HVAC Smart Chip for Residential and Commercial Application
For Conventional HVAC and Heat Pumps HVAC

Condensed Version. June 2012

The following information pertains to residential application of the HVAC Smart Chip (HSC) device (engineering project code EFC or Extend Fan Controller) in the HVAC, which constitutes the majority of the installations.

Device Name:	HVAC Smart Chip or Extend Fan Controller 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 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 code base case HVAC system does not operate the fan after the compressor turns off (i.e., no time delay). Some HVAC systems (less than 8%) continue to operate the fan for a fixed time delay of 90 seconds after the compressor turns off.
Costs Common Units:	Household or tons for RAC, or kBtuh for RGF
Device Equipment Cost ($/unit):	30
Device Incremental Cost ($/unit):	75 (SFM, MFM, and DMO)
Device Installed Cost ($/unit):	75 (SFM, MFM, and DMO)
Device Load Shape:	Residential Central Air Conditioning
Effective Useful Life (years):	10
Program Type:	Retrofit
TOU AC Adjustment:	100%

Net-to-Gross Ratios:	1.00

Section 1. General Device & Baseline Data

1.1 Device Description & Background

This engineering work paper provides engineering estimates of savings for upgrading Heating, Ventilating, and Air Conditioning (HVAC) equipment with an HVAC Smart Chip (HSC) - engineering project code “EFC” or Extend Fan Controller - 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 HSC that does the following:

1) Adjusts fan operation for heating based on gas valve activation time or furnace operating time or Heat Pump activation time.
2) Adjust fan operation for cooling based on air-conditioning compressor run time.
3) The amount of time the fan continues to operate after the furnace is off or after the compressor is off, varies with the amount of time the furnace or compressor are on.
4) The furnace run time indicates how much heat is stored in the heat exchanger. The air conditioner compressor run time indicates how much cold water is condensed on the evaporator coil.
5) Most non-heat pump furnaces fans operate at low speed and this reduces airflow and heating efficiency. The HSC provides high speed fan operation in heating mode to increase heating efficiency and reduce furnace run time.

This Device under study applies to HVAC systems that have a fan off time delay of less than 2 minutes in heating or cooling operation. The Device 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 Devices 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 HSC recovers and delivers more heating and cooling energy to the conditioned space than is possible with conventional fan controllers. The HSC 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.

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. 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 down the condensate drain. The HSC 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 HSC 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 HSC 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 HSC is a small device with 6 color coded 20 gauge wires, powered by low-voltage microprocessor circuitry. The common wire is needed to power the device. The HSC connects to the existing thermostat wires and is mounted in one of three positions:
1) beside the thermostat mounting case
2) in a hole behind thermostat mounting plate where thermostat wires attach to thermostat.
3) at the bus bar of the air handler directly usually by the homeowner or a licensed electrician. This is easiest simplest way to install the HSC. The air handler is usually at the garage or the attic.

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

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

- 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 HVAC Smart Chip (HSC) Device. 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 Device Inspection and Summary viewer tool (MISer Version 1.10.25) and DEER (Version: DEER2008.2.2). See http://www.deeresources.com/. 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 condensable, 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 11.8% (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.

HSC Energy and demand savings for residential air conditioning (RAC - space cooling and space heating) are shown in **Table 1**. Data are based on analysis in **Section 1.4**.

Table 1. HSC 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	1	PG&E Weighted	-24.68	0.07	40.20
Single Family	2	PG&E Weighted	26.42	0.11	36.93
Single Family	3	PG&E Weighted	-0.39	0.10	0.34
Single Family	4	PG&E Weighted	54.53	0.13	28.54
Single Family	5	PG&E Weighted	-7.32	0.07	37.65
Single Family	11	PG&E Weighted	164.42	0.18	33.61
Single Family	12	PG&E Weighted	97.08	0.15	32.40
Single Family	13	PG&E Weighted	202.65	0.17	31.76
Single Family	16	PG&E Weighted	41.14	0.14	70.95
Single Family	PG&E Weighted	PG&E Weighted	111.75	0.15	33.27
Multi Family	1	PG&E Weighted	-11.62	0.05	24.64
Multi Family	2	PG&E Weighted	16.48	0.07	14.79
Multi Family	3	PG&E Weighted	-2.60	0.05	14.71
Multi Family	4	PG&E Weighted	15.89	0.06	11.03
Multi Family	5	PG&E Weighted	-0.08	0.04	9.75

Multi Family	11	PG&E Weighted	80.42	0.10	16.14
Multi Family	12	PG&E Weighted	45.57	0.08	15.96
Multi Family	13	PG&E Weighted	118.64	0.10	13.44
Multi Family	16	PG&E Weighted	42.95	0.09	30.35
Multi Family	PG&E Weighted	PG&E Weighted	51.20	0.08	14.41
Mobile Home	1	PG&E Weighted	16.87	0.11	36.69
Mobile Home	2	PG&E Weighted	200.56	0.20	32.44
Mobile Home	3	PG&E Weighted	116.93	0.15	28.48
Mobile Home	4	PG&E Weighted	243.89	0.18	25.75
Mobile Home	5	PG&E Weighted	101.18	0.14	37.32
Mobile Home	11	PG&E Weighted	406.57	0.28	38.64
Mobile Home	12	PG&E Weighted	331.11	0.25	31.13
Mobile Home	13	PG&E Weighted	499.66	0.27	29.71
Mobile Home	16	PG&E Weighted	190.97	0.21	65.72
Mobile Home	PG&E Weighted	PG&E Weighted	346.33	0.24	34.59

HSC 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**

Table 2. HSC 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	1	PG&E Weighted	-18.02	0.00	38.03
Single Family	2	PG&E Weighted	-17.31	0.00	38.78
Single Family	3	PG&E Weighted	-15.47	0.00	35.11
Single Family	4	PG&E Weighted	-12.26	0.00	27.36
Single Family	5	PG&E Weighted	-17.60	0.00	39.88
Single Family	11	PG&E Weighted	-14.69	0.00	33.57
Single Family	12	PG&E Weighted	-13.74	0.00	31.54
Single Family	13	PG&E Weighted	-13.43	0.00	30.50
Single Family	16	PG&E Weighted	-33.57	0.00	71.38
Single Family	PG&E Weighted	PG&E Weighted	-15.60	0.00	35.10
Multi Family	1	PG&E Weighted	-7.61	0.00	16.62
Multi Family	2	PG&E Weighted	-6.31	0.00	13.97
Multi Family	3	PG&E Weighted	-6.29	0.00	14.29
Multi Family	4	PG&E Weighted	-5.33	0.00	11.84
Multi Family	5	PG&E Weighted	-6.57	0.00	14.88
Multi Family	11	PG&E Weighted	-6.81	0.00	15.23
Multi Family	12	PG&E Weighted	-7.36	0.00	16.44
Multi Family	13	PG&E Weighted	-6.20	0.00	13.74

Multi Family	16	PG&E Weighted	-11.42	0.00	24.47
Multi Family	PG&E Weighted	PG&E Weighted	-6.19	0.00	13.99
Mobile Home	1	PG&E Weighted	-14.10	0.00	32.61
Mobile Home	2	PG&E Weighted	-13.42	0.00	30.91
Mobile Home	3	PG&E Weighted	-12.27	0.00	29.27
Mobile Home	4	PG&E Weighted	-10.02	0.00	23.52
Mobile Home	5	PG&E Weighted	-13.99	0.00	32.76
Mobile Home	11	PG&E Weighted	-15.93	0.00	35.88
Mobile Home	12	PG&E Weighted	-11.56	0.00	26.75
Mobile Home	13	PG&E Weighted	-14.34	0.00	32.05
Mobile Home	16	PG&E Weighted	-29.53	0.00	64.49
Mobile Home	PG&E Weighted	PG&E Weighted	-15.02	0.00	36.51

1.3 Codes & Standards Requirements Analysis

There is no code or standard addressing the HSC. The Device 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 Device can also be retrofit to any RGF thermostat with less than 2-minute time delay or standard temperature delay for heating. Instead of installing at the thermostat, the installation can also be done at the air handler bus bar.

1.4 EM&V, Market Potential, and Other Studies

The forecast values were derived from these sources:

- Incremental (Full) Device Cost is based on what HVAC Contractors charge for the materials, labor, and overhead to install the HVAC Smart Chip.
- 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 HSC 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 non-heat pump heating mode, the HSC microprocessor monitors the following:

1) gas valve activation time
2) determines whether or not to continue operating the fan after the furnace turns on
3) how long the fan should continue operating to maximize heat recovery from the heat exchanger.

In cooling mode the HSC monitors the following:

1) air-conditioning compressor operation time
2) determines whether or not to continue operating the fan after the compressor turns off to transfer heat to the cold evaporator coil
3) how long the fan should continue operating to recover energy stored in the form of condensed cold water on the evaporator coil to further cool the building.

In cooling mode, the HSC uses the evaporator coil as an evaporative cooler. The fan uses 8 to 15 times less power than the compressor and is microprocessor controlled to operate based compressor run time.

Air conditioning equipment manufacturers provide an optional 1.5 minute time delay relay (TDR) kit to improve sensible energy efficiency ratio (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 HSC or EFC are shown in **Figure 1**. The term EFC shown in the graphs and charts refers to the Extend Fan Controller of the HVAC Smart Chip device.

The HSC 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 HSC maximizes heat recovery from the heat exchanger after the furnace is turned off with an extended fan delay of 2 to 4.5 minutes depending on how long the furnace gas valve signal is on during the heating cycle. The HSC 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 HSC 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 HSC are shown in **Figure 2**.

Standard air conditioners have a 0 to 1.5 minute fan time delay. The HSC maximizes recovery of latent cooling from the evaporator after the compressor is turned off with an extended fan delay of 2 to 6 minutes depending on how long the air conditioner compressor is on during the cooling cycle.

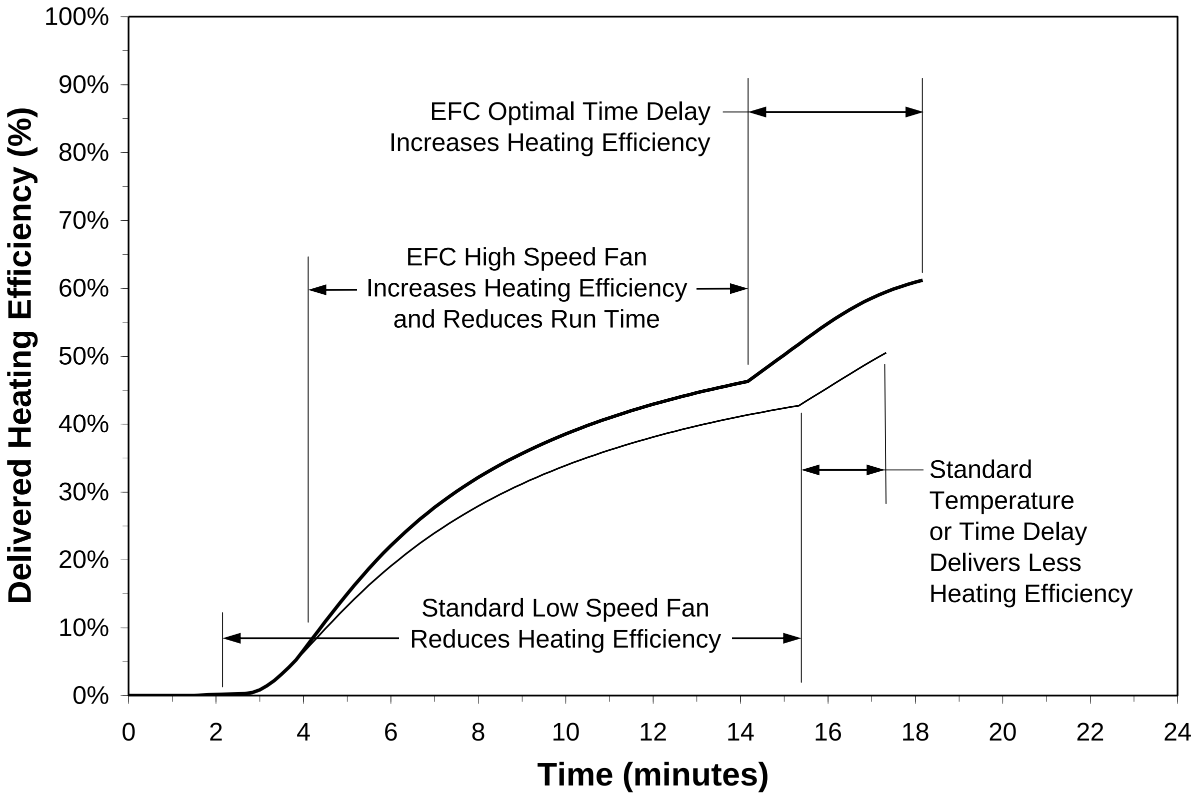

Figure 1. Heating Efficiency Improvement from HVAC Smart Chip (EFC)

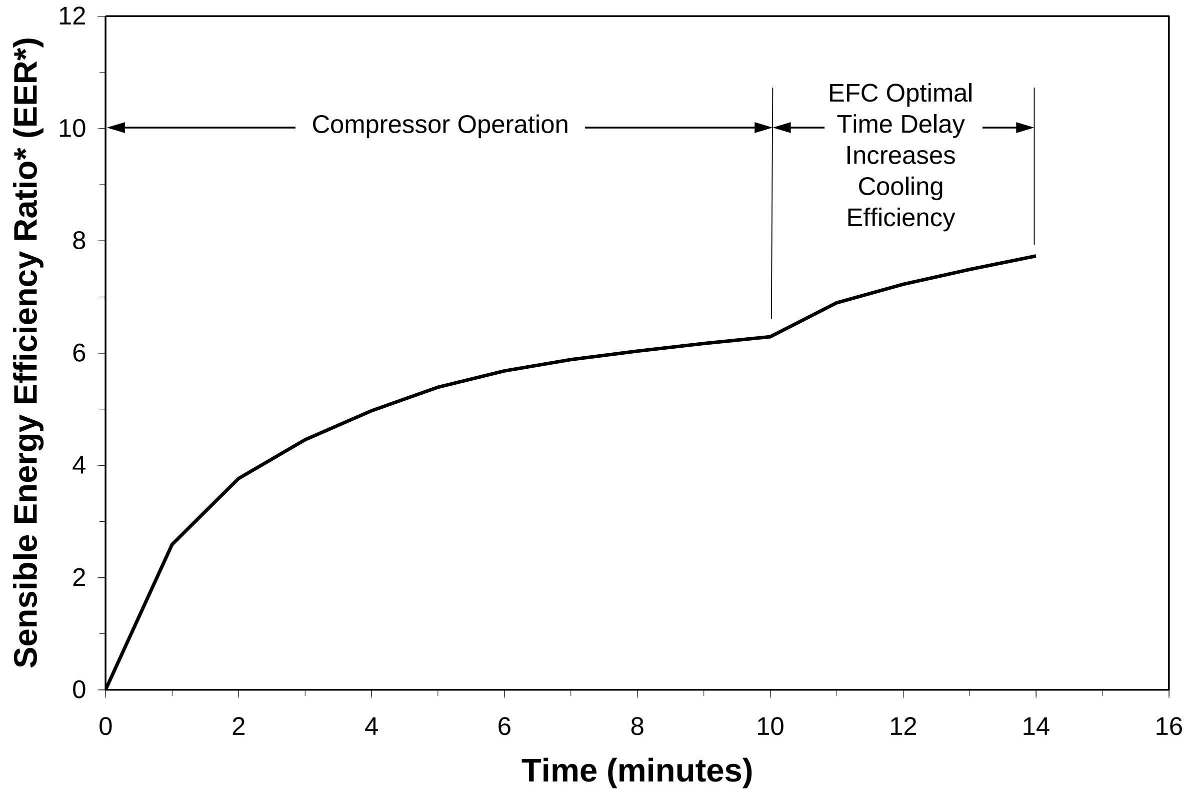

Figure 2. Air Conditioner Sensible EER* Improvement from HVAC Smart Chip (EFC)

The sensible energy efficiency ratio (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 HSC 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 time delay relay (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 HSC is applicable to all existing and new HVAC systems.

HSC units were installed at homes in California and Nevada to evaluate consumer satisfaction. Survey respondents indicated that the HSC 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 HSC 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.

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 some unspecified small 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 deg F to 40 deg F.

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 HSC 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 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 HSC is applicable to all existing and new HVAC systems.

For heating, the HSC 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 Device Characteristics

Pre-Existing Description	Device Description	Estimated Market Share
Heating properly working Temperature Delay at 100 to 110°F, PSC motor	HSC High Speed Fan plus Variable Time Delay (2 to 4 minutes)	35%
Heating degraded Temperature Delay at 130 to 200°F, PSC motor	HSC 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).

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.

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.

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

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 (ft^3/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.

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

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).

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, HVAC Smart Chip 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.

Eq. 3 $\eta = \sum_{i=0}^{t} \frac{Q_{hs\,i}}{Q_{hf\;i}}$

Where,

η = 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**.

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

Where,

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

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

η_{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, HSC 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 HSC 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 HSC 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 HSC 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.

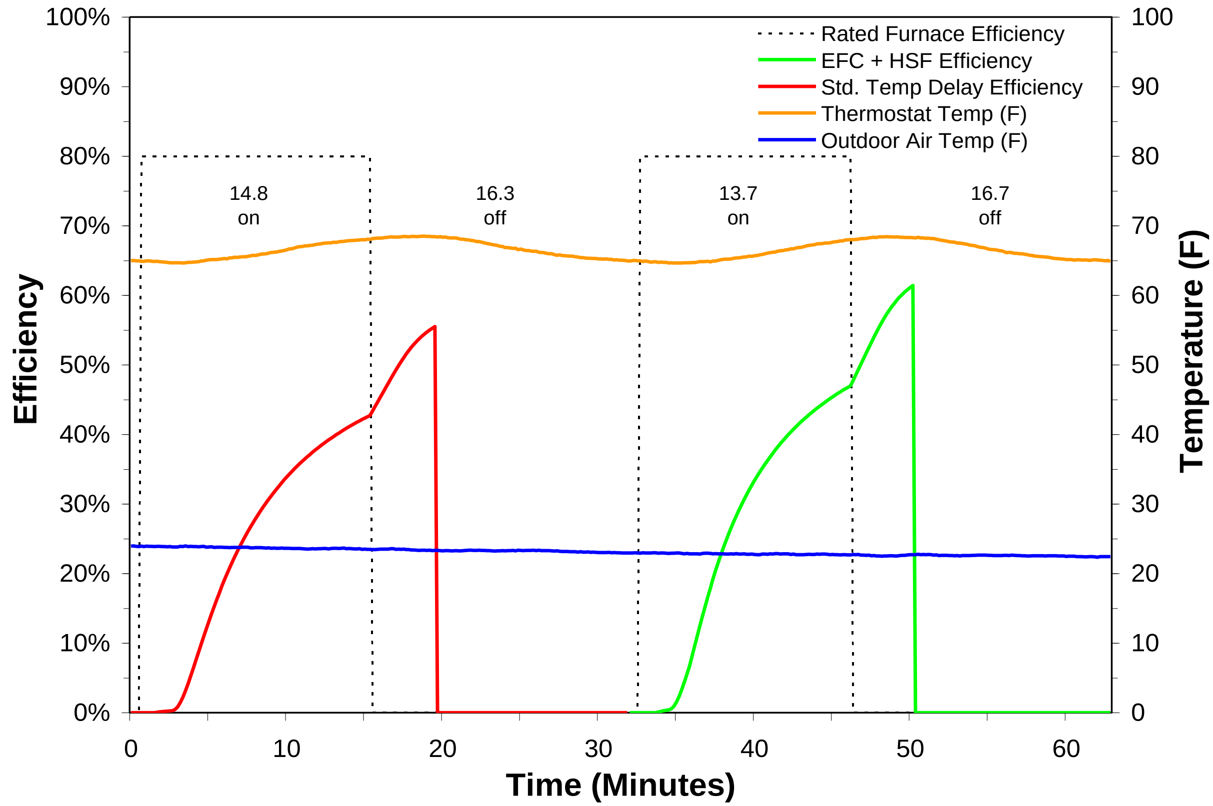

Figure 3. Heating Efficiency with HVAC Smart Chip (EFC) + High Speed Fan (HSF) versus Standard Temperature Delay

Table 5. Measured Heating Efficiency from HVAC Smart Chip + High Speed Fan vs. Standard Temp. Delay

Description	Test 1 Baseline	Test 2 HSC
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
HSC Additional Fan Energy (kWh/cycle)		0.009
HSC 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, HSC 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 HSC 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 HSC saves 5.9% of gas heating energy and -14.5% of heating fan ventilation energy.

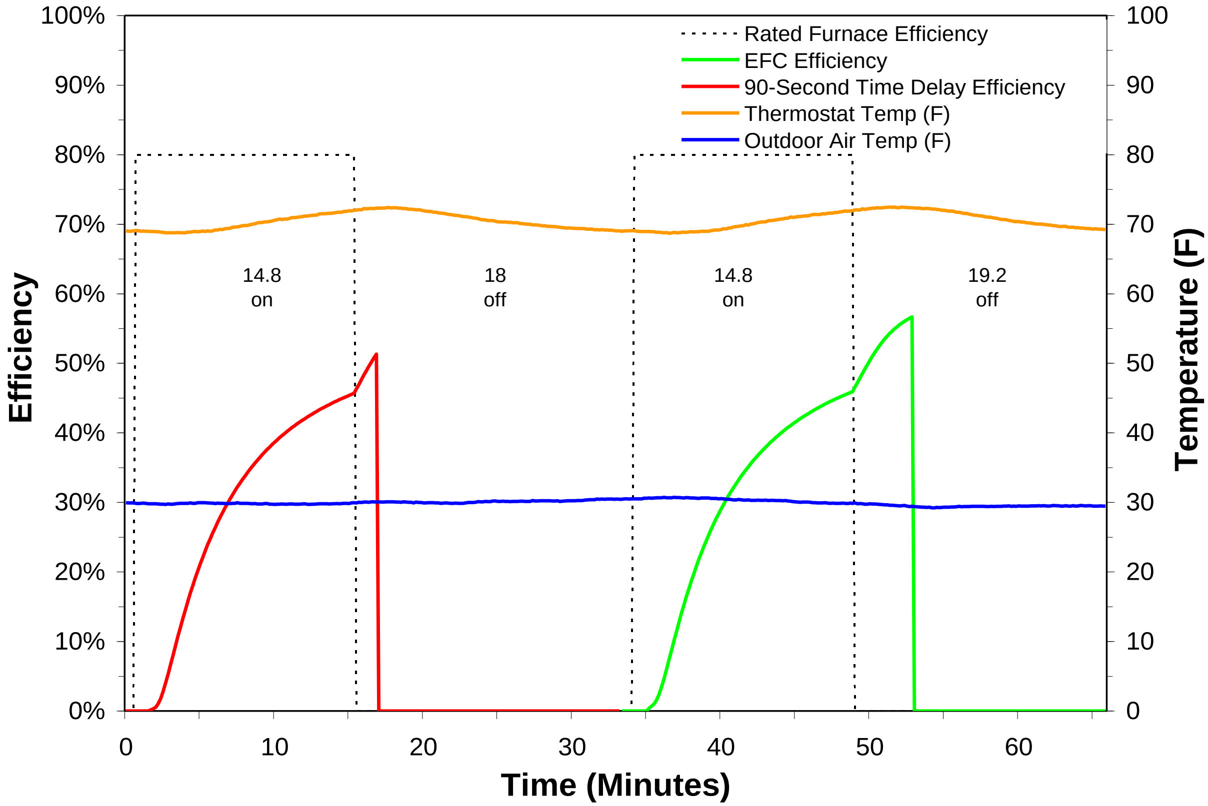

Figure 4. Heating Efficiency with HVAC Smart Chip (EFC) versus 90-Second Time Delay (Low Speed Fan)

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

Description	Test 3 Baseline	Test 4 HSC
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
HSC Additional Fan Energy (kWh/cycle)		0.025
HSC 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, HSC + 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 (HSC) 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 HSC 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 HSC provides a 4-minute time delay with high-speed fan and the fan-off supply plenum temperature is 114.8°F. The HSC increases off cycle from 9.8 to 15.7 minutes or 60.2%. Test 6 HSC 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 (HSC) 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 HSC 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 HSC provides a 4-minute time delay with high-speed fan and the fan-off supply plenum temperature is 118.8°F. The HSC increases off cycle from 50.2 to 67.5 minutes or 34.6%.

HSC test 8 saves 16.9% of gas energy and -30.5% of heating fan ventilation energy. The average savings from HSC (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.

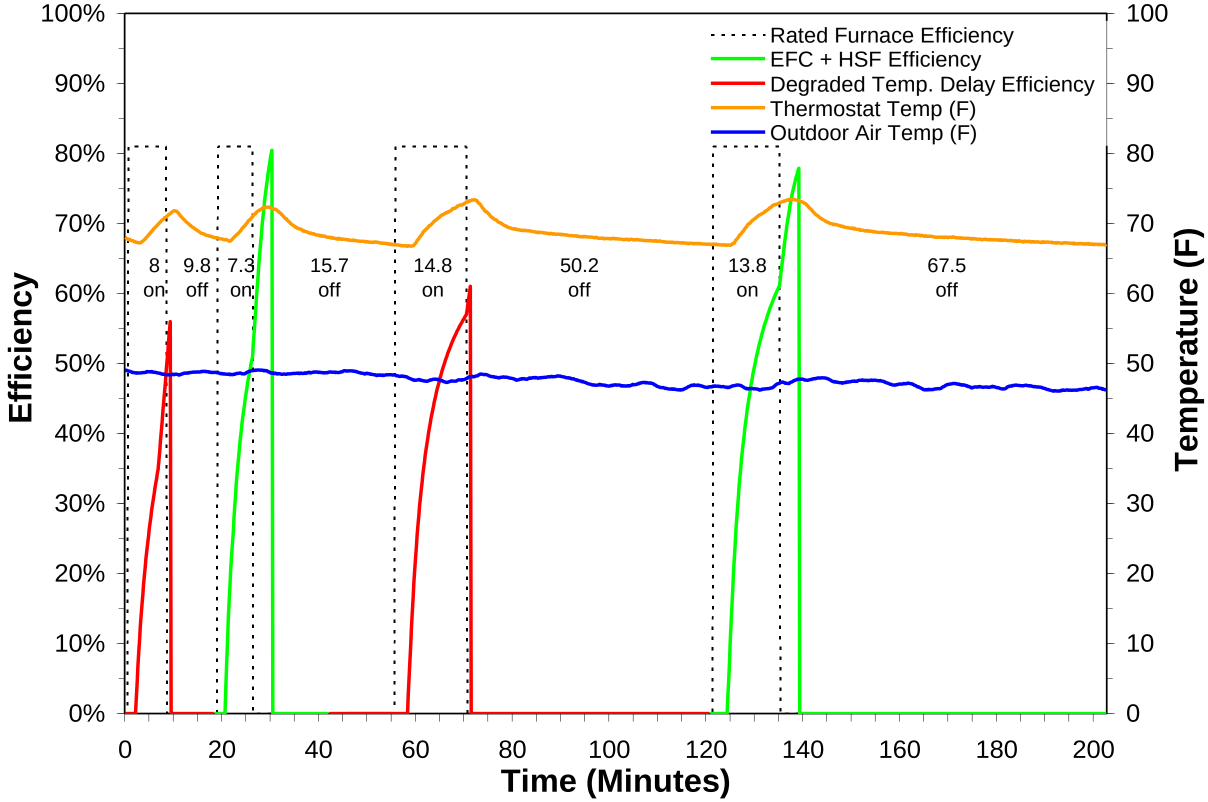

Figure 5. Heating Efficiency with HVAC Smart Chip (EFC) + High Speed Fan (HSF) versus Degraded Temperature Delay

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Table 7. Measured Heating Efficiency with HVAC Smart Chip + HSF vs. Degraded Temp. Delay

Description	Test 5 Baseline	Test 6 HSC	Test 7 Baseline	Test 8 HSC	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	
HSC Additional Fan Energy (kWh/cycle)		0.007		0.029	
HSC 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 HSC fan compared to the standard fan is calculated using **Equation 5**.

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

Where,

S_{vent} = electric residential air conditioner (RAC) or residential gas furnace (RGF) ventilation savings associated with the HSC based on field or laboratory tests (%),

t = time of measurement interval,

m = total time for HSC furnace fan operation,

n = total time for standard heating fan operation,

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

$P_{std\ fan}$ = 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 HSC 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 HSC 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 HSC 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 HSC 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 HSC fan time delay times of 5 minutes. The HSC additional fan energy is 30.6% in cooling mode.

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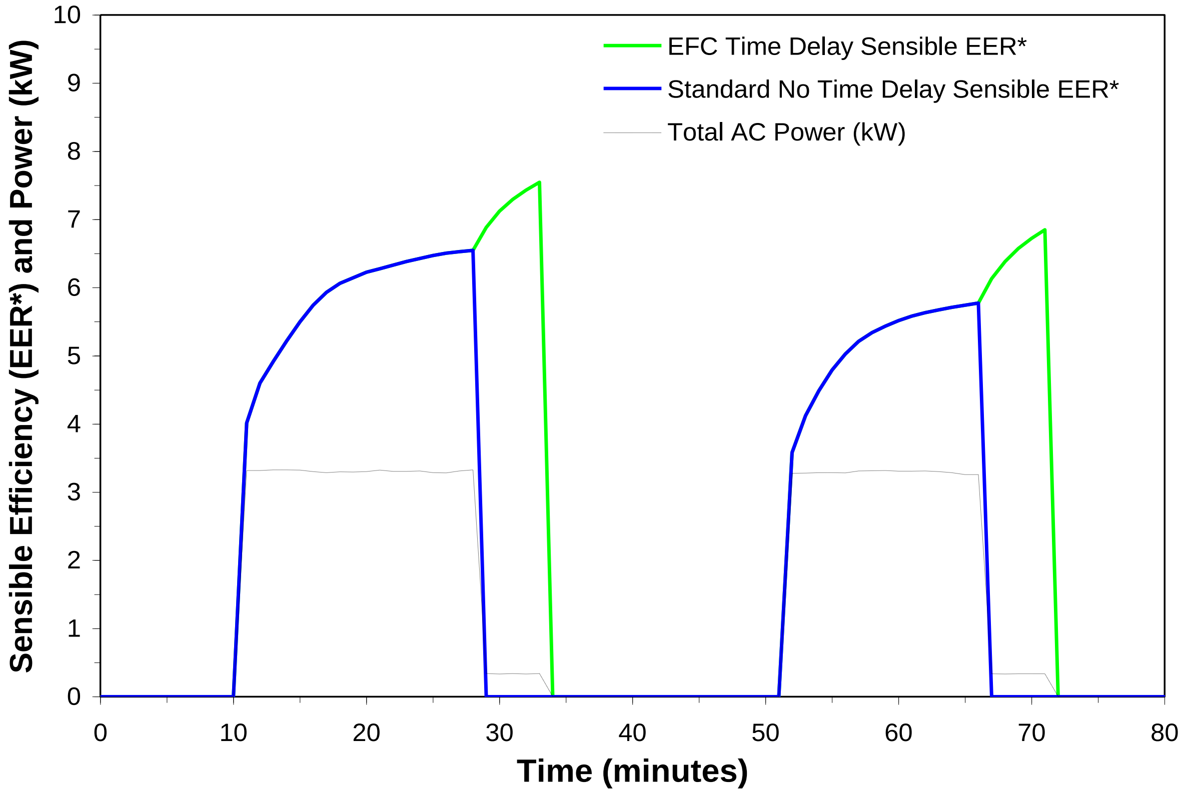

Figure 6. Field Tests Cooling Sensible EER and Power Hvac Smart Chip (EFC) versus no Time Delay

Table 8. Field Tests of Air Conditioner HVAC Smart Chip versus No Time Delay

Description	Test 9	Test 10	Average
Compressor On Time (minutes)	18	15	16.5
HSC Delay After Compressor Off (minutes)	5	5	5
HSC Additional Fan Energy (kWh/cycle)	0.03	0.03	0.03
Std. Delay After Compressor Off (minutes)	0	0	0.00
HSC 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

HSC AC Energy (kWh)	1.02	0.85	0.94
HSC Cooling Delivered (Btu)	7,703	5,828	6,766
HSC 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 HSC 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 HSC fan time delay times of 5 minutes. The HSC additional fan energy is 19.6% in cooling mode.

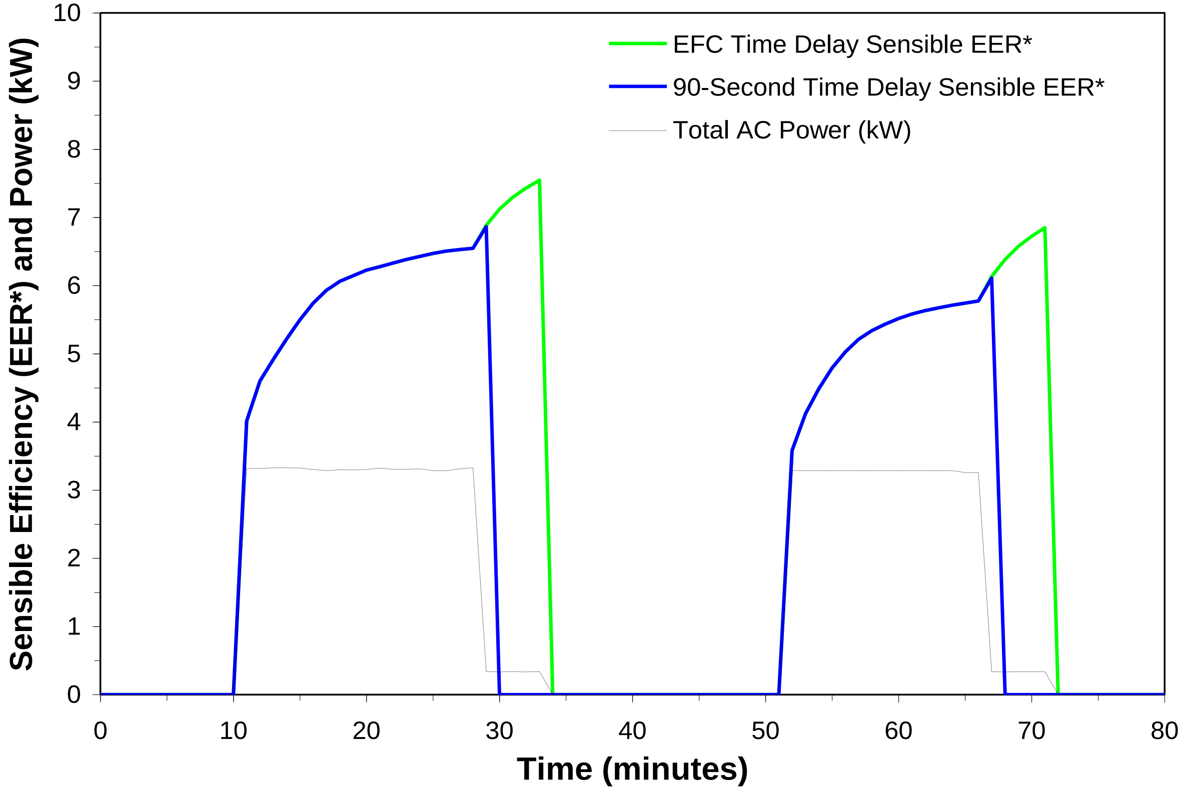

Figure 7. Field Tests Cooling Sensible EER and Power HVAC Smart Chip (EFC) versus 90-second TDR

Table 9. Field Tests of Air Conditioner HVAC Smart Chip versus 90-Second TDR

Description	Test 11	Test 12	Average
Compressor On Time (minutes)	18	15	16.5
HSC Delay After Compressor Off (minutes)	5	5	5
HSC Additional Fan Energy (kWh/cycle)	0.02	0.02	0.02
Std. Delay After Compressor Off (minutes)	1.5	1.5	1.50
HSC 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
HSC AC Energy (kWh)	1.02	0.85	0.94
HSC Cooling Delivered (Btu)	7,703	5,828	6,766
HSC 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 Column O is the Cycle Sensible EER. 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 HSC adjusts the length of the time delay from 1.5 to approximately 6 minutes based on the compressor run time. The average cooling efficiency improvement from the HSC 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 HSC 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 HSC 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 HSC compared to the 90-second delay based on field measurements (see **Table 9**).

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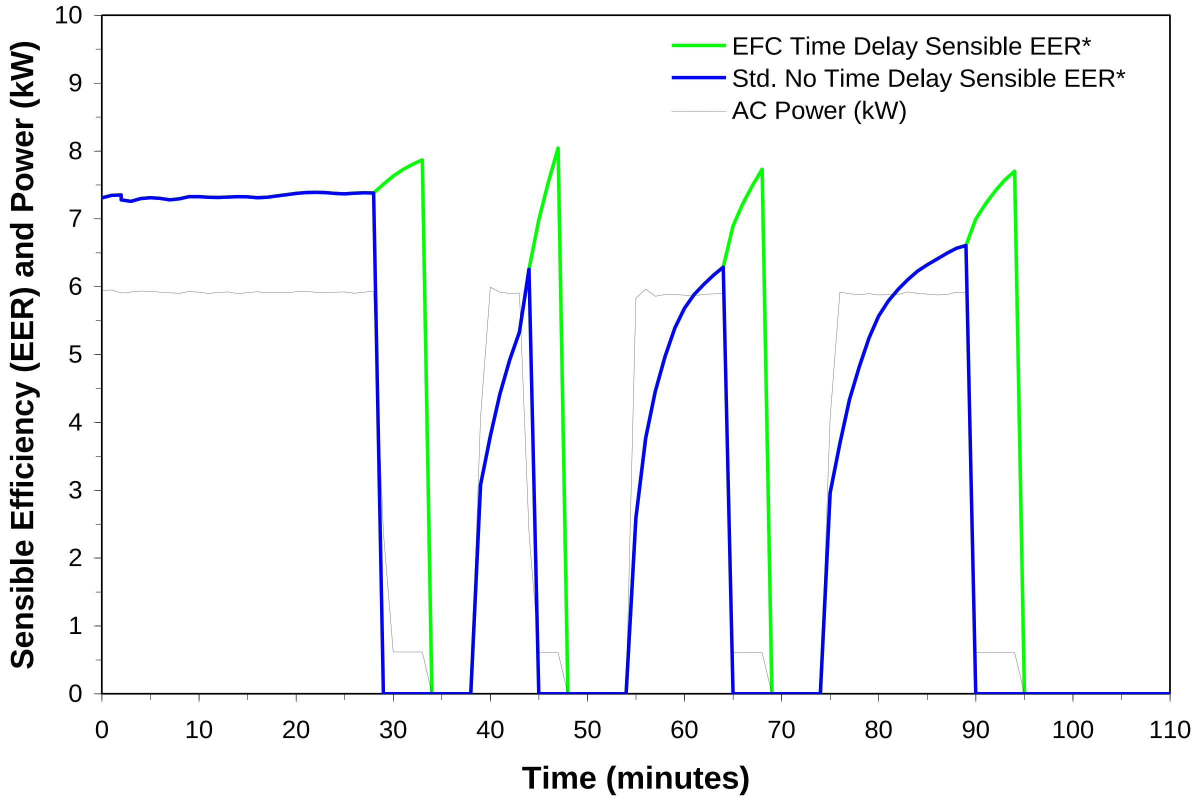

Figure 8. Laboratory Tests of Air Conditioner HVAC Smart Chip (EFC) versus No Time Delay

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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
HSC Delay After Compressor Off (minutes)	5	3	4	5	4.25
HSC 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
HSC 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
HSC AC Energy (kWh)	3.04	0.53	1.02	1.49	1.79
HSC Cooling Delivered (Btu)	23,917	4,288	7,893	11,507	11,901
HSC Application Sensible EER*	7.87	8.04	7.73	7.70	7.84
HSC Cooling Savings	**6.2%**	**22.2%**	**18.7%**	**14.2%**	**15.3%**

Source: Based on Southern California Edison data.

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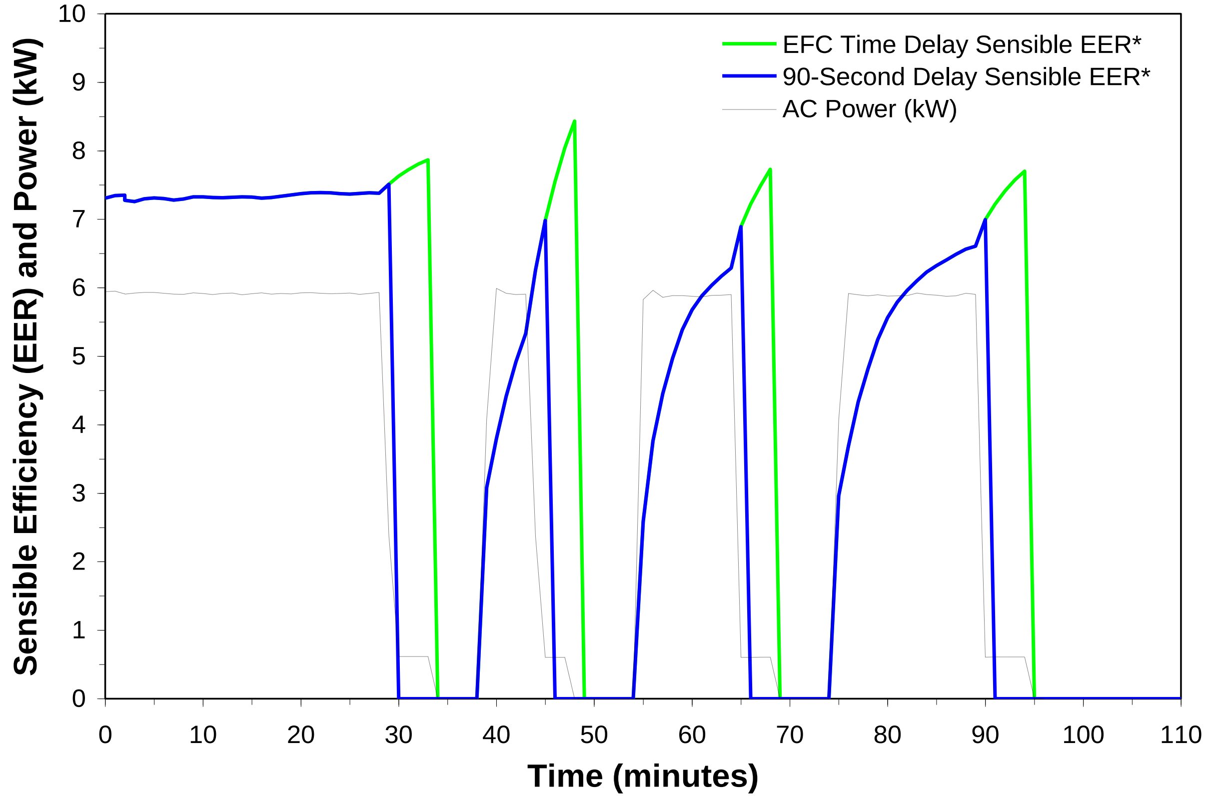

Figure 9. Laboratory Tests of Air Conditioner with HVAC Smart Chip versus 90-Second Time Delay

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Table 11. Laboratory Tests of Air Conditioner with HVAC Smart Chip 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
HSC Delay After Compressor Off (minutes)	5	3	4	5	4.25
HSC 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
HSC 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
HSC AC Energy (kWh)	3.04	0.53	1.02	1.49	1.79
HSC Cooling Delivered (Btu)	23,917	4,288	7,893	11,507	11,901
HSC Application Sensible EER*	7.87	8.04	7.73	7.70	7.84
HSC 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.

Eq. 6 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**.

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

Where,

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

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

$EER_s^*\big|_{Base}$ = 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 HSC are shown in **Table 12**. The savings are based on field tests and laboratory tests of furnaces and air conditioners with and without the HSC. 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 HSC 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 HSC 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 HSC heating ventilation energy savings are -13.8% (i.e., negative) based on the weighted average of temperature and time delay. The HSC cooling ventilation energy savings are -36.2% (i.e., negative) based on the weighted average of temperature and time delay. The HSC 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**.

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

Where,

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

S_{heat_k} = heating energy savings for the HSC 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**.

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

Where,

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

S_{cool_k} = cooling energy savings for the HSC 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**.

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 HSC based on field and laboratory tests and market share (%),

$S_{RGF\,vent_k}$ = RGF ventilation savings for the HSC 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**.

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 HSC based on field and laboratory tests and market share (%),

$S_{RAC\,vent_k}$ = RAC ventilation savings for the HSC 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 HSC

Pre-existing Description	Device Description	HSC Heating Savings	HSC Fan Heating Savings	HSC Fan Cooling Savings	HSC Cooling Savings	Estimated Market Share
Heating Temperature Delay at 100 to 110°F, PSC motor	HSC 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	HSC 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	HSC Variable Time Delay (2 to 4 minutes)	5.9%	-14.5%			30%
Cooling No Time Delay, PSC Motor	HSC Variable Time Delay (1.5 to 5 minutes)			-37.5%	15.3%	90%
Cooling Standard 90 second Time Delay PSC motor	HSC Variable Time Delay (1.5 to 5 minutes)			-19.3%	8.1%	5%
Cooling No Time Delay, Efficient Fan Motor	HSC Variable Time Delay (1.5 to 5 minutes)			-37.5%	15.3%	3%
Cooling Standard 90 second Time Delay, Efficient Fan Motor	HSC 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

HSC units were installed at homes in California and Nevada to evaluate consumer satisfaction. Consumers provided the following feedback after using the HSC for two months during the winter heating season from January through March 2012. 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 ft^2. Survey respondents indicated that the HSC 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 HSC 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. HSC Furnace Fan Off Delay (sec)	240 +/- 2	20
6. Does the HSC 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 HSC provide more comfortable cooling on a scale of 1 to 10?	TBD	TBD
8. Does the HSC save energy compared to not using the HSC? (% Yes)	100%	20
9. How satisfied are you with the HSC 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 PG&E service territory 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 HSC units to be installed at one home.

1.6 Pre-Existing Baseline and Device Effective Useful Lives

The pre-existing baseline Device 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 Device is installed inside the HVAC equipment and is dependent on the life of the equipment. The HSC Device is not installed inside the air conditioner, furnace, forced-air unit, or thermostat. Therefore, the HSC EUL is not dependent on the life of the air conditioner, furnace, FAU, or thermostat. The HSC is a small microcontroller device which is installed in the wall behind the thermostat on the low-voltage wires (common wire is needed) coming from the HVAC equipment or at the air handler bus bar or terminal block.

The effective useful lifetime of the HSC is assumed to be 10 years based on the EUL of programmable thermostats (DEER 2008). However, since the HSC is solid-state its lifetime could be longer (i.e. 25 years) as there are no moving parts or parts to wear out and 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 HSC is 1.0 based on the EUL for comprehensive air conditioning Devices.

Section 2. Engineering Calculations

The engineering calculations for annual natural gas and electricity savings and peak demand reduction are provided 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 PG&E 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 PGE 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**.

Eq. 12 $UEC_{cool\ vent} = UEC_{RAC\ vent} – UEC_{RGF\ vent}$

Where,

$UEC_{cool\ vent}$ = baseline cooling electric ventilation exclusive of heating (kWh/year),
$UEC_{RAC\ vent}$ = baseline electric ventilation for residential air conditioning including cooling and heating (i.e., furnace) from DEER 2008a (kWh/year), and
$UEC_{RGF\ vent}$ = 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**.

Eq. 13 $ES_{HSC\ heat} = UEC_{RAC\ heat} \times \overline{S_{heat}}$

Where,

$ES_{HSC\ heat}$ = energy savings for the HSC Device for space heating (therm/year),
$UEC_{RAC\ heat}$ = baseline space heating from DEER 2008a (therm/year), and
$\overline{S_{heat}}$ = weighted average space heating energy savings associated with the HSC 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.

Eq. 14 $ES_{HSC\ cool} = [UEC_{RAC\ cool} \times \overline{S_{cool}}] + [UEC_{RAC\ vent} \times (\overline{S_{cool}} + \overline{S_{RAC\ vent}})] + [UEC_{RGF\ vent} \times \overline{S_{RGF\ vent}}]$

Where,

$ES_{HSC\ cool}$ = energy savings for the HSC Device for space cooling (kWh/year),
$UEC_{RAC\ cool}$ = baseline space cooling from DEER 2008a (kWh/year),
$\overline{S_{cool}}$ = weighted average space cooling electric energy savings associated with the HSC based on field and laboratory tests (%),
$\overline{S_{RAC\ vent}}$ = weighted average RAC ventilation savings associated with the HSC based on field and laboratory tests (%), and
$\overline{S_{RGF\ vent}}$ = weighted average RGF ventilation savings associated with the HSC 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**.

Eq. 15 $PDS_{HSC} = DF \times \{[UPD_{RAC\ cool} \times \overline{S_{cool}}] + [UPD_{RAC\ vent} \times (\overline{S_{cool}} + \overline{S_{RAC\ vent}})]\}$

Where,

PDS_{HSC} = peak demand savings for the HSC Device (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),
$UPD_{RAC\ cool}$ = baseline space cooling peak demand from DEER 2008a (kW), and
$UPD_{RAC\ vent}$ = 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.

Eq. 16 $ES_{HSC\ heat} = UEC_{heat} \times \overline{S_{heat}} \times ECU$

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**.

Eq. 17

$$ES_{\mathrm{HSC\ cool}} = \left\{[\mathrm{UEC}_{\mathrm{cool}} \times \overline{S_{cool}}\,] + [\mathrm{UEC}_{\mathrm{vent}} \times (\overline{S_{cool}} + \overline{S_{RAC\ vent}}\,)] + [\mathrm{UEC}_{\mathrm{vent}} \times \overline{S_{RGF\ vent}}\,]\right\} \times \mathrm{ECU}$$

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**.

Eq. 18

$$PDS_{\mathrm{HSC}} = \left\{\mathrm{DF} \times \left\{[\mathrm{UPD}_{\mathrm{RAC\ cool}} \times \overline{S_{cool}}\,] + [\mathrm{UPD}_{\mathrm{RAC\ vent}} \times (\overline{S_{cool}} + \overline{S_{RAC\ vent}}\,)]\right\}\right\} \times \mathrm{ECU}$$

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