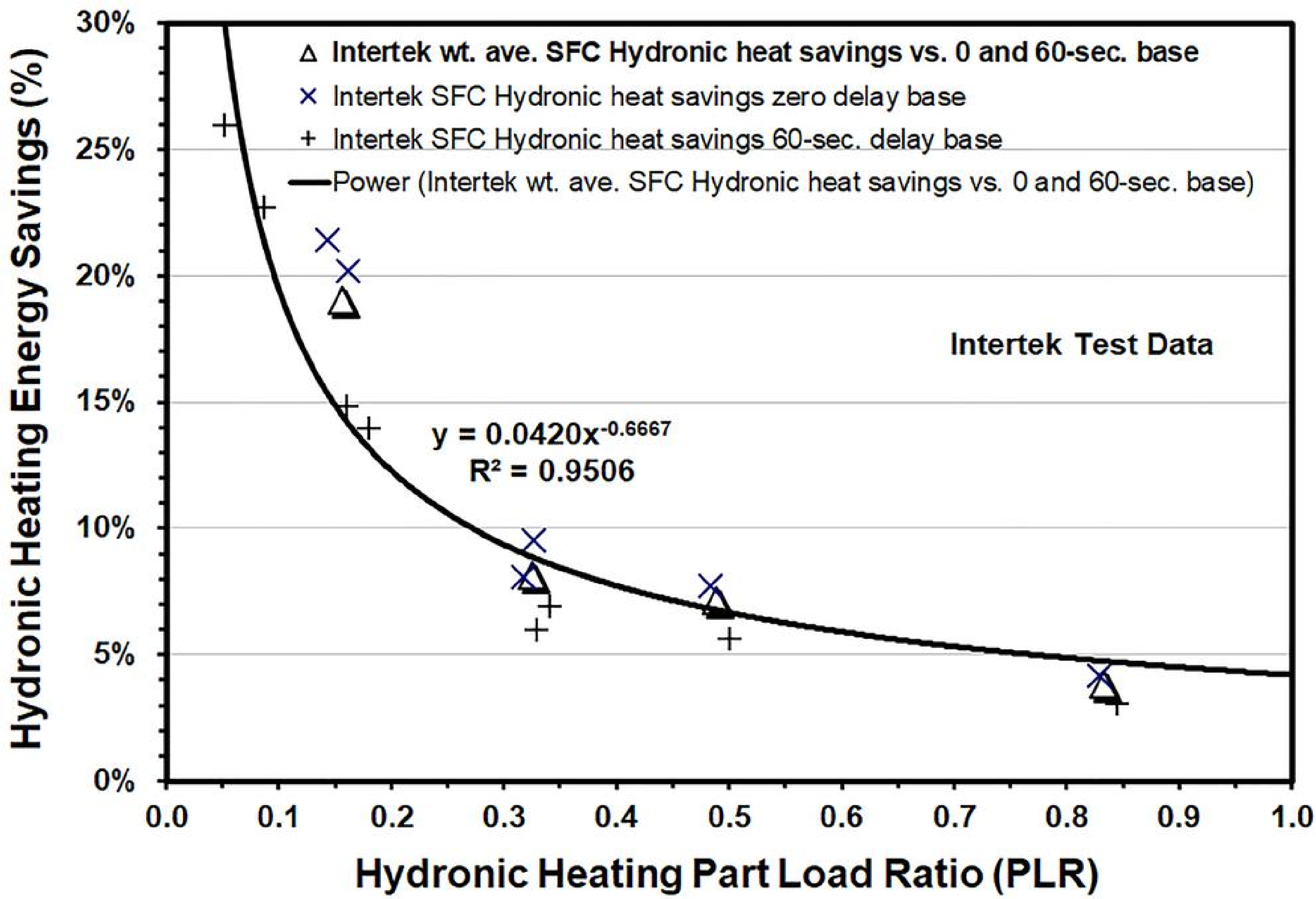
TEST	OAT (°F)	BASE FAN-OFF DELAY	PLR	HYD INPUT BASE BTU [A]	HYD OUTPUT BASE (BTU) [B]	HYD BASE EFFICIENCY [C=A/B]	HYD INPUT WITH SFC BTU [D]	HYD OUTPUT WITH SFC BTU [E]	HYD EFFICIENCY WITH SFC [F=E/D]	HYD ENERGY SAVINGS WITH SFC [G=1-C/F]
173	130	0	0.009	970	122	0.126	970	360	0.37	66.0%
174	130	0	0.039	2,365	512	0.216	2,365	839	0.35	39.0%
175	130	0	0.143	4,584	1,869	0.408	4,584	2,379	0.52	21.4%
176	130	0	0.326	9,223	4,260	0.462	9,223	4,709	0.51	9.5%
177	130	0	0.484	14,102	6,325	0.449	14,102	6,854	0.49	7.7%
178	130	0	0.829	23,893	10,834	0.453	23,893	11,303	0.47	4.2%
179	130	60	0.020	970	256	0.264	970	433	0.45	40.7%
180	130	60	0.052	2,365	674	0.285	2,365	911	0.39	26.0%
181	130	60	0.161	4,584	2,099	0.458	4,584	2,464	0.54	14.8%
182	130	60	0.341	9,185	4,458	0.485	9,185	4,789	0.52	6.9%
183	130	60	0.500	14,102	6,540	0.464	14,102	6,929	0.49	5.6%
184	130	60	0.845	23,893	11,040	0.462	23,893	11,387	0.48	3.0%
185	140	0	0.013	874	185	0.211	874	502	0.57	63.2%
186	140	0	0.069	2,365	1,006	0.426	2,365	1,548	0.65	35.0%
187	140	0	0.161	4,467	2,358	0.528	4,467	2,954	0.66	20.2%
188	140	0	0.317	9,650	4,643	0.481	9,650	5,051	0.52	8.1%

TEST	OAT (°F)	BASE FAN-OFF DELAY	PLR	HYD INPUT BASE BTU [A]	HYD OUTPUT BASE (BTU) [B]	HYD BASE EFFICIENCY [C=A/B]	HYD INPUT WITH SFC BTU [D]	HYD OUTPUT WITH SFC BTU [E]	HYD EFFICIENCY WITH SFC [F=E/D]	HYD ENERGY SAVINGS WITH SFC [G=1-C/F]
189	140	60	0.025	874	368	0.421	874	592	0.68	37.8%
192	140	60	0.088	2,365	1,282	0.542	2,365	1,658	0.70	22.7%
193	140	60	0.179	4,467	2,627	0.588	4,467	3,052	0.68	13.9%
194	140	60	0.329	9,522	4,820	0.506	9,522	5,127	0.54	6.0%
Average	**134**	**30**	**0.247**	**7,241**	**3,314**	**0.412**	**7,241**	**3,692**	**0.51**	**19.2%**

Findings from the Intertek tests show hydronic energy savings (therms) vary as a function of the heating Part Load Ratio (PLR). The PLR for each hour is calculated as follows and is an output from DEER2020 DOE-2.3 or EnergyPlus.

```
PLR Hydronic Heating = Hydronic Heating Load (Btu/hr) / Hydronic Heating Capacity (Btu/hr)
```

Laboratory tests with and without the SFC in heating mode provide data to evaluate heating energy savings. Hydronic heating energy savings and the average heating energy savings versus PLR are plotted in the following figure.



Hydronic Heating Energy Savings versus PLR

After the PLR is calculated using the EnergyPlus prototypes or MASControl3 DEER2020 DOE-2.3 prototypes, the equation below applies the hydronic heating energy savings versus PLR determined from laboratory tests to calculate energy savings based on the annual hydronic heating unit energy consumption (UEC). R3174

$$\text{Hydronic Heating Energy Savings (therm)} = \text{Total Baseline Hydronic Heating UEC (therm)} \times (0.0420(\text{PLR})^{-0.6667})$$

MASControl3 is used to generate DEER2020 DOE-2.3 building energy simulation prototypes. R3129 The post processor uses the the above equation based on Intertek tests to calculate hydronic heating energy savings. The average hydronic heating savings are 19.2% for all MFm building types and climate zones (see Appendix B). R3127 The extra hydronic heating fan energy is 1.26 kWh/therm savings (1.26 =29.7 kWh/23.6 therm).

MFm Hydronic Heating Savings Based on Hourly PLR from DEER2020 DOE-2.3

CLIMATE ZONE	AVE. HEATING PLR	BASE ENERGY USE (THERM/YR)	ENERGY SAVINGS (THERM/YR)	EXTRA FAN ENERGY (KWH/YR)	HOUSING STOCK WEIGHT	ANNUAL ENERGY SAVING (%)
CZ01	0.093	138.8	24.7	-36.8	0.000	17.8%
CZ02	0.079	125.5	23.7	-30.4	0.016	18.9%
CZ03	0.082	147.9	28.0	-36.7	0.030	18.9%
CZ04	0.073	104.0	19.3	-23.4	0.062	18.5%
CZ05	0.072	148.6	28.4	-34.9	0.005	19.1%
CZ06	0.071	91.0	17.2	-21.0	0.086	19.0%
CZ07	0.058	73.7	14.8	-16.4	0.053	20.0%
CZ08	0.076	74.3	13.9	-17.6	0.096	18.8%
CZ09	0.077	126.3	23.9	-30.4	0.286	19.0%
CZ10	0.081	127.5	24.1	-33.1	0.073	18.9%
CZ11	0.068	151.8	30.1	-37.3	0.031	19.8%
CZ12	0.071	153.8	30.6	-38.2	0.144	19.9%
CZ13	0.069	166.2	33.2	-42.5	0.076	20.0%
CZ14	0.072	182.3	34.9	-41.7	0.012	19.2%
CZ15	0.094	83.4	14.2	-18.2	0.026	17.0%
CZ16	0.108	243.0	39.8	-47.7	0.005	16.4%
Average	**0.074 ± 0.003**	**122.9 ± 13.1**	**23.6 ± 2.7**	**-29.7 ± 3.5**		**19.2 ± 2.2%**

GAS UNIT ENERGY SAVINGS - WATER SOURCE HEAT PUMP HEATING (THERMS)

The water source heat pump (WSHP) heating savings (therms) for building HVAC type rDXWP are based on the hydronic therm heating UEC times 0.766 based on 4.3 COP for water source heat pump heating (0.766=1-1/4.3). The 4.3 COP is from ASHRAE 90.1 Table 6.8.1-2 Electrically Operated Unitary and Applied Heat Pumps—Minimum Efficiency Requirements. R1036 The WSHP (rDXWP) gas heating UEC (therm) values are calculated using the following equation.

```
Water Source Heat Pump Heating Gas UEC (therm) = Hydronic Heating UEC (therm) * 0.766
```

The WSHP heating unit energy savings (UES) are based on the air source heat pump (rDXHP) heating percentage savings based on Intertek and field test studies for extended variable fan-off delays for residential heat pumps (see Appendix B). R3127 Findings from these studies show HP heating energy savings (kWh) vary as a function of the HP heating part load ratio (PLR). The WSHP heating PLR for each hour is calculated as follows and is an output from DOE-2.3 or EnergyPlus.

```
PLR = Water Source Heat Pump Heating Load (Btu/hr) / Water Source Heat Pump Heating Capacity (Btu/hr)
```

After the PLR is calculated, the equation below applies the heating energy savings versus PLR determined from laboratory tests for the air source heat pump to calculate WSHP unit energy savings (UES) based on the UEC values. R3174

$$\text{WSHP (rDXWP) Heating Energy Savings (therm)} = \text{Total Baseline WSHP UEC (therm)} \times 0.0592 \times (\text{PLR})^{-0.434}$$

Hourly data of multi-family (MFm) heat pump heating energy use from DEER2020 DOE-2.3 models were used to calculate hourly PLR and energy savings values and calculate annual PLR values and annual average energy savings. The average annual PLR values range from 0.057 to 0.111 depending on climate zone with an average of 0.075 ± 0.004. WSHP electric heating fan energy is included in the percentage savings calculations. WSHP heating energy savings are normalized per square foot of building floor area.

Life Cycle

Effective useful life (EUL) is an estimate of the median number of years that a measure installed through a program is still in place and operable. Remaining useful life (RUL) is an estimate of the median number of years that a technology or piece of equipment replaced or altered by an energy efficiency program would have remained in service and operational had the program intervention not caused the replacement or alteration. R181 R1503

The following CPUC-approved EUL and RUL values are applicable for the NR and the AOE measure offerings.

Effective Useful Life and Remaining Useful Life

EFFECTIVE USEFUL LIFE ID	EUL DESCRIPTION (TEXT)	SECTOR (TEXT)	EUL YEARS (YR)	START DATE (TEXT)	EXPIRE DATE (TEXT)
HV-EffFurn	**High Efficiency Furnace**	**Res**	**20.00**	**2013-01-01**	
HV-ResAC	**High Efficiency Air Conditioner (package and split systems)**	**Res**	**15.00**	**2013-01-01**	
HV-ResHP	**High Efficiency Heat Pump**	**Res**	**15.00**	**2013-01-01**	

Effective Useful Life and Remaining Useful Life – Host

HOST EUL ID	EUL DESCRIPTION (TEXT)	SECTOR (TEXT)	RUL YEARS (YR)	START DATE (TEXT)	EXPIRE DATE (TEXT)
HV-EffFurn	**High Efficiency Furnace**	**Res**	**6.70**	**2013-01-01**	
HV-ResAC	**High Efficiency Air Conditioner (package and split systems)**	**Res**	**5.00**	**2013-01-01**	
HV-ResHP	**High Efficiency Heat Pump**	**Res**	**5.00**	**2013-01-01**	

Base Case Material Cost ($/Unit)

The SFC is add on equipment (AOE) or normal replacement (NR) measure application type for a residential HVAC system and there is no base case material cost. Therefore, the base case material cost is zero.

Measure Case Material Cost ($/Unit)

The smart fan controller measure case material cost is $60/unit based on the average cost from two smart fan controller manufacturers. Measure case equipment costs are normalized per square foot of building floor area. R3132 ("Equipment Costs" tab)

Base Case Labor Cost ($/Unit)

The SFC is add on equipment (AOE) or normal replacement (NR) measure application type for a residential HVAC system and there is no base case labor cost. Therefore, the base case labor cost is zero.

Measure Case Labor Cost ($/Unit)

Measure case labor costs are $110/unit based on 2022 RSMeans labor rates for residential HVAC contractors and electricians. Measure case labor costs are normalized per square foot of building floor area. R3132 ("Equipment Costs" tab)

Net-to-Gross

The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. This NTG ratio is based on recommendations included in the 2019 Residential HVAC Impact Evaluation study conducted by DNV GL. R3048 The recommended NTG ratio of 0.88 was adopted by the California Public Utilities Commission (CPUC) in DEER *Resolution E-5152* for program year 2023. R1503 (Page A-31 Table A-5-1)

Net to Gross Ratio

NET TO GROSS RATIO ID	NTG DESCRIPTION (TEXT)	NTG ELECTRIC (RATIO)	NTG GAS (RATIO)	START DATE (TEXT)	EXPIRE DATE (TEXT)
Res-sAll-mHVAC-FanCtrl	**Residential fan motor control to delay turning off fan subsequent to heating/cooling cycle**	**0.8800**	**0.8800**	**2023-01-01**	

Gross Savings Installation Adjustment (GSIA)

The gross savings installation adjustment (GSIA) rate represents the ratio of the number of verified installations of the measure to the number of claimed installations reported by the utility. This factor varies by end use, sector, technology, application, and delivery method. This GSIA rate is the current “default” rate specified for measures for which an alternative GSIA has not been estimated and approved. R1270

Gross Savings Installation Adjustments - Default

GSIA ID	GSIA (RATIO) R1270
Def-GSIA	**1.0000**

Non-Energy Impacts

Non-energy impacts for this measure have not been quantified.

DEER Differences Analysis

This measure is an early adopter of DEER Measure ID "RE-ResAC-FanCtrls" for ExAnte 2023. This section provides a summary of inputs and methods based on the Database of Energy Efficient Resources (DEER), and the rationale for inputs and methods that are not DEER-based. Cooling energy savings for each HVAC system are based on Southern California Edison (SCE) Emerging Technologies (ET) Report ET11SCE1130 and the statewide Fan Controller for Air Conditioner, Residential (SWHC029-03) measure package. R972 Heating energy savings are based on Intertek tests and DEER2020 MASControl3 DOE-2.3 simulations (Appendices A, B, C, and D, post processor workbooks, and calibrated UEC data). R3126 R3127 R3128 R3129 R3136 R3137 R3138 R3142 R3174

DEER Difference Summary

DEER ITEM	COMMENT
Modified DEER methodology	Yes
Scaled DEER measure	Yes
DEER Base Case	Yes
DEER Measure Case	Yes
DEER Building Types	Yes
DEER Operating Hours	Yes
DEER eQUEST Prototypes	Yes (MASControl version 3 for residential buildings, existing vintage)
DEER Version	DEER2024 used for UEC values with percentage annual savings based on SCE ET11SCE1130 and Intertek laboratory tests
Reason for Deviation from DEER	DEER does not provide space heating energy savings for the SFC. This measure is an early adopter of "RE-ResAC-FanCtrls" for Ex Ante 2023.
DEER Measure IDs Used	RE-ResAC-FanCtrls

References

R1036 American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 2013. *ASHRAE Standard 90.1*. Atlanta (GA): ASHRAE.

R1270 California Public Utilities Commission (CPUC), Energy Division. 2020. *Energy Efficiency Policy Manual Version 6.* April. Page 34-35. **Download** (PDF, 1.1 MB)

R1503 California Public Utilities Commission (CPUC). 2021. *Resolution E-5152.* August 6. **Download** (PDF, 1.7 MB)

R1587 DNV GL. 2021. *Impact Evaluation of Smart Thermostats. Residential Sector - Program Year 2019*. Prepared for the California Public Utilities Commission (CPUC). CALMAC ID: CPU0232.01. June 16
Download (PDF, 5.5 MB)

R181 Kema, Inc. 2008. "Summary of EUL-RUL Analysis for the April 2008 Update to DEER." Memorandum submitted to Itron, Inc.
Download (DOC, 37.0 KB)

R2130 Mowris, R. 2022. "2021 DNV recommendations regarding fan control measures." Memorandum submitted to the California Public Utilities Commission (CPUC). April 11. **Download** (PDF, 1.5 MB)

R2163 .

R3046 Southern California Edison (SCE). 2021. "SWHC029-03 Fan Controller for Residential Air Conditioners - Industry Standard Practice (ISP)." December. **Download** (DOCX, 33.6 KB)

R3048 DNV GL. 2021. *Impact Evaluation Report Residential HVAC Sector - Program Year 2019, EM&V Group A*. Prepared for the California Public Utilities Commission (CPUC). CALMAC ID: CPU0229.01. May 2021.
Download (PDF, 4.0 MB)

R3121 State of Wisconsin Department of Administration, Division of Energy. 2003. *Electricity Used by New Furnaces: A Wisconsin Field Study*. Technical Report 230-1. Madison, Wisconsin: Wisconsin Department of Administration. October. **Download** (PDF, 700.7 KB)

R3122 Pigg, S. (Energy Center of Wisconsin), and T. Talerico (Glacier Consulting Group, LLC). 2004. “Electricity Savings from Variable-Speed Furnaces in Cold Climates.” *Proceedings of the 2004 ACEEE Summer Study on Energy Efficiency in Buildings, 1:264-279.* Washington, DC: American Council for an Energy Efficient Economy (ACEEE).
Download (PDF, 252.0 KB)

R3123 State of Wisconsin Department of Administration, Division of Energy. 2004. *ECM Furnace Impact Assessment Report: Focus on Energy Public Benefits Evaluation*. Prepared by Glacier Consulting Group, LLC and PA Government Services Inc. June 28. **Download** (PDF, 960.0 KB)

R3124 Public Services Commission of Wisconsin (PSCW). 2009. *ECM Furnace Impact Assessment Report: Focus on Energy Evaluation*. Prepared by Glacier Consulting Group, LLC and PA Consulting Group. January 12. **Download** (PDF, 630.3 KB)

R3126 Intertek. 2015. "Appendix A: Performance Evaluation Based on Intertek Test Data of an Efficient Fan Controller (EFC) Installed on Split and Package Air Conditioners with Gas Furnaces." Intertek Project No. G101756555. Revised July 15, 2022. **Download** (PDF, 1.9 MB)

R3127 Intertek. 2016. "Appendix B: Intertek Performance Evaluation of an Efficient Fan Controller (EFC) Installed on Heat Pump and Hydronic Split-Systems." Intertek Project No. G102791047. Revised July 15, 2022. **Download** (PDF, 1.5 MB)

R3128 Verified, Inc. 2022. "Appendix C: Modeling Assumptions for SFC SWHC059-01." **Download** (PDF, 3.0 MB)

R3129 Jacobs, P. (Building Metrics, Inc). 2022. "Appendix D: SWHC059-01 SFC Residential DEER2020 MASControl3 DOE2.3 Building Simulation Specifications." **Download** (PDF, 1.9 MB)

R3130 McWilliams, J. 2022. "DEER EnergyPlus™ Prototype Calibration: DEER EnergyPlus Transition Webinar #2." April 25. **Download** (PDF, 2.8 MB)

R3132 Verified, Inc. 2023. "SWHC059-01_cost_references_20230323.xlsx." **Download** (XLSX, 23.8 KB)

R3136 Building Metrics, Inc. 2022. "SWHC059-01_doe-2.3_input_files.zip." **Download** (ZIP, 23.7 MB)

R3137 Building Metrics, Inc. 2022. "SWHC059-01_mascontrol3_prototype_files.zip." **Download** (ZIP, 73.3 KB)

R3138 Building Metrics, Inc. 2021. "SWHC059-01_post_processer_excel_workbooks.zip." **Download** (ZIP, 334.8 MB)

R3139 Verified, Inc. 2022. "SWHC059-01_market_share_data_20230503.xlsx." **Download** (XLSX, 716.4 KB)

R3140 Verified, Inc. 2022. "SWHC059-01_intertek_summary_data.xlsx."
Download (XLSX, 293.8 KB)

R3141 Verified, Inc. 2019. "SWHC059-01_field_test_data.xlsx."
Download (XLSX, 32.7 MB)

R3142 Building Metrics, Inc. 2021. "SWHC059-01_doe-2.3_output_files.zip."
Download (ZIP, 6.5 GB)

R3174 Verified, Inc. 2023. "SWHC059-01_uec_and_savings_from_swhc029-03_energyplus_and_mascontrol3_doe-2.3_20230428.xlsx."
Download (XLSX, 70.7 KB)

R972 Southern California Edison (SCE), Design and Engineering Services. 2012. *Effects of Delaying Evaporator Fan Cycle Off Time for Residential Air-conditioning Units*. ET11SCE1130. March 20.
Download (PDF, 1.6 MB)