

WPSDGEREHC0024
Revision # 0

San Diego Gas & Electric
Energy Efficiency Engineering

California HVAC Upgrade: Efficient Fan Controller (EFC) – Residential

At a Glance Summary

Measure Name:	Efficient Fan Controller (EFC) - Residential
Savings Impacts Energy Common Units (ECU):	Household or tons for Residential Air Conditioner (RAC) or kBtuh for Residential Gas Furnace (RGF) space heating only
Customer Base Case Description:	The customer base case heating, ventilating, and air conditioning (HVAC) system has low-speed fan operation in heating mode. After the furnace turns off the fan continues to operate for a fixed time delay of 90 seconds or the fan continues to operate based on a temperature delay which turns off the fan when the plenum temperature falls below a control threshold of 100 to 200°F depending on whether or not the temperature delay sensor is operating or set properly. In cooling mode the fan turns off when the compressor turns off (i.e., no time delay). Some customer base case systems (less than 8%) continue to operate the fan for a fixed time delay of 90 seconds after the compressor turns off.
Code Base Case Description:	The code base case description is the same as the customer base case description (above).
Costs Common Units:	Household or tons for RAC, or kBtuh for RGF
Measure Equipment Cost (\$/unit):	25
Measure Incremental Cost (\$/unit):	75 (SFM, MFM, and DMO)
Measure Installed Cost (\$/unit):	75 (SFM, MFM, and DMO)
Measure Load Shape:	26 = Res. Central Air Conditioning
Effective Useful Life (years):	10
Program Type:	Retrofit
TOU AC Adjustment:	100%
Net-to-Gross Ratios:	1.00
Important Comments:	DEER Vintage Weighting

E3 Calculator Data – EFC for Residential Air Conditioner (RAC) Cooling and Heating

DEER 2008 ImpactID	Measure Description	Building Type	Building Vintage	Climate Zone	Above Code Annual Electric Savings (kWh/unit)	Above Code Peak Electric Demand Reduction (kW/unit)	Above Code Annual Savings (Therms /unit)	Incremental Measure Cost (\$/unit)	Effective Useful Life (years)	Net to Gross Ratio	Total Resource Cost (TRC) Test
SFM-w06-vSDGx-hAC-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	6	84.13	0.1	22.13	75	10	1	4.15
SFM-w07-vSDGx-hAC-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	7	75.14	0.11	15.67	75	10	1	3.4
SFM-w08-vSDGx-hAC-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	8	129.02	0.14	19.15	75	10	1	4.78
SFM-w10-vSDGx-hAC-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	10	149.18	0.15	25.24	75	10	1	5.79
SFM-w14-vSDGx-hAC-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	14	290.13	0.2	33.16	75	10	1	9.16
SFM-w15-vSDGx-hAC-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	15	542.52	0.2	13.12	75	10	1	11.16
SFM-wSDG-vEx-hAC-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	SDG Weighted	211.69	0.15	21.41	75.00	10.00	1.00	6.41
MFM-w06-vSDGx-hAC-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	6	23.13	0.06	7.55	75	10	1	1.48
MFM-w07-vSDGx-hAC-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	7	19.79	0.06	6.01	75	10	1	1.26
MFM-w08-vSDGx-hAC-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	8	50.65	0.07	6.97	75	10	1	1.93
MFM-w10-vSDGx-hAC-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	10	76.85	0.09	11.17	75	10	1	2.87
MFM-w14-vSGx-hAC-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	14	195.83	0.13	18.09	75	10	1	5.71
MFM-w15-vSDGx-hAC-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	15	344.33	0.14	6.59	75	10	1	6.99
MFM-wSDG-vEx-hAC-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	SDG Weighted	118.43	0.09	9.40	75.00	10.00	1.00	3.37
DMO-w06-vSDGx-hAC-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	6	265.75	0.13	17.34	75	10	1	6.76
DMO-w07-vSDGx-hAC-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	7	236.33	0.16	14.58	75	10	1	6.13
DMO-w08-vSDGx-hAC-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	8	511.41	0.23	21.16	75	10	1	11.64
DMO-w10-vSDGx-hAC-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	10	507.25	0.25	22.25	75	10	1	11.83
DMO-w14-vSDGx-hAC-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	14	688.2	0.32	39.97	75	10	1	16.9
DMO-w15-vSGDx-hAC-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	15	962.2	0.33	18.63	75	10	1	19.16
DMO-wSDG-vEx-hAC-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	SDG Weighted	528.52	0.24	22.32	75.00	10.00	1.00	12.07

See **Section 1.5** for baseline unit energy consumption (UEC) values.

E3 Calculator Data – EFC for Residential Gas Furnace (RGF) Space Heating Only

DEER 2008 ImpactID	Measure Description	Building Type	Building Vintage	Climate Zone	Above Code Annual Electric Savings (kWh/unit)	Above Code Peak Electric Demand Reduction (kW/unit)	Above Code Annual Savings (Therms /unit)	Incremental Measure Cost (\$/unit)	Effective Useful Life (years)	Net to Gross Ratio	Total Resource Cost (TRC) Test
SFM-w06-vSDGx-hGF-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	6	-8.42	0	20.01	75	10	1	1.91
SFM-w07-vSDGx-hGF-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	7	-6.51	0	14.83	75	10	1	1.41
SFM-w08-vSDGx-hGF-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	8	-7.67	0	17.73	75	10	1	1.69
SFM-w10-vSDGx-hGF-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	10	-10.14	0	23.64	75	10	1	2.25
SFM-w14-vSDGx-hGF-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	14	-14.71	0	33.72	75	10	1	3.21
SFM-w15-vSDGx-hGF-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	15	-5.96	0	14.63	75	10	1	1.4
SFM-wSDG-vEx-hGF-tWt-bCAv-eMsr	EFC	SFM	SDG Weighted	SDG Weighted	-8.90	0.00	20.76	75.00	10.00	1.00	1.98
MFM-w06-vSDGx-hGF-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	6	-3.29	0	7.78	75	10	1	0.74
MFM-w07-vSDGx-hGF-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	7	-2.61	0	6.05	75	10	1	0.58
MFM-w08-vSDGx-hGF-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	8	-2.94	0	6.7	75	10	1	0.64
MFM-w10-vSDGx-hGF-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	10	-4.59	0	10.35	75	10	1	0.98
MFM-w14-vSDGx-hGF-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	14	-10.26	0	18.37	75	10	1	1.71
MFM-w15-vSDGx-hGF-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	15	-2.18	0	4.97	75	10	1	0.47
MFM-wSDG-vEx-hGF-tWt-bCAv-eMsr	EFC	MFM	SDG Weighted	SDG Weighted	-4.31	0.00	9.04	75.00	10.00	1.00	0.85
DMO-w06-vSDx-hGF-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	6	-6.04	0	14.87	75	10	1	1.42
DMO-w07-vSDGx-hGF-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	7	-5.67	0	13.89	75	10	1	1.33
DMO-w08-vSDGx-hGF-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	8	-7.07	0	16.8	75	10	1	1.6
DMO-w10-vSDGx-hGF-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	10	-10.9	0	25.01	75	10	1	2.38
DMO-w14-vSDGx-hGF-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	14	-18.74	0	40.97	75	10	1	3.88
DMO-w15-vSDGx-hGF-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	15	-18.93	0	19.09	75	10	1	1.65
DMO-wSDG-vEx-hGF-tWt-bCAv-eMsr	EFC	DMO	SDG Weighted	SDG Weighted	-11.23	0.00	21.77	75.00	10.00	1.00	2.04

Work Paper Approvals

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Date

Document Revision History

Revision 0	October 25, 2010	Adapted from SoCalGas Workpaper SCG0077 Revision #0 dated April 4, 2010, developed by Verified, Inc. Revised weighting in multiple tables for SDGE Climate zones. Added SDGE Work paper number.
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Section 1. General Measure & Baseline Data

1.1 Measure Description & Background

This work paper provides engineering estimates of savings for upgrading Heating, Ventilating, and Air Conditioning (HVAC) equipment with an Efficient Fan Controller (EFC) to recover additional heating and cooling capacity and operate HVAC equipment at higher efficiency. The savings documented here are for the installation of a patent pending EFC that adjusts fan operation for heating based on gas valve activation time (which is a proxy for furnace operation), and fan operation for cooling based on fan run time (which is a proxy for compressor operation). The amount of time the fan operates after the furnace is off or after the compressor is off varies with the amount of time the furnace or compressor are on. The furnace run time indicates how much heat is stored in the heat exchanger. The air conditioner fan run time indicates how much cold water is condensed on the evaporator coil. Most furnaces fans operate at low speed and this reduces airflow and heating efficiency. The EFC provides high speed fan operation in heating mode to increase heating efficiency and reduce furnace run time.¹ This measure applies to HVAC systems that have a fan off time delay of less than 2 minutes in heating or cooling operation. The measure applies to standard and high efficiency furnaces and heat pumps in heating mode and air conditioners with furnaces in cooling and heating mode. The savings estimates assume a baseline temperature delay or 90 second fan time delay on heating and no time delay on cooling. Some units have a 60 to 90 second time delay on cooling. With these units the savings will be slightly lower compared to units with no existing time delay. If an HVAC unit includes a high efficiency fan motor, the savings will be higher due to lower power consumption of the fan motor. Savings for combined measures are discussed in **Table 10**.

Conventional fan controllers typically operate the ventilation fan for 0 to 90 seconds after the furnace or compressor turn off and this wastes heating and cooling energy that is not delivered to the conditioned space. The EFC recovers and delivers more heating and cooling energy to the conditioned space than is possible with conventional fan controllers. The EFC improves the efficiency of HVAC equipment by delivering additional heating or cooling capacity for a small amount of additional electric energy (kWh).

Air conditioners cool conditioned spaces by removing sensible and latent heat from the return air which reduces the supply air temperature and humidity. 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.² Most evaporators are cold and wet (below 40 to 50°F) after the compressor turns off. Cooling energy left on the evaporator coil after the compressor turns off is generally wasted. The evaporator absorbs heat from the attic and cold water on the coil flows

¹ Some newer heating systems with standard 90-second time delay do not allow high speed fan operation without switching the fan control jumper.

² 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.

down the condensate drain. The EFC recovers the remaining cooling energy from evaporator coil by operating the fan after the compressor turns off to cool the conditioned space.

Most furnaces fans operate at low speed and this reduces airflow and heating efficiency. The EFC provides high speed fan operation in heating mode to increase heating efficiency and reduce furnace run time. Most furnace heat exchangers are still hot (above 135 to 210°F) after the furnace fan turns off. The EFC recovers the remaining heat energy from the hot furnace heat exchanger after the furnace turns off and delivers this heat to the conditioned space.

The EFC is a small low-voltage microprocessor controller approximately the size of a US penny. The EFC connects to the existing thermostat wires and is mounted in one of three positions: 1) behind the thermostat mounting plate, 2) between the thermostat and the thermostat mounting plate (with sufficient clearance), or 3) in a hole behind thermostat mounting plate where thermostat wires attach to thermostat.

This measure is cross cutting for use the residential market sector and available for use in the commercial sector.

The values used to forecast the measure's impacts are as follows:

- Incremental Measure Cost: \$75 per air conditioner,
- Annual Energy Savings: See **Table 1** and **Table 2**,
- Demand Reduction: See **Table 1** and **Table 2**,
- Effective Useful Life: 10 years, and
- Net to Gross Ratio: 1.0 (Comprehensive Space Conditioning).

1.2 DEER Differences Analysis

The Database for Energy Efficiency Resources (DEER 2008) does not provide energy savings for the Efficient Fan Controller (EFC) measure. The cooling, heating, and ventilation Unit Energy Consumption (UEC) values for residential air conditioners (RAC) and residential gas furnaces (RGF) are based on the DEER2008 UEC values from the Measure Inspection and Summary viewer tool (MISer Version 1.10.25) and DEER (Version: DEER2008.2.2). See <http://www.deeresources.com/>. UEC values and DEER 2008 ImpactIDs listed in **Section 1.5** are in the embedded Excel Workbook #1 (see References Section). The DEER annual cooling and heating energy consumption are average values assuming no degradation due to excessive duct leakage, improper refrigerant charge and airflow, restrictions, non condensables, or blocked condenser coils. If the unit efficiency is degraded, the UEC will increase and this will increase the energy savings (therms, kWh and kW) beyond the estimates provided in this work paper. The annual natural gas savings (therm/yr) are based on weighted average savings of 11% (see **Table 12**). The annual electricity energy savings (kWh/yr) are based on 14.8% weighted average cooling savings and include the impact of increased ventilation energy use of 13.8% for space heating ventilation and -36.2% for space cooling ventilation.

EFC Energy and demand savings for residential air conditioning (RAC - space cooling and heating) are shown in **Table 1**. Data are based on analysis in **Section 1.4** provided in the embedded Excel workbooks #1 and #2 in the References Section.

Table 1. EFC Energy and Demand Savings Impacts by Building Type – RAC

Building Type	Climate Zone	Vintage	Net Elec Savings (kWh/yr)	Elec Demand Savings (kW)	Annual Gas Savings (therm/yr)
Single Family	6	SDG Weighted	84.13	0.1	22.13
Single Family	7	SDG Weighted	75.14	0.11	15.67
Single Family	8	SDG Weighted	129.02	0.14	19.15
Single Family	10	SDG Weighted	149.18	0.15	25.24
Single Family	14	SDG Weighted	290.13	0.2	33.16
Single Family	15	SDG Weighted	542.52	0.2	13.12
Single Family	SDG Weighted	SDG Weighted	211.69	0.15	21.41
Multi Family	6	SDG Weighted	23.13	0.06	7.55
Multi Family	7	SDG Weighted	19.79	0.06	6.01
Multi Family	8	SDG Weighted	50.65	0.07	6.97
Multi Family	10	SDG Weighted	76.85	0.09	11.17
Multi Family	14	SDG Weighted	195.83	0.13	18.09
Multi Family	15	SDG Weighted	344.33	0.14	6.59
Multi Family	SDG Weighted	SDG Weighted	118.43	0.09	9.40
Mobile Home	6	SDG Weighted	265.75	0.13	17.34
Mobile Home	7	SDG Weighted	236.33	0.16	14.58
Mobile Home	8	SDG Weighted	511.41	0.23	21.16
Mobile Home	10	SDG Weighted	507.25	0.25	22.25
Mobile Home	14	SDG Weighted	688.2	0.32	39.97
Mobile Home	15	SDG Weighted	962.2	0.33	18.63
Mobile Home	SDG Weighted	SDG Weighted	528.52	0.24	22.32

EFC Energy and demand savings for residential gas furnace (RGF - space heating only) are shown in **Table 2**. Data are based on analysis in **Section 1.4** provided in the embedded Excel workbooks #1 and #2 in the References Section.

Table 2. EFC Energy and Demand Savings Impacts by Building Type – RGF

Building Type	Climate Zone	Vintage	Net Elec Savings (kWh/yr)	Elec Demand Savings (kW)	Annual Gas Savings (therm/yr)
Single Family	6	SDG Weighted	-8.42	0	20.01
Single Family	7	SDG Weighted	-6.51	0	14.83
Single Family	8	SDG Weighted	-7.67	0	17.73
Single Family	10	SDG Weighted	-10.14	0	23.64
Single Family	14	SDG Weighted	-14.71	0	33.72
Single Family	15	SDG Weighted	-5.96	0	14.63
Single Family	SDG Weighted	SDG Weighted	-8.90	0.00	20.76
Multi Family	6	SDG Weighted	-3.29	0	7.78
Multi Family	7	SDG Weighted	-2.61	0	6.05
Multi Family	8	SDG Weighted	-2.94	0	6.7
Multi Family	10	SDG Weighted	-4.59	0	10.35
Multi Family	14	SDG Weighted	-10.26	0	18.37
Multi Family	15	SDG Weighted	-2.18	0	4.97
Multi Family	SDG Weighted	SDG Weighted	-4.31	0.00	9.04
Mobile Home	6	SDG Weighted	-6.04	0	14.87
Mobile Home	7	SDG Weighted	-5.67	0	13.89
Mobile Home	8	SDG Weighted	-7.07	0	16.8
Mobile Home	10	SDG Weighted	-10.9	0	25.01
Mobile Home	14	SDG Weighted	-18.74	0	40.97
Mobile Home	15	SDG Weighted	-18.93	0	19.09
Mobile Home	SDG Weighted	SDG Weighted	-11.23	0.00	21.77

1.3 Codes & Standards Requirements Analysis

There is no code or standard addressing the EFC. The measure can be retrofit to any RAC with gas furnace or heat pump having a thermostat with less than 2-minute time delay for cooling or heating or standard temperature delay for heating. The measure can also be retrofit to any RGF thermostat with less than 2-minute time delay or standard temperature delay for heating.

1.4 EM&V, Market Potential, and Other Studies

The forecast values were derived from these sources:

- Incremental (Full) Measure Cost is based on what HVAC Contractors charge for the materials, labor, and overhead to install the Efficient Fan Controller.
- Annual Energy Savings is based on the Percentage Energy Savings times the Baseline Electrical Usage as described in **Section 1.4.5** (Estimated Energy Savings).

- Percentage Energy Savings are based on Field and Laboratory Tests as described in **Section 1.4.3** (Field Test Data) and **Section 1.4.4** (Laboratory Test Data).

1.4.1 Abstract

The EFC improves on the conventional temperature or time delay relay (TDR) which will continue to operate the fan after the furnace or compressor turns off. In heating mode, the EFC micro-computer monitors gas valve activation time and determines whether or not to continue operating the fan after the furnace turns on and how long the fan should continue operating to maximize heat recovery from the heat exchanger. In cooling mode the EFC monitors fan operation and determines whether or not to continue operating the fan after the compressor turns off to transfer heat to the cold evaporator coil and recover energy stored in the form of condensed cold water on the evaporator coil to further cool the building. In cooling mode the EFC uses the evaporator coil as an evaporative cooler. The fan uses 8 to 15 times less power than the compressor and is adaptively controlled to operate based on fan run time (which is a proxy for compressor operation). Air conditioning equipment manufacturers provide an optional 1.5 minute TDR kit to improve SEER by 2 to 3%. Furnace manufacturers provide either a 1.5 minute fan time delay or a temperature delay that extends fan operation from 1 to 4 minutes by shutting off the fan when the supply air is less than 110°F. The standard furnace TDR improves AFUE by 2 to 3%. The delivered furnace efficiency improvements from EFC are shown in **Figure 1**. The EFC maximizes heating efficiency by increasing fan speed from low to high four minutes after the furnace is turned on. Standard furnace fans operate at low speed delivering less heating capacity to the conditioned space at lower efficiency compared to operating the fan at high speed. The EFC maximizes heat recovery from the heat exchanger after the furnace is turned off with an extended fan delay of 2 to 4 minutes depending on how long the furnace gas valve signal is on during the heating cycle. The EFC improves heating efficiency by 7 to 10% above standard temperature delay and 6 to 8% above standard 90-second delay. For systems with degraded temperature sensors the EFC saves 7 to 23% depending on furnace run time and ambient conditions. Savings will be greater for furnaces with degraded temperature delay. The delivered air conditioner sensible energy efficiency ratio (EER*) improvements from EFC are shown in **Figure 2**. Standard air conditioners have a 0 to 1.5 minute fan time delay. The EFC maximizes recovery of latent cooling from the evaporator after the compressor is turned off with an extended fan delay of 1.5 to 5 minutes depending on how long the air conditioner compressor is on during the cooling cycle.

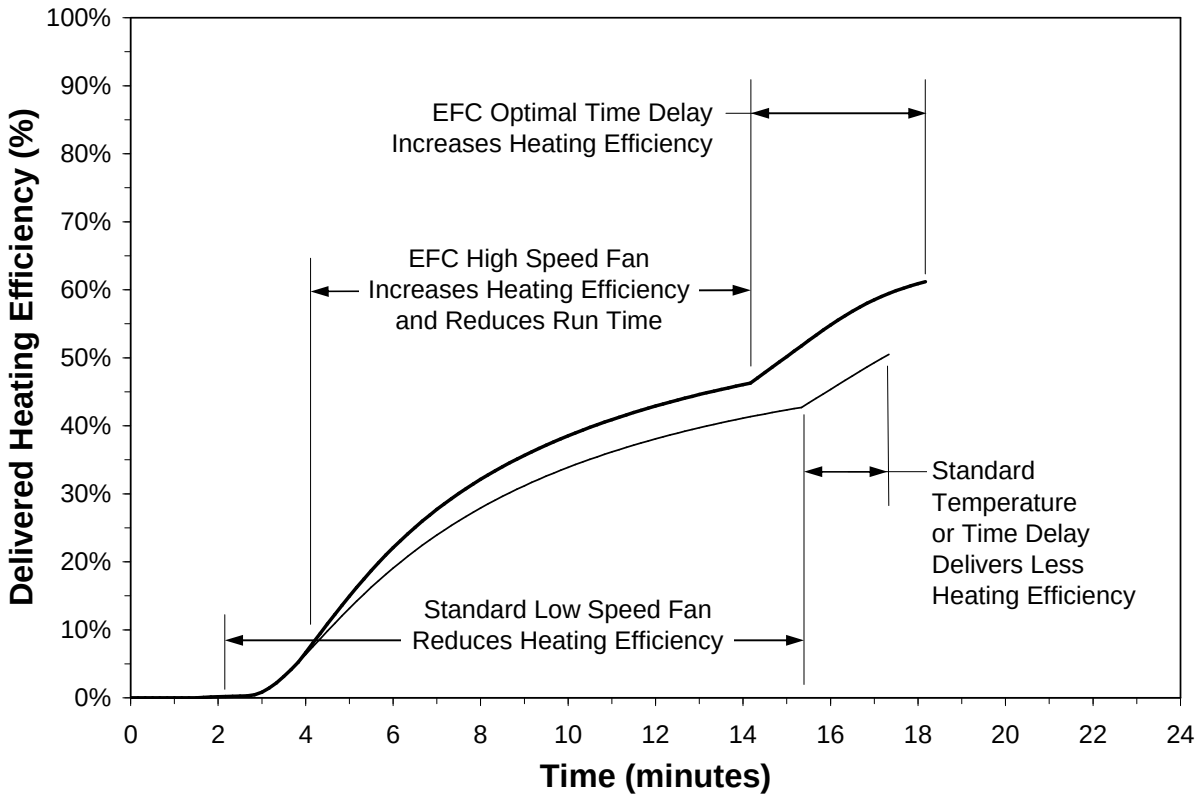


Figure 1. Heating Efficiency Improvement from EFC

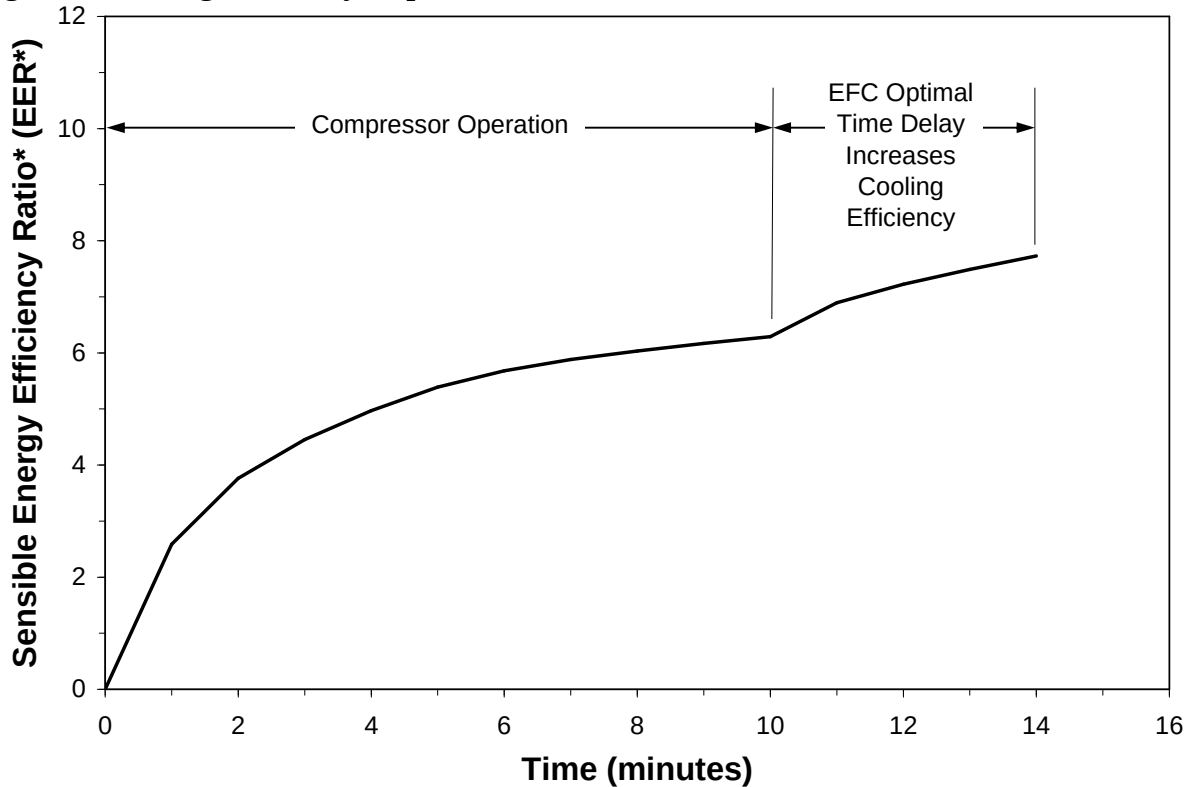


Figure 2. Air Conditioner Sensible EER* Improvement from EFC

The SEER cycling test is performed with a dry evaporator coil. In California the air conditioner condenses moisture from the air onto the cold evaporator coil. The EFC intelligently optimizes the fan operation after the compressor turns off to improve the EER and SEER. Many new air conditioning systems are installed without the standard manufacturer TDR due to market barriers (i.e., information, availability, or organizational practices) or the evaporator and condenser are replaced without replacing the furnace forced air unit (FAU).

Most furnaces operate at low fan speed with a time or temperature delay relay that stops the fan with heat left in the heat exchanger at temperatures between 100°F and 200°F. Most air conditioners do not have a fan time delay. Therefore, the EFC is applicable to all existing and new HVAC systems.

EFC units were installed at homes in California and Nevada to evaluate consumer satisfaction. Survey respondents indicated that the EFC provides more comfortable heating with an overall rating of 7.5 ± 0.18 out of 10 points. One hundred percent of survey respondents indicated that the EFC saves energy. Survey respondents indicate high satisfaction with an overall rating of 10 out of 10 points.

1.4.2 Baseline

The baseline furnace and air conditioner characteristics are provided in **Table 3**. For heating the baseline is either temperature controlled, degraded temperature controlled, or time controlled delay on the furnace fan. The estimated market share for heating system controls is as follows: 35% for properly working temperature delay, 35% for degraded temperature delay, and 30% for time delay.³ For cooling the baseline is either no time delay or time delay of 90 seconds. The estimated market share for cooling systems with no time delay is 90% and the estimated market share for cooling systems with 90-second time delay is 10%. Furnaces having temperature delay controllers typically turn on the furnace fan at supply plenum temperatures ranging from 135 to 160°F and turn off the furnace fan at supply plenum temperatures ranging from 100 to 110°F (Carrier 1973). Over time the bi-metal temperature sensor accuracy and performance degrades and the sensors will drift up by approximately 30 to 60°F. This causes the standard temperature delay controller to not turn on the furnace fan until the plenum temperature is 140 to 160°F which can take more than 4 minutes. When the furnace turns off the degraded sensor will cause the controller to turn off the furnace fan with supply plenum temperatures still at or above 120 to 210°F. This will typically occur within 40 to 90 seconds instead of 180 to 240 seconds. Degraded bi-metal temperature sensors leave a significant amount of heat stranded in the heat exchanger (i.e., 15 to 25%). For systems with degraded bi-metal sensors the EFC can save 15 to 65% depending on furnace run time and ambient conditions. Newer heating systems are sold with adjustable time delay controllers with factory settings of 90 to 120 seconds (Carrier 2006, Lennox 1998, Lennox 1998a, Trane 2009, Rheem 2005). The 90 second time delay will turn off

³ Most HVAC manufacturers introduced heating time delay controls with 90-second factory settings in the early 1980s. New furnaces currently sold are manufactured with 90-second time delays. Furnaces systems more than 20 years old typically have temperature delays. Approximately 50% of the older systems have degraded temperature delays due to dirt build-up or excessive supply plenum temperatures which cause the delays to drift upward by approximately 30°F to 40°F.

the furnace with supply plenum temperatures still at or above 110 to 120°F. Some newer air conditioners can have an optional time delay relay kit installed with factory settings of 90 seconds (Carrier 2006a, Carrier 2010). Most existing and new air conditioners do not have a cooling fan time delay. Therefore, the EFC is applicable to all existing and new HVAC systems. For heating, the EFC will correct for improperly operating temperature delays with degraded bi-metal temperature sensors with less material and labor cost than would be required to replace degraded temperature sensors and controllers. Increasing the heating fan speed from low and high will increase power use by approximately 18 to 21% (60 to 150W) for permanent split capacitance (PSC) motors depending on the size of the fan motor and total system static pressure. PSC blower motors that are worn out will use more power in high speed due to increased bearing friction. Worn out PSC blower motors should be replaced.

Table 3. Pre-Existing Baseline and Measure Characteristics

Pre-Existing Description	Measure Description	Estimated Market Share
Heating properly working Temperature Delay at 100 to 110°F, PSC motor	EFC High Speed Fan plus Variable Time Delay (2 to 4 minutes)	35%
Heating degraded Temperature Delay at 130 to 200°F, PSC motor	EFC High Speed Fan plus Variable Time Delay (2 to 4 minutes)	35%
Heating 90 second Time Delay, PSC motor	Variable Time Delay (2 to 4 minutes)	30%
Cooling No Time Delay, PSC Motor	Variable Time Delay (1.5 to 5 minutes)	90%
Cooling 90 second Time Delay, PSC Motor	Variable Time Delay (1.5 to 5 minutes)	5%
Cooling No Time Delay, Efficient Motor	Variable Time Delay (1.5 to 5 minutes)	3%
Cooling 90 second Time Delay, Efficient Motor	Variable Time Delay (1.5 to 5 minutes)	2%

1.4.3 Field Test Data

Field measurements and equipment accuracy are provided in **Table 4**.

Table 4. Field Measurements, Measurement Equipment, and Accuracy

Field Measurement	Measurement Equipment	Measurement Accuracy
Relative humidity (%) and temperature in degrees Fahrenheit (°F) of return and supply, thermostat, and outdoor condenser entering air	Platinum Resistance Pt100 1/3 Class B 6-channel humidity and temperature data loggers.	Temperature: 0.1°C or 0.18°F RH: ± 0.5 RH at 23°C and 10, 20, 30, 40, 50, 60, 70, 80, 90 % RH
Airflow in cubic feet per minute (cfm) across air conditioner evaporator coil	Digital pressure gauge and fan-powered flow hood, flow meter pitot tube array, and electronic balometer	Fan-powered flowhood: ± 3% Flow meter pitot tube array: ± 7% Electronic balometer: ± 4%
Total power in kilowatts (kW) of air conditioner compressor and fans	True RMS 4-channel power data loggers and 4-channel power analyzer	Data loggers, CTs, PTs: ± 1% Power analyzer: ± 1%
Total gas energy use (Btu) of furnace	Natural gas utility diaphragm flow meter	± 1% of reading
Combustion efficiency, CO	Digital combustion analyzer	Combustion efficiency: ±0.1% CO: ± 5%, O2: ±0.3%

Return and supply temperatures were measured inside the return and supply ducts either in the plenums or near the plenums. Temperature and power were measured at intervals of 10 to 60 seconds. Airflow was measured before and after making any changes to the supply/return ducts, opening vents, or installing new air filters that would affect airflow. Return and supply enthalpies were derived from the temperature measurements using standard psychrometric algorithms (REFPROP 2010). The “application” EER* is calculated from the combination of enthalpy, airflow, and power measurements. Measurements of air conditioner performance were made continuously.

The heating or cooling capacity of the HVAC system is measured as the rate of delivered heating or cooling energy per measurement interval (i.e., English units of British thermal units per hour).⁴ Heating of air occurs in the heat exchanger of the furnace or heat pump. Cooling occurs in the evaporator coil of the air conditioner. The heating capacity or energy is based on the measured airflow rate, specific volume, and sensible temperature difference across the return and supply plenums. **Equation 1** provides the calculation of sensible heating energy delivered to the conditioned space by the HVAC system.

$$\text{Eq. 1} \quad Q_{hs} = \frac{cfm \times 60}{v} \times c_v \times (T_r - T_s)$$

Where,

Q_{hs} = sensible heating energy delivered to the conditioned space over the measurement interval (i.e., Btu/hr),

cfm = airflow rate in cubic feet per minute (cfm),

v = specific volume per pound of dry air (ft³/lbm),

c_v = specific heat of dry air = 0.24 Btu/lbm-°F,

T_r = dry bulb temperature of return air in plenum entering the heat exchanger (°F), and

T_s = dry bulb temperature of supply air in plenum leaving the heat exchanger (°F).

The cooling capacity is based on the measured airflow rate, specific volume, and enthalpy difference across the return and supply plenums. **Equation 2** provides the calculation of total cooling energy removed from the air by the HVAC system.

$$\text{Eq. 2} \quad Q_c = \frac{cfm \times 60}{v} \times (h_r - h_s)$$

Where,

Q_c = cooling energy removed from the air by the HVAC system over the measurement interval (Btu/hr),

h_r = enthalpy of return air entering the evaporator coil (i.e., Btu/lbm), and

h_s = enthalpy of supply air leaving the evaporator coil (i.e., Btu/lbm).

⁴ The British Thermal Unit (Btu) is the unit of heat required to raise the temperature of one pound of water one degree Fahrenheit (°F). The Btu is equivalent to 1055.06 joules or 251.997 calories.

Laboratory and field test data show that standard fan delays are insufficient to harvest available cooling stored in the evaporator and that medium fan speed and standard fan delays are insufficient to harvest available heating stored in the heat exchanger. The combustion efficiency, EFC efficiency, and standard temperature delay efficiency are illustrated in **Figure 3** and **Table 5** for an 80 AFUE gas furnace. **Equation 3** shows how the heating efficiency is calculated.

$$\text{Eq. 3 } h = \sum_{i=0}^t \frac{Q_{hs_i}}{Q_{hf_i}}$$

Where,

h = heating efficiency (ratio or %),

i = measurement interval for which data is collected ranging from 10 to 60 seconds,

t = total number of measurement intervals for the test,

Q_{hs_i} = sensible heating energy delivered to the conditioned space per measurement interval (Btu/hr), and

Q_{hf_i} = heating energy fuel input per measurement interval (Btu/hr).

The heating energy savings (S_{heat}) based on the heating efficiency improvement are calculated using **Equation 4**.

$$\text{Eq. 4 } S_{\text{heat}} = h_{\text{EFC}} - h_{\text{Base}}$$

Where,

S_{heat} = heating energy savings for the EFC (ratio or %),

h_{EFC} = delivered heating efficiency of the EFC with high speed fan and/or optimal time delay from 2 to 4 minutes (ratio or %), and

h_{Base} = delivered heating efficiency of the base case thermostat with temperature delay, 90-second time delay, or degraded temperature delay (ratio or %).

The rated furnace efficiency, EFC plus high speed fan (HSF) efficiency, and standard temperature delay efficiency for an 80% AFUE gas furnace is shown in **Figure 3** and **Table 5**. The furnace is turned on when the thermostat temperature is below 65°F and turned off when the thermostat temperature is above 68°F. The low speed fan requires 14.8 minutes of furnace operation to increase the thermostat temperature to above 68°F, and the baseline working temperature delay provides 4.2 minutes of additional fan operation and supply plenum fan off temperature of 99.4°F. The EFC provides high speed fan operation 4 minutes after the furnace is turned on and this increases furnace efficiency by 5.9% and reduces furnace operation by 1.1 minutes or 7.9%. The EFC provides a 4 minute time delay with high speed fan recovering slightly more energy than the standard temperature delay with fan off supply plenum temperature of 98.3°F and increased off cycle of 1%. The EFC saves 7.9% of gas heating energy and -4.6% of heating fan ventilation energy. High speed fan power is 722W or 17.8% greater than low speed fan power which is 613W.

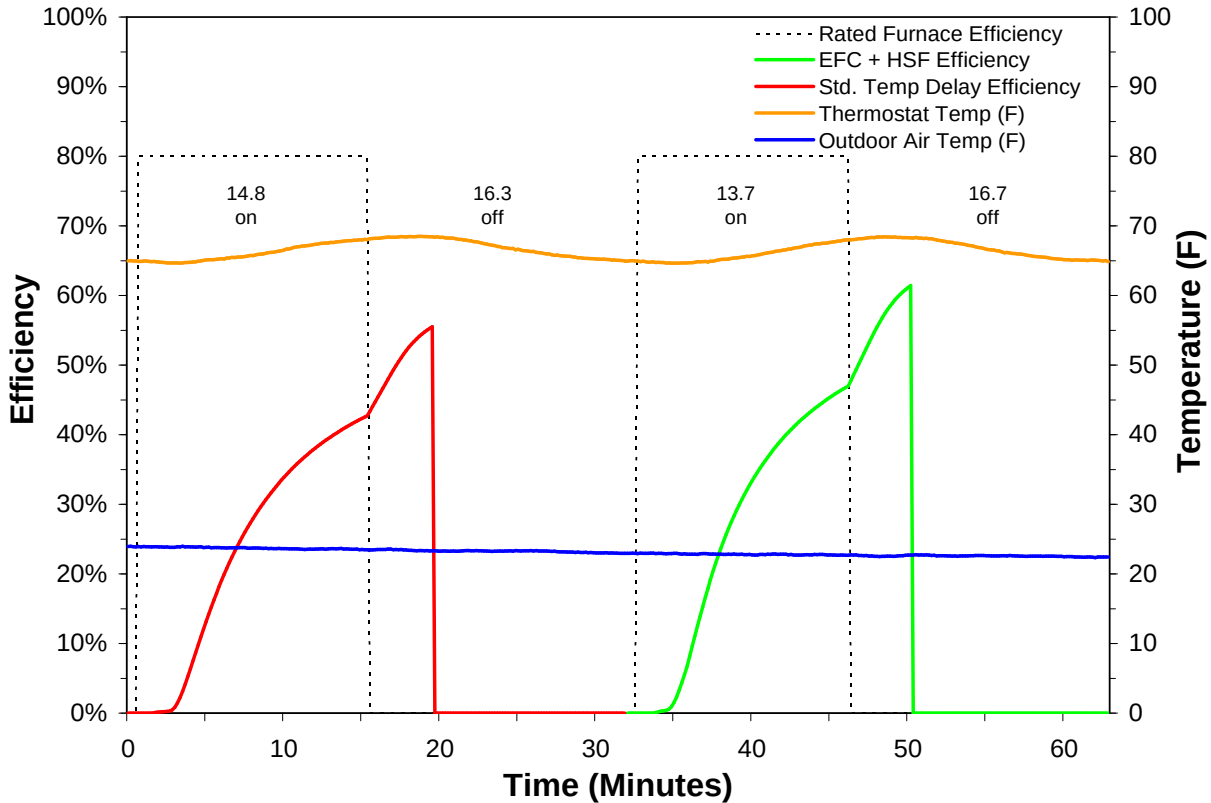


Figure 3. Heating Efficiency with EFC + HSF versus Standard Temperature Delay

Table 5. Measured Heating Efficiency from EFC + HSF vs. Standard Temp. Delay

Description	Test 1 Baseline	Test 2 EFC
Furnace On Time (minutes)	14.8	13.7
Furnace Off Cycle Time (minutes)	16.3	16.7
Fan Delay After Furnace Off (minutes)	4.2	4
EFC Additional Fan Energy (kWh/cycle)		0.009
EFC Additional Fan Energy		-4.6%
Furnace Energy Used (Btu)	-32,689	-30,118
Heat Energy Delivered to Space (Btu)	-18,147	-18,493
Delivered Efficiency	55.5%	61.4%
Savings Based on Heating Capacity (%)		5.9%
Savings from Run Time and Off Cycle (%)		9.9%
Average Savings		7.9%
Furnace Off Thermostat Temperature (F)	68.1	68.0
Fan Off Plenum Temperature (F)	99.4	98.3
Fan Off Supply Temperature (F)	95.7	94.0
Furnace On Thermostat Temperature before Cycle (F)	64.9	64.9

The rated furnace efficiency, EFC efficiency, and 90-second time delay efficiency for an 80% AFUE gas furnace is shown in **Figure 4** and **Table 6**. The furnace is turned on when the thermostat temperature is below 69°F and turned off when the thermostat temperature is above 72°F. The baseline time delay provides 1.5 minutes of additional fan operation and supply plenum fan off temperature of 143.9°F. The EFC provides a 4 minute time delay with fan off

supply plenum temperature of 97.9°F and increased off cycle by 1.2 minutes or 6.5%. The EFC saves 5.9% of gas heating energy and -14.5% of heating fan ventilation energy.

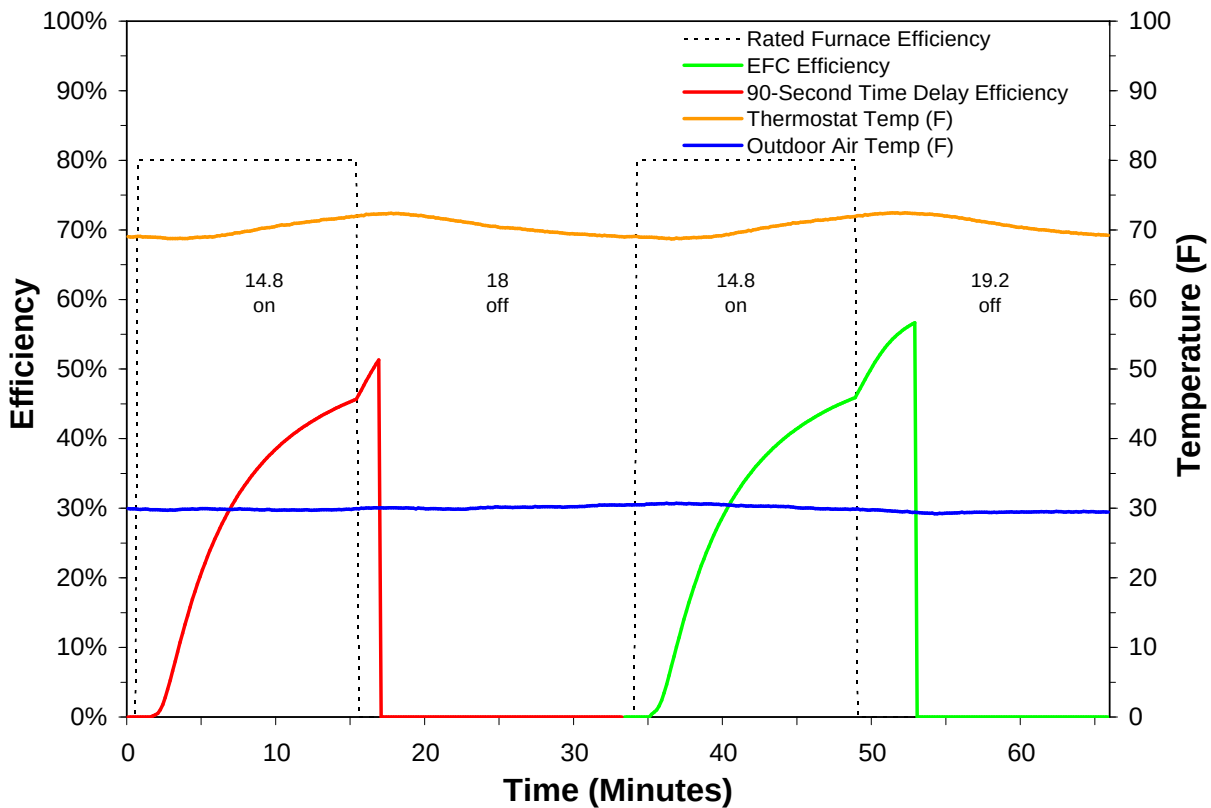


Figure 4. Heating Efficiency with EFC versus 90-Second Time Delay (Low Speed Fan)

Table 6. Measured Heating Efficiency with EFC vs. 90-Sec. Time Delay (Low Speed Fan)

Description	Test 3 Baseline	Test 4 EFC
Furnace On Time (minutes)	14.8	14.8
Furnace Off Cycle Time (minutes)	18.0	19.2
Fan Delay After Furnace Off (minutes)	1.5	4
EFC Additional Fan Energy (kWh/cycle)		0.025
EFC Additional Fan Energy		-14.5%
Furnace Energy Used (Btu)	-32,689	-32,689
Heat Energy Delivered to Space (Btu)	-16,769	-18,523
Delivered Efficiency	51.3%	56.7%
Savings Based on Heating Capacity (%)		5.4%
Savings from Run Time and Off Cycle (%)		6.5%
Average Savings		5.9%
Furnace Off Thermostat Temperature (F)	72.0	72.1
Fan Off Plenum Temperature (F)	143.9	97.9
Fan Off Supply Temperature (F)	116.9	97.3
Furnace On Thermostat Temperature before Cycle (F)	69.0	69.0

The rated furnace efficiency, EFC + HSF efficiency, and degraded temperature delay efficiency for an 81% AFUE gas furnace is shown in **Figure 5** and **Table 7**. For test 5 (baseline) and test 6 (EFC) the furnace is turned on when the thermostat temperature is below 68°F and turned off when the thermostat temperature is above 71°F. The low speed fan requires 8.0 minutes of

furnace operation to increase the thermostat temperature to above 71°F. The baseline degraded temperature delay provides 0.7 minutes of additional fan operation and the supply plenum fan-off temperature is 198.8°F. The EFC provides high speed fan operation 4 minutes after the furnace is turned on. This increases furnace efficiency by 7.1% and reduces furnace operation by 0.7 minutes or 8.8%. The EFC provides a 4-minute time delay with high-speed fan and the fan-off supply plenum temperature is 114.8°F. The EFC increases off cycle from 9.8 to 15.7 minutes or 60.2%. Test 6 EFC saves 24.5% of gas energy and -13.8% of heating fan ventilation energy. The high-speed fan power is 450W or 22.1% greater than low-speed fan power which is 368W.

For the test 7 (baseline) and test 8 (EFC) the furnace is turned on when the thermostat temperature is below 67°F and turned off when the thermostat temperature is above 73°F. The low speed fan requires 14.8 minutes of furnace operation to increase the thermostat temperature to above 73°F. The baseline degraded temperature delay provides 1 minute of additional fan operation and the supply plenum fan-off temperature is 206.4°F. The EFC provides high speed fan operation 4 minutes after the furnace is turned on. This increases furnace efficiency by 7.7% and reduces furnace operation by 1 minute or 6.8%. The EFC provides a 4-minute time delay with high-speed fan and the fan-off supply plenum temperature is 118.8°F. The EFC increases off cycle from 50.2 to 67.5 minutes or 34.6%. EFC test 8 saves 16.9% of gas energy and -30.5% of heating fan ventilation energy. The average savings from EFC (tests 6 and 8) versus degraded temperature delay (tests 5 and 7) are 20.7% of gas heating energy and -22.2% of heating fan ventilation energy. The high-speed fan power is 450W or 23.2% greater than low-speed fan power which is 365W.

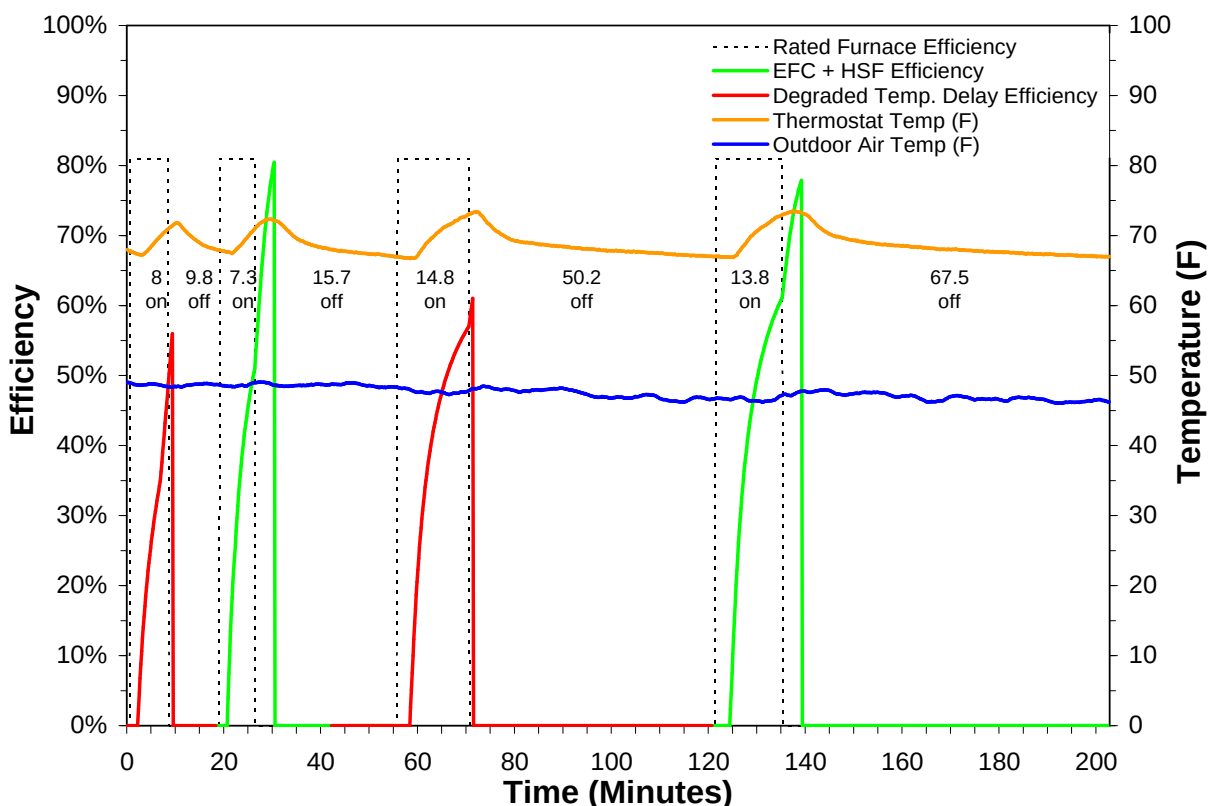


Figure 5. Heating Efficiency with EFC + HSF versus Degraded Temperature Delay

Table 7. Measured Heating Efficiency with EFC + HSF vs. Degraded Temp. Delay

Description	Test 5 Baseline	Test 6 EFC	Test 7 Baseline	Test 8 EFC	Average
Furnace On Time (minutes)	8.0	7.3	14.8	13.8	7.5%
Furnace Off Cycle Time (minutes)	9.8	15.7	50.2	67.5	46.9%
Fan Delay After Furnace Off (minutes)	0.8	4.0	1.0	4.0	
EFC Additional Fan Energy (kWh/cycle)		0.007		0.029	
EFC Additional Fan Energy		-13.8%		-30.5%	-22.2%
Furnace Energy Used (Btu)	-15,617	-14,315	-28,956	-27,004	
Heat Energy Delivered to Space (Btu)	-8,740	-11,519	-17,674	-21,033	
Delivered Efficiency	56.0%	80.5%	61.0%	77.9%	
Savings Based on Heating Capacity (%)		24.5%		16.9%	20.7%
Savings from Run Time and Off Cycle (%)		67.7%		41.3%	54.5%
Average Savings		24.5%		16.9%	20.7%
Furnace Off Thermostat Temperature (F)	71.1	71.2	73.1	73.0	
Fan Off Plenum Temperature (F)	198.8	114.8	206.4	118.8	
Fan Off Supply Temperature (F)	136.3	100.7	140.9	103.4	
Furnace On T-stat Temp. before Cycle (F)	68.0	68.0	67.0	67.0	

The ratio of additional electric power to operate the EFC fan compared to the standard fan is calculated using **Equation 5**.

$$\text{Eq. 5 EFC Fan Energy} = S_{vent} = \frac{\sum_{i=0}^m (t_i \times P_{std \text{ fan } i}) - \sum_{j=0}^n (t_j \times P_{EFC \text{ fan } j})}{\sum_{i=0}^m (t_i \times P_{std \text{ fan } i})}$$

Where,

S_{vent} = electric residential air conditioner (RAC) or residential gas furnace (RGF)

ventilation savings associated with the EFC based on field or laboratory tests (%),

t = time of measurement interval,

m = total time for EFC furnace fan operation,

n = total time for standard heating fan operation,

$P_{EFC \text{ fan}}$ = power of heating fan with EFC (W),

$P_{std \text{ fan}}$ = power of heating fan with standard control (W).

The test data presented in this report indicate 17.8 to 22.6% more fan energy is required for the permanent split-capacitance (PSC) motor (722W versus 613W and 450W versus 367W). A review of manufacturer product literature indicates that 20.5% more power is generally required to operate a PSC motor at high speed compared to medium speed (Lennox 1998a). In heating mode, the EFC requires 4.6% more electricity than furnace fans with standard temperature delay fan, 22.3% more electricity than furnace fans with degraded temperature delay, and 14.5% more electricity than furnace fans with 90-second time delay fan. In cooling mode, the EFC requires 37.5% more electricity than the fans with no delay and 19.3% more electricity than fans with 90-second time delay fan. The additional electricity required to operate the EFC fan is 13.8% in heating mode and 36.2% in cooling mode based on the weighted average of temperature and time delay market share (see **Table 12**).

Field measurements of the cooling sensible energy efficiency ratio (EER*) and total power (kW) for an air conditioner with a standard no time delay on the fan are shown in **Figure 6** and **Table 8**. The average cooling efficiency improvement from the EFC compared to the standard no TDR unit is 14.5% +/- 2% based on these measurements. The field tests were conducted with average air conditioner run times of 16.5 minutes and average EFC fan time delay times of 5 minutes. The EFC additional fan energy is 30.6% in cooling mode.

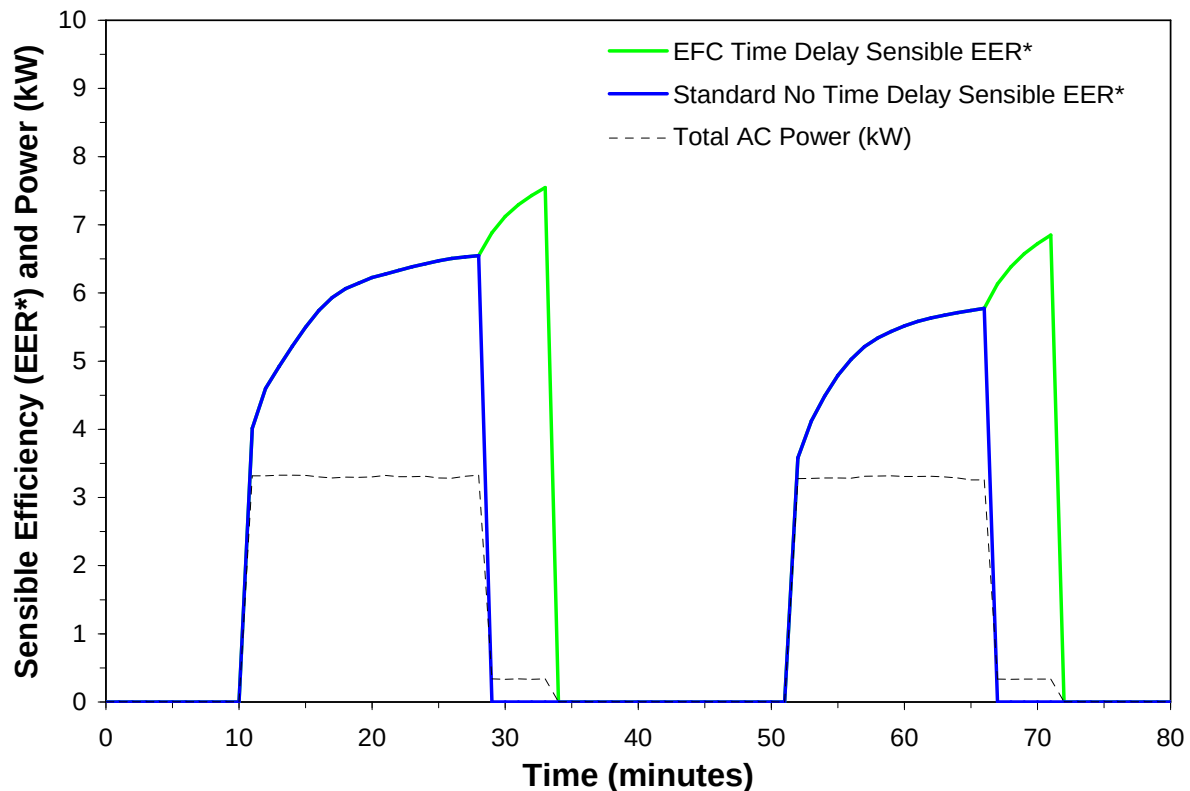


Figure 6. Field Tests Cooling Sensible EER and Power EFC versus no Time Delay

Table 8. Field Tests of Air Conditioner EFC versus No Time Delay

Description	Test 9	Test 10	Average
Compressor On Time (minutes)	18	15	16.5
EFC Delay After Compressor Off (minutes)	5	5	5
EFC Additional Fan Energy (kWh/cycle)	0.03	0.03	0.03
Std. Delay After Compressor Off (minutes)	0	0	0.00
EFC Additional Fan Cooling Energy	-27.8%	-33.3%	-30.6%
Std. AC Energy (kWh)	0.99	0.82	0.91
Standard Cooling Delivered (Btu)	6,497	4,752	5,625
Std. 90-Sec. Delay Cool Efficiency	6.55	5.77	6.16
EFC AC Energy (kWh)	1.02	0.85	0.94
EFC Cooling Delivered (Btu)	7,703	5,828	6,766
EFC Cooling Efficiency	7.55	6.85	7.20
Cooling Efficiency Improvement	13.3%	15.7%	14.5%

Field measurements of the cooling sensible energy efficiency ratio (EER*) and total power (kW) for an air conditioner with a 90-second time delay on the fan are shown in **Figure 7** and **Table 9**.

The average cooling efficiency improvement from the EFC compared to the 90-second TDR is 9.5% +/- 1.3% based on the field measurements. The field tests were conducted with average air conditioner run times of 16.5 minutes and average EFC fan time delay times of 5 minutes. The EFC additional fan energy is 19.6% in cooling mode.

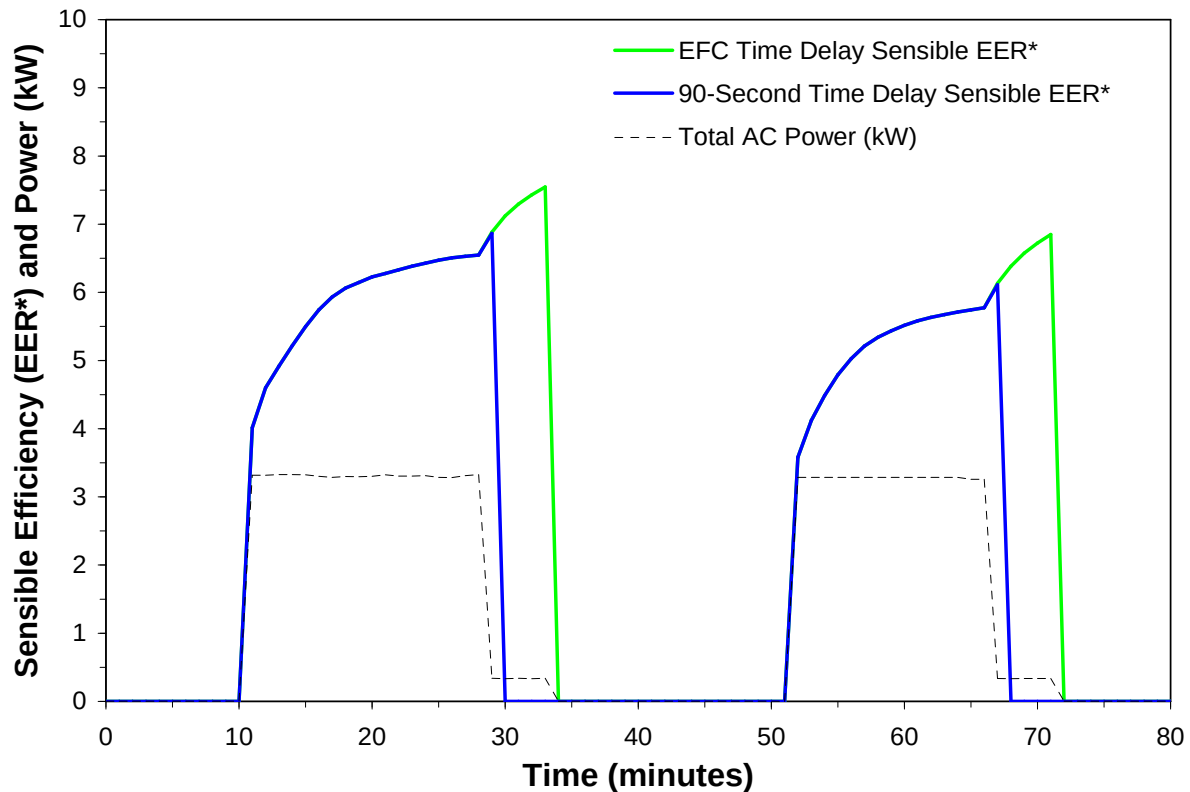


Figure 7. Field Tests Cooling Sensible EER and Power EFC versus 90-second TDR

Table 9. Field Tests of Air Conditioner EFC versus 90-Second TDR

Description	Test 11	Test 12	Average
Compressor On Time (minutes)	18	15	16.5
EFC Delay After Compressor Off (minutes)	5	5	5
EFC Additional Fan Energy (kWh/cycle)	0.02	0.02	0.02
Std. Delay After Compressor Off (minutes)	1.5	1.5	1.50
EFC Additional Fan Cooling Energy	-17.9%	-21.2%	-19.6%
Std. AC Energy (kWh)	1.00	0.83	0.91
Standard Cooling Delivered (Btu)	6,881	5,091	5,986
Std. 90-Sec. Delay Cool Efficiency	6.89	6.14	6.51
EFC AC Energy (kWh)	1.02	0.85	0.94
EFC Cooling Delivered (Btu)	7,703	5,828	6,766
EFC Cooling Efficiency	7.55	6.85	7.20
Cooling Efficiency Improvement	8.7%	10.4%	9.5%

1.4.4 Laboratory Test Data

The amount of moisture converted to sensible cooling is dependent on the airflow and the length of time the fan runs at the end of the compressor cycle. **Figure 8** and **Table 10** show laboratory

test data from Southern California Edison from the embedded Excel Workbook #2 in tab "SCE Data Fig7-8", Column O is the Cycle Sensible EER (see References Section). The sensible EER improvement decreases with increasing compressor run time from 22.2% for 5-minute run time to 6.2% for 30 minute compressor run time. The EFC adjusts the length of the time delay from 1.5 to 5 minutes based on the fan run time which is a proxy for the compressor run time. The average cooling efficiency improvement from the EFC compared to the standard unit is 15.3% +/- 5.7% based on these measurements. These savings are comparable to the average cooling efficiency improvement of 14.5% +/- 2% for the EFC compared to no time delay based on field measurements (see **Table 8**). **Figure 9** and **Table 11** show the same data set but with the baseline having a 90 second time delay. The average cooling efficiency improvement from the EFC compared to the 90-second delay is 8.1% +/- 2.4%. These savings are comparable to the average cooling efficiency improvement of 9.5% +/- 1.3% for the EFC compared to the 90-second delay based on field measurements (see **Table 9**).

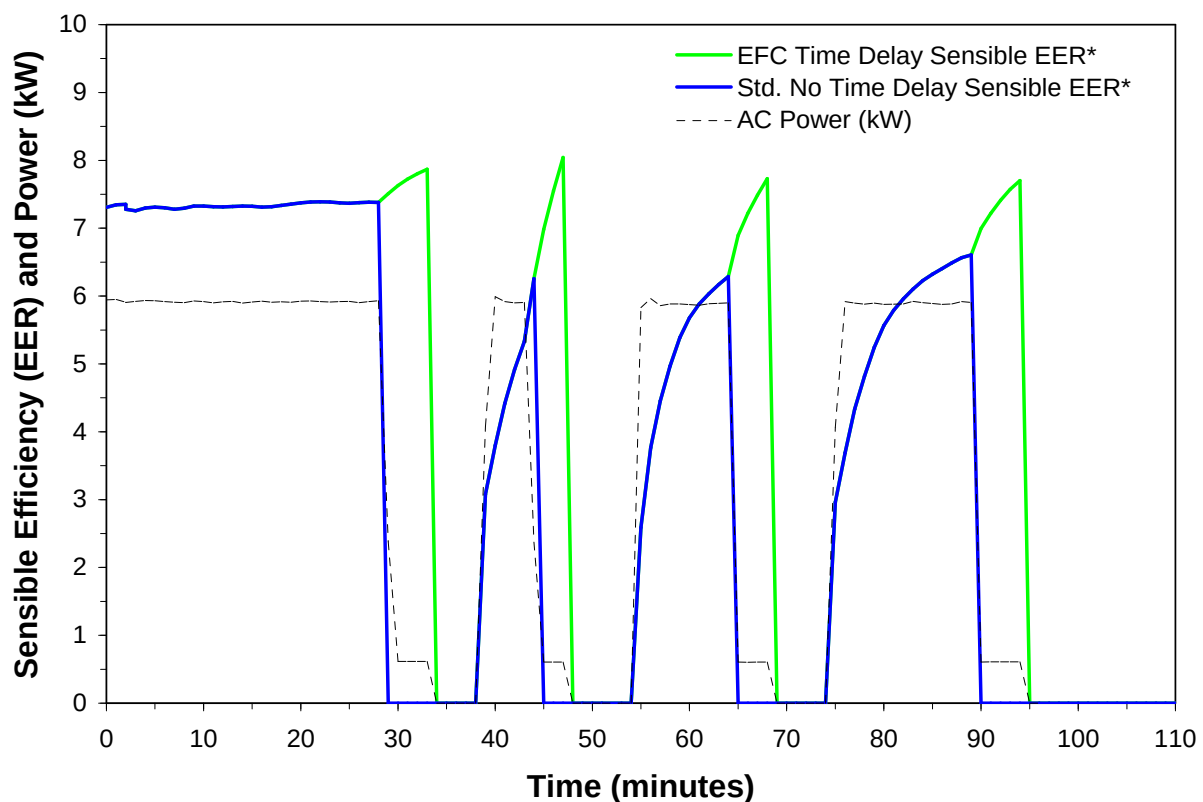


Figure 8. Laboratory Tests of Air Conditioner EFC versus No Time Delay

Table 10. Laboratory Tests of Air Conditioner with no Time Delay

Description	Test 13	Test 14	Test 15	Test 16	Average
Compressor On Time (minutes)	30	5	10	15	17.5
EFC Delay After Compressor Off (minutes)	5	3	4	5	4.25
EFC Additional Fan Energy (kWh/cycle)	0.05	0.03	0.04	0.05	0.04
Std. Delay After Compressor Off (minutes)	0	0	0	0	0.00
EFC Additional Fan Cooling Energy	-16.7%	-60.0%	-40.0%	-33.3%	-37.5%
No Time Delay AC Energy (kWh)	2.96	0.50	0.98	1.44	1.73
No Time Delay Cooling Delivered (Btu)	21,838	3,146	6,167	9,538	12,492
No Time Delay Application Sensible EER*	7.38	6.26	6.29	6.61	6.82
EFC AC Energy (kWh)	3.04	0.53	1.02	1.49	1.79
EFC Cooling Delivered (Btu)	23,917	4,288	7,893	11,507	11,901
EFC Application Sensible EER*	7.87	8.04	7.73	7.70	7.84
EFC Cooling Savings	6.2%	22.2%	18.7%	14.2%	15.3%

Source: Based on Southern California Edison data.

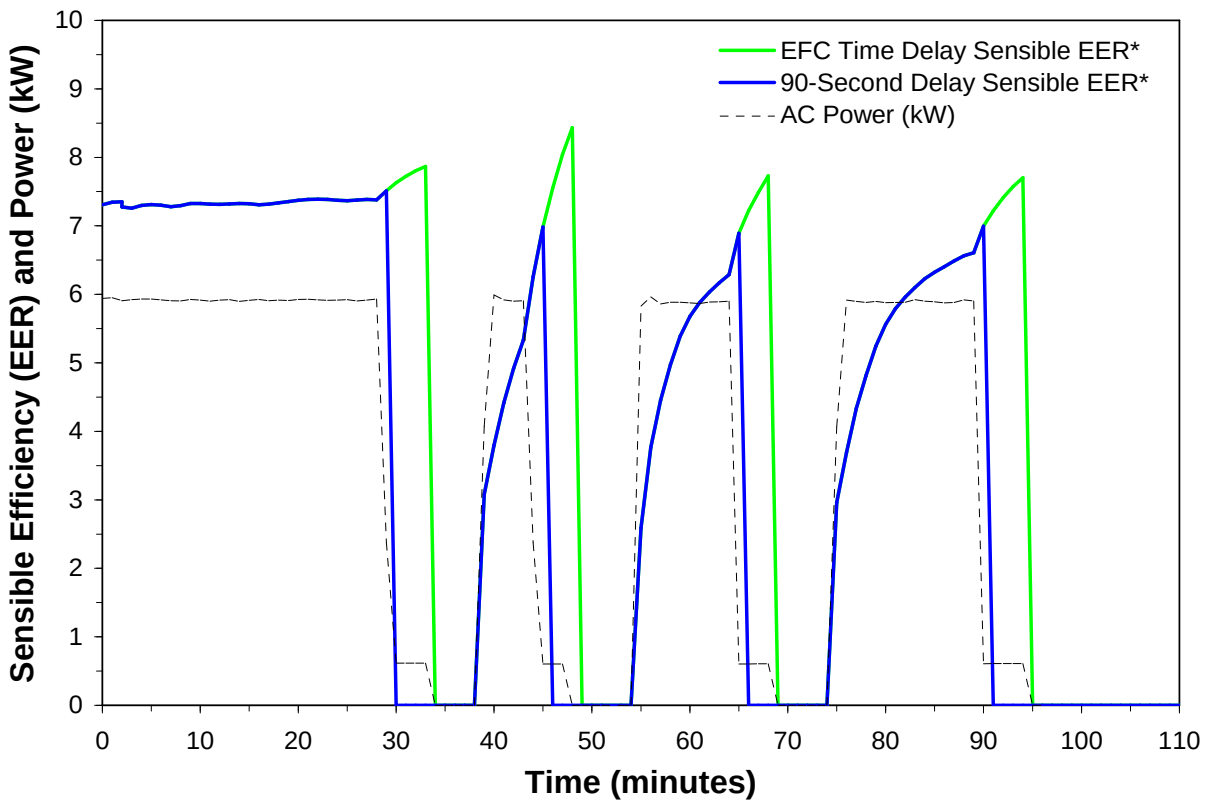


Figure 9. Laboratory Tests of Air Conditioner with EFC versus 90-Second Time Delay

Table 11. Laboratory Tests of Air Conditioner with EFC and 90-Second Time Delay

Description	Test 17	Test 18	Test 19	Test 20	Average
Compressor On Time (minutes)	30	5	10	15	17.5
EFC Delay After Compressor Off (minutes)	5	3	4	5	4.25
EFC Additional Fan Energy (kWh/cycle)	0.05	0.03	0.04	0.05	0.04
Std. Delay After Compressor Off (minutes)	1.5	1.5	1.5	1.5	1.50
EFC Additional Fan Cooling Energy	-11.1%	-23.1%	-21.7%	-21.2%	-19.3%
No Time Delay AC Energy (kWh)	3.00	0.52	1.00	1.46	1.76
No Time Delay Cooling Delivered (Btu)	22,738	3,765	7,029	10,365	13,251
No Time Delay Application Sensible EER*	7.57	7.27	7.06	7.11	7.42
EFC AC Energy (kWh)	3.04	0.53	1.02	1.49	1.79
EFC Cooling Delivered (Btu)	23,917	4,288	7,893	11,507	11,901
EFC Application Sensible EER*	7.87	8.04	7.73	7.70	7.84
EFC Cooling Savings	3.9%	10.7%	9.5%	8.4%	8.1%

Source: Based on Southern California Edison.

Equation 6 shows how the application sensible EER* is calculated.

$$\text{Eq. 6} \quad \text{Sensible } EER_s^* = \sum_{i=0}^n \frac{Q_{cs_i}}{P_i}$$

Where,

EER_s^* = application sensible energy efficiency ratio (Btu/hr-W),

Q_{cs_i} = sensible cooling energy removed from the air by the air conditioner over the measurement interval (Btu/hr),

P_i = total power to operate the air conditioner compressor, fan, and controls over the measurement interval (W).

The cooling energy savings (S_{cool}) based on cooling Sensible EER improvements are calculated using **Equation 7**.

$$\text{Eq. 7} \quad S_{cool} = \frac{EER_s^*|_{EFC}}{EER_s^*|_{Base}} - 1$$

Where,

S_{cool} = cooling energy savings for the EFC (%),

$EER_s^*|_{EFC}$ = EFC sensible cooling efficiency with optimal time delay from 1.5 to 5 minutes, and

$EER_s^*|_{Base}$ = base sensible cooling efficiency with no delay or 90-second time delay.

1.4.5 Estimated Energy Savings

The estimated space cooling and heating energy savings for each market share for the EFC are shown in **Table 12**. The savings are based on field tests and laboratory tests of furnaces and air conditioners with and without the EFC. The estimated weighted average heating energy savings are 11.8% based on field tests (see tests 1 through 8 in **Tables 5, 6, and 7**). In heating mode, the EFC requires 4.6% more ventilation electricity than heating systems with standard temperature delay fan and 14.5% more electricity than ventilation systems with 90-second time delay. In

cooling mode, the EFC requires 37.5% more ventilation electricity than the standard cooling system with no time delay and 19.3% more ventilation electricity than the system with 90-second time delay. The EFC heating ventilation energy savings are -13.8% (i.e., negative) based on the weighted average of temperature and time delay. The EFC cooling ventilation energy savings are -36.2% (i.e., negative) based on the weighted average of temperature and time delay. The EFC cooling savings are 14.8% based on the weighted average savings from field and laboratory tests and estimated market share.

The test data presented in this report indicate 20.6% more fan power is required at high speed compared to low speed for the permanent split-capacitance (PSC) motor for a 3-ton unit (450W high speed versus 372W low speed) and 17.8% for a 4-ton unit (722W high speed versus 613W low speed). A review of manufacturer product literature indicates 20.5% more power is required to operate at high speed during the time delay (Lennox 1998a). The weighted average ventilation electricity savings are -13.8% instead of -20.6% due to running the fan in high speed during furnace operation which reduces both furnace and fan energy consumption.

The weighted average space heating savings are calculated using **Equation 8**.

$$\text{Eq. 8} \quad \overline{S_{heat}} = \sum_{k=0}^p S_{heat_k} \times M_k$$

Where,

$\overline{S_{heat}}$ = weighted average space heating energy savings for the EFC based field tests and market share (%),

S_{heat_k} = heating energy savings for the EFC for market segment “k” (%), and

M_k = market segment “k” for the following base thermostat control market segments: working temperature delay, degraded temperature delay, or 90-second time delay (%).

The weighted average space cooling savings are calculated using **Equation 9**.

$$\text{Eq. 9} \quad \overline{S_{cool}} = \sum_{k=1}^p S_{cool_k} \times M_k$$

Where,

$\overline{S_{cool}}$ = weighted average space cooling energy savings for the EFC based on field and laboratory tests and market share (%),

S_{cool_k} = cooling energy savings for the EFC for market segment “k” (%), and

M_k = market segment “k” for the following base thermostat control market segments: no time delay PSC motor, 90-second time delay PSC motor, no time delay EC motor, 90-second time delay EC motor (%).

The weighted average RGF ventilation savings are calculated using **Equation 10**.

$$\text{Eq. 10 } \overline{S_{RGF vent}} = \sum_{k=1}^p S_{RGF vent_k} \times M_k$$

Where,

$\overline{S_{RGF vent}}$ = weighted average RGF ventilation energy savings associated with the EFC based on field and laboratory tests and market share (%),
 $S_{RGF vent_k}$ = RGF ventilation savings for the EFC for market segment “k” (%), and
 M_k = market segment “k” for the following base thermostat control market segments: working temperature delay, degraded temperature delay, or 90-second time delay (%).

The weighted average RAC ventilation savings are calculated using **Equation 11**.

$$\text{Eq. 11 } \overline{S_{RAC vent}} = \sum_{k=1}^p S_{RAC vent_k} \times M_k$$

Where,

$\overline{S_{RAC vent}}$ = weighted average RAC ventilation energy savings associated with the EFC based on field and laboratory tests and market share (%),
 $S_{RAC vent_k}$ = RAC ventilation savings for the EFC for market segment “k” (%), and
 M_k = market segment “k” for the following base thermostat control market segments: no time delay PSC motor, 90-second time delay PSC motor, no time delay EC motor, 90-second time delay EC motor (%).

Table 12. Estimated Space Heating and Cooling Energy Savings for EFC

Pre-existing Description	Measure Description	EFC Heating Savings	EFC Fan Heating Savings	EFC Fan Cooling Savings	EFC Cooling Savings	Estimated Market Share
Heating Temperature Delay at 100 to 110°F, PSC motor	EFC High-Speed Fan plus Variable Time Delay (2 to 4 minutes)	7.9%	-4.6%			35%
Heating Temperature Degraded Delay at 130 to 200°F, PSC motor	EFC High-Speed Fan plus Variable Time Delay (2 to 4 minutes)	20.7%	-22.3%			35%
Heating 90 second Time Delay, PSC motor low speed	EFC Variable Time Delay (2 to 4 minutes)	5.9%	-14.5%			30%
Cooling No Time Delay, PSC Motor	EFC Variable Time Delay (1.5 to 5 minutes)			-37.5%	15.3%	90%
Cooling Standard 90 second Time Delay PSC motor	EFC Variable Time Delay (1.5 to 5 minutes)			-19.3%	8.1%	5%
Cooling No Time Delay, Efficient Fan Motor	EFC Variable Time Delay (1.5 to 5 minutes)			-37.5%	15.3%	3%
Cooling Standard 90 second Time Delay, Efficient Fan Motor	EFC Variable Time Delay (1.5 to 5 minutes)			-19.3%	8.1%	2%
Weighted Average		11.8%	-13.8%	-36.2%	14.8%	

1.4.5 Consumer Satisfaction Study

EFC units were installed at homes in California and Nevada to evaluate consumer satisfaction. Consumers provided the following feedback after using the EFC for two months during the winter heating season from January through March 2012. Additional consumer survey responses will be obtained after the summer cooling season. Consumer satisfaction survey data are provided in **Table 13**. The average number of occupants is 3.2 +/- 0.1 and the average conditioned floor area is 2800 ft². Survey respondents indicated that the EFC provides more comfortable heating with an overall rating of 7.5 ± 0.18 out of 10 points. One hundred percent of survey respondents indicated that the EFC saves energy. Survey respondents indicate high satisfaction with an overall rating of 10 out of 10 points.

Table 13. Consumer Satisfaction Survey Data

Description	Average	Respondents
1. Number of Occupants	3.2 +/- 0.1	20
2. Conditioned Floor Area (ft ²)	2,800 +/- 49	20
3. Air Conditioner Average Fan Off Delay (sec)	TBD	TBD
4. Pre-Existing Average Furnace Fan Off Delay (sec)	109.6 +/- 3.3	20
5. EFC Furnace Fan Off Delay (sec)	240 +/- 2	20
6. Does the EFC provide more comfortable heating on a scale of 1 to 10? (10=more, 5=same, 1=less).	7.5 +/- 0.18	20
7. Does the EFC provide more comfortable cooling on a scale of 1 to 10?	TBD	TBD
8. Does the EFC save energy compared to not using the EFC? (% Yes)	100%	20
9. How satisfied are you with the EFC on a scale of 1 to 10? (1=Low, 10=High).	10 +/- 0	20

1.5 Baseline Unit Energy Consumption (UEC) Values

The weighted baseline unit energy consumption (UEC) values for the Southern California service area for Single Family (SFM), Multifamily (MFM), and Double-wide Mobile (DMO) prototypical buildings and Residential Air Conditioner (RAC) with Gas Furnace (GF) HVAC system are shown in **Table 14** and Residential gas Furnace (RGF) HVAC system are shown in **Table 15**. The UEC values are from the DEER 2008.2.1 MISer (DEER 2008a). Section 2 provides engineering calculations used to develop estimates of the baseline annual cooling electric ventilation from the total baseline annual electric ventilation and the baseline annual heating electric ventilation. The baseline and energy savings should be defined in “Common energy units” rather than per household to allow for multiple EFC units to be installed at one home.

Table 14. Weighted Baseline UEC per Household –RAC with Gas Furnace (DEER 2008 MISer)

DEER2008 ImpactID	Weighted Building Vintage Climate Zone	Baseline Annual Gas Heating (therm/yr)	Baseline Annual Heating Elec Ventilation (kWh/yr)	Baseline Annual Cooling Elec Ventilation (kWh/yr)	Baseline Annual Elec Cooling (kWh/yr)	Baseline Annual Elec Cooling (kW)	Baseline Annual Elec Ventilation (kW)
SFM-w06-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	6	187.9	61.2	148.7	839.6	1.878	0.255
SFM-w07-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	7	133.1	47.3	118.1	721.8	1.864	0.258
SFM-w08-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	8	162.6	55.7	184.3	1,188.90	2.538	0.336
SFM-w10-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	10	214.3	73.7	209.3	1,377.80	2.724	0.341
SFM-w14-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	14	281.6	106.9	382.6	2,610.50	3.686	0.473
SFM-w15-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	15	111.4	0	0	3,662.00	3.963	0.466
SFM-wSDG-vEx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	SDG Weighted	181.82	57.47	173.83	1733.43	2.78	0.35
MFM-w06-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	6	64.1	23.9	39.4	235.2	0.616	0.09
MFM-w07-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	7	51	18.9	33.7	199.9	0.616	0.085
MFM-w08-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	8	59.2	21.4	71.3	464.8	0.85	0.117
MFM-w10-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	10	94.8	33.3	103.9	699.9	1.173	0.148
MFM-w14-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	14	153.6	74.6	244.4	1,744.30	1.781	0.231
MFM-w15-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	15	55.9	15.8	366.5	2,868.60	2.112	0.252
MFM-wSDG-vEx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	SDG Weighted	79.77	31.32	143.20	1035.45	1.19	0.15
DMO-w06-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	6	147.3	43.9	260.2	2,210.60	2.732	0.254
DMO-w07-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	7	123.8	41.2	206.6	1,932.10	3.164	0.277
DMO-w08-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	8	179.6	51.4	424.5	4,113.10	4.568	0.389
DMO-w10-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	10	188.9	79.2	372	4,035.10	4.999	0.404
DMO-w14-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	14	339.4	136.2	568	5,592.60	6.053	0.5
DMO-w15-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	15	158.2	137.5	573.7	7,451.60	6.332	0.5
DMO-wSDG-vEx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	SDG Weighted	189.53	81.57	400.83	4222.52	4.64	0.39

Table 15. Weighted Baseline UEC per Household –RGF Only (DEER 2008 MISer)

DEER2008 ImpactID	Weighted Building Vintage Climate Zone	Baseline Annual Gas Heating (therm/yr)	Baseline Annual Heating Elec Ventilation (kWh/yr)	Baseline Annual Cooling Elec Ventilation (kWh/yr)	Baseline Annual Elec Cooling (kWh/yr)	Baseline Annual Elec Cooling (kW)	Baseline Annual Elec Ventilation (kW)
SFM-w06-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	6	169.9	61.2				
SFM-w07-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	7	125.9	47.3				
SFM-w08-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	8	150.6	55.7				
SFM-w10-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	10	200.7	73.7				
SFM-w14-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	14	286.3	106.9				
SFM-w15-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	15	124.2	43.3				
SFM-wSDG-vEx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	SDG Weighted	176.27	64.68				
MFM-w06-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	6	66	23.9				
MFM-w07-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	7	51.4	18.9				
MFM-w08-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	8	56.9	21.4				
MFM-w10-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	10	87.9	33.3				
MFM-w14-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	14	155.9	74.6				
MFM-w15-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	15	42.2	15.8				
MFM-wSDG-vEx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	SCG Weighted	66.5	24.6				
DMO-w06-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	6	126.3	43.9				
DMO-w07-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	7	118	41.2				
DMO-w08-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	8	142.7	51.4				
DMO-w10-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	10	212.4	79.2				
DMO-w14-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	14	347.9	136.2				
DMO-w15-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	15	162.1	137.5				
DMO-wSDG-vEx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	SCG Weighted	235.3	218				

Energy common units for RAC and RGF are shown in **Tables 16** and **17**.

Table 16. Energy Common Units for RAC HVAC System (DEER 2008 MISer)

DEER2008 ImpactID	Weighted Building Vintage Climate Zone	HVA C System	Energy Common Units 1 description	Number Energy Common Units 1
SFM-w06-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	6	RAC	tons cool cap	3.51
SFM-w07-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	7	RAC	tons cool cap	2.51
SFM-w08-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	8	RAC	tons cool cap	3.14
SFM-w10-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	10	RAC	tons cool cap	3.63
SFM-w14-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	14	RAC	tons cool cap	3.99
SFM-w15-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	15	RAC	tons cool cap	4.63
SFM-wSDG-vEx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	SDG Weighted	RAC	tons cool cap	3.57
MFM-w06-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	6	RAC	tons cool cap	1.52
MFM-w07-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	7	RAC	tons cool cap	1.38
MFM-w08-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	8	RAC	tons cool cap	1.41
MFM-w10-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	10	RAC	tons cool cap	2.01
MFM-w14-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	14	RAC	tons cool cap	2.32
MFM-w15-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	15	RAC	tons cool cap	2.5
MFM-wSDG-vEx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	SCG Weighted	RAC	tons cool cap	1.76
DMO-w06-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	6	RAC	tons cool cap	3.5
DMO-w07-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	7	RAC	tons cool cap	3.5
DMO-w08-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	8	RAC	tons cool cap	3.5
DMO-w10-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	10	RAC	tons cool cap	3.5
DMO-w14-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	14	RAC	tons cool cap	3.5
DMO-w15-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	15	RAC	tons cool cap	3.5
DMO-wSDG-vEx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	SCG Weighted	RAC	tons cool cap	3.5

Table 17. Energy Common Units for RGF HVAC System (DEER 2008 MISer)

DEER2008 ImpactID	Weighted Building Vintage Climate Zone	HVAC System	Energy Common Units 1 description	Number Energy Common Units
SFM-w06-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	6	RGF	kBtuh furnace	63.15
SFM-w07-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	7	RGF	kBtuh furnace	47.49
SFM-w08-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	8	RGF	kBtuh furnace	57.18
SFM-w10-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	10	RGF	kBtuh furnace	71.93
SFM-w14-vSGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	14	RGF	kBtuh furnace	80.03
SFM-w15-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	15	RGF	kBtuh furnace	89.88
SFM-wSDG-vEx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	SDG Weighted	RGF	kBtuh furnace	68.28
MFM-w06-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	6	RGF	kBtuh furnace	29.94
MFM-w07-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	7	RGF	kBtuh furnace	25.63
MFM-w08-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	8	RGF	kBtuh furnace	27.85
MFM-w10-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	10	RGF	kBtuh furnace	37.66
MFM-w14-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	14	RGF	kBtuh furnace	45.38
MFM-w15-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	15	RGF	kBtuh furnace	48.66
MFM-wSDG-vEx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	SDG Weighted	RGF	kBtuh furnace	31.19
DMO-w06-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	6	RGF	kBtuh furnace	55.01
DMO-w07-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	7	RGF	kBtuh furnace	55.06
DMO-w08-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	8	RGF	kBtuh furnace	55.02
DMO-w10-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	10	RGF	kBtuh furnace	54.96
DMO-w14-vSGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	14	RGF	kBtuh furnace	54.96
DMO-w15-vSDGx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	15	RGF	kBtuh furnace	54.96
DMO-wSDG-vEx-hGF-tWt-bCAv-eMsR-mRG-HV-EffFurn-90AFUE	SDG Weighted	RGF	kBtuh furnace	54.98

Tables 18 and 19 provide baseline UEC data normalized per “Energy Common Units” (ECU), i.e., tons cooling capacity or kBtuh furnace capacity.

Table 18. Weighted Baseline UEC per ECU – RAC with Gas Furnace (DEER 2008 MISer)

DEER2008 ImpactID	Weighted Building Vintage Climate Zone	Baseline Annual Gas Heating (therm/yr-ECU)	Baseline Annual Heating Elec Ventilation (kWh/yr-ECU)	Baseline Annual Cooling Elec Ventilation (kWh/yr-ECU)	Baseline Annual Elec Cooling (kWh/yr-ECU)	Baseline Annual Elec Cooling (kW/ECU)	Baseline Annual Elec Ventilation (kW/ECU)
SFM-w06-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	6	53.48	17.42	42.31	238.91	0.534	0.073
SFM-w07-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	7	52.96	18.83	46.99	287.25	0.742	0.103
SFM-w08-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	8	51.74	17.73	58.65	378.38	0.808	0.107
SFM-w10-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	10	59.03	20.29	57.64	379.52	0.75	0.094
SFM-w14-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	14	70.65	26.82	96	655.05	0.925	0.119
SFM-w15-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	15	24.04	0	0	790.59	0.856	0.101
SFM-wSDG-vEx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	SDG Weighted	51.98	16.85	50.27	454.95	0.77	0.10
MFM-w06-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	6	42.16	15.72	25.89	154.62	0.405	0.059
MFM-w07-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	7	36.96	13.72	24.41	144.76	0.446	0.061
MFM-w08-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	8	41.92	15.14	50.51	329.19	0.602	0.083
MFM-w10-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	10	47.19	16.6	51.72	348.31	0.584	0.073
MFM-w14-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	14	66.29	32.18	105.43	752.55	0.768	0.1
MFM-w15-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	15	22.39	6.34	146.68	1148.01	0.845	0.101
MFM-wSDG-vEx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	SDG Weighted	42.82	16.62	67.44	479.57	0.61	0.08
DMO-w06-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	6	42.1	12.54	74.4	631.98	0.781	0.073
DMO-w07-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	7	35.39	11.78	59.07	552.41	0.905	0.079
DMO-w08-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	8	51.36	14.68	121.36	1175.92	1.306	0.111
DMO-w10-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	10	54.01	22.65	106.36	1153.59	1.429	0.115
DMO-w14-vSGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	14	97.02	38.93	162.36	1598.71	1.73	0.143
DMO-w15-vSDGx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	15	45.21	39.32	163.99	2130.13	1.81	0.143
DMO-wSDG-vEx-hAC-tWt-bCAv-eMsR-mRE-HV-ResAC-14S	SDG Weighted	54.18	23.32	114.59	1207.12	1.33	0.11

Table 19. Weighted Baseline UEC per ECU – RGF Only (DEER 2008 MISer)

DEER2008 ImpactID	Weighted Building Vintage Climate Zone	Baseline Annual Gas Heating (therm/yr-ECU)	Baseline Annual Heating Elec Ventilation (kWh/yr-ECU)	Baseline Annual Cooling Elec Ventilation (kWh/yr-ECU)	Baseline Annual Elec Cooling (kWh/yr-ECU)	Baseline Annual Elec Cooling (kW/ECU)	Baseline Annual Elec Ventilation (kW/ECU)
SFM-w06-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	6	2.69	0.97				
SFM-w07-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	7	2.65	1				
SFM-w08-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	8	2.63	0.97				
SFM-w10-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	10	2.79	1.02				
SFM-w14-vSGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	14	3.58	1.34				
SFM-w15-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	15	1.38	0.48				
SFM-wSDG-vEx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	SDG Weighted	2.62	0.96				
MFM-w06-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	6	2.21	0.8				
MFM-w07-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	7	2	0.74				
MFM-w08-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	8	2.04	0.77				
MFM-w10-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	10	2.33	0.89				
MFM-w14-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	14	3.44	1.64				
MFM-w15-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	15	0.87	0.33				
MFM-wSDG-vEx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	SDG Weighted	2.13	0.79				
DMO-w06-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	6	2.3	0.8				
DMO-w07-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	7	2.14	0.75				
DMO-w08-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	8	2.59	0.93				
DMO-w10-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	10	3.86	1.44				
DMO-w14-vSGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	14	6.33	2.48				
DMO-w15-vSDGx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	15	2.95	2.5				
DMO-wSDG-vEx-hGF-tWt-bCAv-eMsr-mRG-HV-EffFurn-90AFUE	SDG Weighted	4.28	3.97				

1.6 Pre-Existing Baseline and Measure Effective Useful Lives

The pre-existing baseline measure characteristics are provided in **Table 3**. For heating the baseline is either temperature controlled or time controlled delay on the furnace fan. For cooling the baseline is either no time delay or time delay of 90 seconds. The baseline measure is installed inside the HVAC equipment and is dependent on the life of the equipment. The EFC measure is not installed inside the air conditioner, furnace, forced-air unit, or thermostat. Therefore, the EFC EUL is not dependent on the life of the air conditioner, furnace, FAU, or thermostat. The EFC is a small microchip approximately the size of a US penny which is installed in the wall behind the thermostat on the low-voltage wires coming from the HVAC equipment. The effective useful lifetime of the EFC is assumed to be 10 years based on the EUL of programmable thermostats (DEER 2008). However, since the EFC is solid-state its lifetime could be longer (i.e., 15 to 25 years) since there are no moving parts or parts to wear out since the product operates on low voltage without the need for a battery,

1.7 Net-to-Gross Ratios

A net to gross ratio of the EFC is 1.0 based on the EUL for comprehensive air conditioning measures.

Section 2. Engineering Calculations

The engineering calculations for annual natural gas and electricity savings and peak demand reduction are provided in the embedded Excel workbook using the following equations. The baseline annual gas heating (therm/yr) values shown in **Table 14**, column 3, and the baseline annual electric cooling (kWh/yr) values shown in **Table 14**, column 5, are taken directly from the 2008 DEER Update (DEER 2008a) for the Southern California weighted vintage for each climate zone and residential air conditioner (RAC) HVAC system (includes gas furnace and air conditioner). The baseline annual heating electric ventilation (kWh/yr) values shown in **Table 15**, column 4, are taken directly from the 2008 DEER Update (DEER 2008a) for the SCG weighted vintage for each climate zone and residential gas furnace (RGF) HVAC system (excludes air conditioning). The baseline annual cooling electric ventilation values shown in **Table 14**, column 5, are calculated using **Equation 12**.

$$\text{Eq. 12} \quad \text{UEC}_{\text{cool vent}} = \text{UEC}_{\text{RAC vent}} - \text{UEC}_{\text{RGF vent}}$$

Where,

$\text{UEC}_{\text{cool vent}}$ = baseline cooling electric ventilation exclusive of heating (kWh/year),

$\text{UEC}_{\text{RAC vent}}$ = baseline electric ventilation for residential air conditioning including cooling and heating (i.e., furnace) from DEER 2008a (kWh/year), and

$\text{UEC}_{\text{RGF vent}}$ = baseline heating-only electric ventilation for residential gas furnace (RGF) excluding cooling from DEER 2008a (kWh/year).

The annual heating energy savings shown in **Table 1** for RAC are calculated using **Equation 13** and the baseline UEC values shown in **Table 14**.

$$\text{Eq. 13} \quad \text{ES}_{\text{EFC heat}} = \text{UEC}_{\text{RAC heat}} \times \overline{S_{\text{heat}}}$$

Where,

$\text{ES}_{\text{EFC heat}}$ = energy savings for the EFC measure for space heating (therm/year),
 $\text{UEC}_{\text{RAC heat}}$ = baseline space heating from DEER 2008a (therm/year), and
 $\overline{S_{\text{heat}}}$ = weighted average space heating energy savings associated with the EFC based on field and laboratory tests (%).

The annual net electric energy savings shown in **Table 1** are calculated using **Equation 14** and the baseline UEC values shown in **Table 14** for RAC and **Table 15** for RGF.

$$\text{Eq. 14} \quad \text{ES}_{\text{EFC cool}} = [\text{UEC}_{\text{RAC cool}} \times \overline{S_{\text{cool}}}] + [\text{UEC}_{\text{RAC vent}} \times (\overline{S_{\text{cool}}} + \overline{S_{\text{RAC vent}}})] \\ + [\text{UEC}_{\text{RGF vent}} \times \overline{S_{\text{RGF vent}}}]$$

Where,

$\text{ES}_{\text{EFC cool}}$ = energy savings for the EFC measure for space cooling (kWh/year),
 $\text{UEC}_{\text{RAC cool}}$ = baseline space cooling from DEER 2008a (kWh/year),
 $\overline{S_{\text{cool}}}$ = weighted average space cooling electric energy savings associated with the EFC based on field and laboratory tests (%),
 $\overline{S_{\text{RAC vent}}}$ = weighted average RAC ventilation savings associated with the EFC based on field and laboratory tests (%), and
 $\overline{S_{\text{RGF vent}}}$ = weighted average RGF ventilation savings associated with the EFC based on field and laboratory tests (%).

The annual peak demand savings (PDS) shown in **Table 1** are calculated using **Equation 15** and the baseline Unit Peak Demand (UPD) values shown in **Table 14**.

$$\text{Eq. 15} \quad \text{PDS}_{\text{EFC}} = \text{DF} \times \{[\text{UPD}_{\text{RAC cool}} \times \overline{S_{\text{cool}}}] + [\text{UPD}_{\text{RAC vent}} \times (\overline{S_{\text{cool}}} + \overline{S_{\text{RAC vent}}})]\}$$

Where,

PDS_{EFC} = peak demand savings for the EFC measure (kW),
 DF = diversity factor of 0.33 for space cooling assuming one-third of air conditioners are on at any given time during the peak period (dimensionless),
 $\text{UPD}_{\text{RAC cool}}$ = baseline space cooling peak demand from DEER 2008a (kW), and
 $\text{UPD}_{\text{RAC vent}}$ = baseline ventilation peak demand from DEER 2008a (kW).

Tables 18 and 19 provide baseline UEC data normalized per “Energy Common Units” (ECU), i.e., tons cooling capacity or kBtuh furnace capacity. ECU data are provided in **Tables 16 and 17**. These data can be used with **Equation 16** to calculate annual heating energy savings.

$$\text{Eq. 16} \quad \text{ES}_{\text{EFC heat}} = \text{UEC}_{\text{heat}} \times \overline{S_{\text{heat}}} \times \text{ECU}$$

Where,

ECU = Energy Common Unit per **Table 16** for RAC and **Table 17** for RGF.

The annual net electric energy savings are calculated using **Equation 17**, baseline UEC data per ECU in **Tables 18** and **19**, and ECU data in **Tables 16** and **17**.

$$\text{Eq. 17} \quad \text{ES}_{\text{EFC cool}} = \left\{ [\text{UEC}_{\text{cool}} \times \overline{S_{\text{cool}}}] + [\text{UEC}_{\text{vent}} \times (\overline{S_{\text{cool}}} + \overline{S_{\text{RACvent}}})] + [\text{UEC}_{\text{vent}} \times \overline{S_{\text{RGFvent}}}] \right\} \times \text{ECU}$$

The annual peak demand savings (PDS) are calculated using **Equation 18** and the baseline UEC data per ECU in **Tables 18** and **19**, and ECU data in **Tables 16** and **17**.

$$\text{Eq. 18} \quad \text{PDS}_{\text{EFC}} = \left\{ \text{DF} \times \left\{ [\text{UPD}_{\text{RAC cool}} \times \overline{S_{\text{cool}}}] + [\text{UPD}_{\text{RAC vent}} \times (\overline{S_{\text{cool}}} + \overline{S_{\text{RACvent}}})] \right\} \right\} \times \text{ECU}$$

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SCG Excel Workbook #1 with DEER2008 Data, E3 Inputs, and Energy Savings Calculations (embedded “Workpaper_Verified_EFC_DEER2008-BaseResEnergyUse_v0.xls”).



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Attachment

Workpaper Tables in Excel format



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CONTROLLER.xlsx