Smart Efficient Fan Controller with Fault Detection Diagnostics

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Abstract

Heating, Ventilating, Air Conditioning (HVAC) consumption in the US accounts for 33% of average summer peak-day electricity loads, 13% of total electricity use, and 44% of total natural gas use. Research studies indicate that most existing residential HVAC systems are oversized and improperly installed causing short cycling and reduced efficiency. Furthermore, most systems have no fan-off delay or short delays leaving significant unrecovered energy in the system at the end of each cycle. This paper describes a patented Smart Efficient Fan Controller® (EFC®) that provides longer variable fan-off delays to improve cooling and heating efficiency and Fault Detection Diagnostics (FDD) to adjust delays based on low cooling or heating capacity. Patented Smart EFC® algorithms can be licensed and deployed on smart communicating thermostats and fans to increase savings. Tests of the Smart EFC® were performed in the field and at a third-party ISO-certified laboratory used by manufacturers and USDOE to test HVAC equipment for compliance with Federal efficiency standards. Based on field and laboratory tests, the Smart EFC® cooling savings are 11.3 ± 2.7%, gas furnace heating savings are 15.7 ± 1.7%, heat pump heating savings are 9.7 ± 1.6%, and hydronic heating savings are 17.9 ± 1.6%. California uses approximately 0.74 quadrillion Btu (quads) or 0.79 exajoules (EJ) per year for space cooling and heating. Assuming the Smart EFC® can save 11.3% on cooling and 14.7% on heating, the estimated potential annual energy savings are 0.096 quadrillion Btu (quads) or 0.1 exajoules (EJ) or 4.1% of the total estimated annual energy use in California of 2.4 quads or 2.53 EJ.

Introduction

Residential and commercial heating, ventilating, and air conditioning (HVAC) consumption in the United States accounts for 30% of average summer peak-day electricity loads, 13% of total electricity use, and 44% of total natural gas use [1]. A 2002 study published by the Hewlett Foundation indicates that improving HVAC cooling and heating efficiency represents one of the largest economically achievable opportunities for energy efficiency and peak demand savings [2]. Market research data indicates that about 77% of existing air conditioners in the United States have no fan-off delay and 23% have fixed fan-off delays ranging from 30 to 90 seconds [12]. Direct Expansion (DX) vapor-compression refrigerant-based Air Conditioning (AC) systems with no fan-off delay or fixed fan-off delays leave water and unrecovered evaporative cooling energy on the evaporator coil at the end of each cycle. Field studies indicate that it takes about 15 to 30 minutes for water left on the coil to flow down the condensate drain or evaporate [12]. Gas furnace, heat pump, and hydronic heating systems in the US operate with fixed fan-off delays of zero to 120 seconds, which leaves unrecovered heat in the Heat Exchanger (HX). For DX cooling systems, the Smart Efficient Fan Controller® (EFC®) recovers latent energy from the evaporator coil by providing an extended variable fan-off delay after the AC compressor turns off to evaporatively cool the conditioned space, satisfy the cooling thermostat setpoint longer and lengthen the off cycle.[1] For heating systems, the Smart EFC® provides an extended variable fan-off delay after the heating system turns off to overshoot the thermostat setpoint and lengthen the off cycle. For gas furnace heating systems, the EFC® can operate the fan at a higher speed to satisfy the thermostat sooner.

This paper provides field and laboratory test results of a patented Smart EFC® installed on residential split and packaged HVAC systems with DX cooling and gas furnace, heat pump, or forced-air hydronic hot water heating [7].[2] The Smart EFC algorithms can be deployed on smart communicating

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[1] Latent energy 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.

[2] US Patent 8763920C1, US Patent 9328933, US Patent 9500386. US Patent 9671125, US Trademark Efficient Fan Controller® Reg. No. 5,163,211 (First Use 03-01-2012), EFC® Reg. No. 5,198,335 (First Use 03-01-2012)

thermostats and smart fans to improve the efficiency of these products. The Smart EFC® is a hybrid evaporative cooling and heating technology that monitors the duration of the cooling or heating cycle and provides a variable fan-off delay based on HVAC system type, mode of operation, and the duration of the cooling and heating cycle including both the on and the off cycle (hereafter "on/off cycle"). The Smart EFC® includes Fault Detection Diagnostic (FDD) algorithms to increase thermal comfort and heating and cooling savings by dynamically adjusting the variable fan-off delay based on the performance of the system and presence of faults or severe weather conditions that can impact cooling or heating capacity and the duration of on/off cycle. For gas furnace forced air units enabled with the fan-on control set to high speed, the Smart EFC® will control the fan from low- or medium-speed to a high fan after the heat exchanger reaches operating temperature to satisfy the heating thermostat setpoint sooner and reduce furnace operation.

Field tests were performed on two DX AC gas furnace split-systems with (hereafter units #1 and #2) at a single-family residential building located in Reno, Nevada. **Table 1** provides a description of units #1 and #2. Laboratory tests were also performed on one DX AC gas furnace split-system unit #3, one DX AC gas furnace packaged unit #4, one DX Heat Pump (HP) split-system unit #5, and one DX AC Hydronic (HYD) heating split-system unit #6. **Table 2** provides a description of laboratory test units #3, #4, #5, and #6. The laboratory equipment was set up in two chambers to simulate indoor and outdoor conditions per ANSI/AHRI 210/240 [3]. Test conditions differ from those used to rate cooling and heating systems to match typical installations in California.[3]

Table 1: Description of Field Test Units #1 and #2

Description	**Unit #1: 3.5-ton[4] Split AC Gas Furnace**	**Unit #2: 5-ton Split AC Gas Furnace**
Indoor AC model	C23-41(FC)	RCF6024STAMCA
Rated SEER/EER	10/8	14/11.7
Rated heating efficiency	80% AFUE	80% AFUE
HX/Coil	AC/Gas HX	AC/Gas HX
Rated total and sensible cooling capacity, airflow, & static pressure	40,600 Btu/hr (11.9 kW) total and 27,608 Btu/hr (8.09 kW) sensible, 1200 cfm (566.34 lps) at 0.5 IWC (124.54 Pa)	58,000 Btu/hr (17.0 kW) total and 41,500 Btu/hr (12.16 kW) sensible, 1188 scfm (560.67 lps) at 0.5 IWC (124.54 Pa)
Outdoor AC model	HS23-461-2P	RA1460AJ1NA
Fan speed	Low, Med, High	Low, Med, High
Refrigerant charge	R22 117 ounces (3.32 kg)	R410A 162 Ounces (4.593 kg)
Duct leakage @ 25 Pa	21%	21% and 6%
Heating model	GUA120A020AIN	R801SA125524MSA
Rated heating capacity, airflow, & static pressure	100,000 Btu/hr (29.3 kW) 1012 scfm (477.61 lps) at 0.5 IWC (127.3 Pa)	100,000 Btu/hr (29.3 kW) and 1080 scfm (509.7 lps) @ 0.8 IWC (201.8 Pa)
Fan-off delay cooling	0 seconds cooling	0 seconds cooling
Fan-off delay heating	120 seconds heating	30 and 45 seconds heating

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[3] Cooling tests were performed at Outdoor Air Temperature (OAT) Dry-Bulb (DB) 95°F (35°C) and Indoor Air Temperature (IAT) DB 75°F (23.9°C) and Wet Bulb (WB) 62°F (16.7°C). Gas heating tests were performed at OAT DB 47°F (8.3°C) and IAT DB 72°F (22.2°C) and WB 53°F (11.7°C). Heat pump tests were performed at following OAT DB 17°F (-8.3°C), 35°F (1.7°C), 47°F (8.3°C), and 62°F (16.7°C) and IAT DB 70°F (21.1°C) and WB 55°F (12.8°C). Hydronic heating tests were performed at OAT DB 47°F (8.3°C) with Hot Water Temperature (HWT) 130°F (54.4°C) and 140°F (60°C) and IAT DB 70°F (21.1°C) DB and WB 55°F (12.8°C). ANSI/AHRI 210/240 Standard EER_A test conditions are OAT DB 95°F (35°C) and IAT DB 80°F (26.67°C), WB 67°F (19.44°C), EER_B test conditions are OAT DB 82°F (45.6°C) and IAT DB 80°F (26.67°C), WB 67°F (19.44°C). SEER test conditions are: OAT DB 82°F (45.6°C), IAT DB 80°F (44.2°C), and WB 57°F (31.7°C).

[4] One ton of cooling is defined as heat energy removed from one short ton of water (2,000 pounds or 907.1847 kg) to produce one ton of ice at 32°F (0°C) in 24 hours. Energy required for phase change of liquid water at 32°F (0°C) into solid ice at 32°F is referred to as heat of fusion equal to 144 Btu/lb times 2,000 lbs of water or 288,000 Btu of energy over 24 hour period or 12,000 Btu/hour to make one ton of ice in one day. British thermal unit (Btu) is heat required to raise temperature of one pound (0.454 kg) of water one °F (0.556°C). Btu is equivalent to 1055.06 joules or 251.997 calories.

Table 2: Description of Laboratory Test Units #3, #4, #, 5, and #6

Description	**Unit #3: 3-ton Split AC Gas Furnace**	**Unit #4: 3-ton Pkg AC Gas Furnace**	**Unit #5: 1.5-ton Split Heat Pump**	**Unit #6: 1.5-ton Split AC HYD Heat**
Indoor AC model	CNRHP3617ATA	GPG1336070M41BA	ARUF25B14AA	19CDX-HW
Rated SEER/EER	13/11.2	13/11	14	13/11.7
Rated heating efficiency	80% AFUE	80% AFUE	3.76 COP	78% Efficiency
AC/HX Coil	DX AC/Gas HX	DX AC/Gas HX	DX AC/HP	DX AC/HYD Coil
Rated total and sensible cooling capacity, airflow, & static pressure	33,800 Btu/hr (9.9 kW) total, 25,660 Btu/hr (7.52 kW) sensible, 1200 cfm (566.34 lps) at 0.5 IWC (124.54 Pa)	35800 Btu/hr (9.9 kW) total, 28547 Btu/hr (8.37 kW) sensible, 1188 cfm (560.67 lps) at 0.5 IWC (124.54 Pa)	17,300 Btu/hr (5.07 kW) total and 12,283 Btu/hr (3.6 kW) sensible, 525 cfm (247.77 lps) at 0.4 IWC (101.8 Pa)	17,500 Btu/hr (5.13 kW) total and 12,425 Btu/hr (3.64 kW) sensible, 550 scfm (259.57 lps) at 0.3 IWC (74.72 Pa)
Outdoor AC model	24ABS336A300	GPG1336070M41BA	GSZ140181KD	MHH-19-410
Fan speed and RPM	Low 1050, Med 1080, High 1100	Low 850, Medium 980, High 1040	1043 RPM	1550 RPM
Refrigerant charge	R22 86.4 oz. (2.5 kg)	R410A 70 oz (2 kg)	R22 92 oz (2.64 kg)	R410A 102 oz (3 kg)
Duct leakage @ 25 Pa	6%	6%	6%	6%
Heating model	58STA070-12	GPG1336070M41BA	ARUF25B14AA	R801SA125524MSA
Rated heating capacity, airflow, & static pressure	54,000 Btu/hr (15.83 kW) 1140 scfm (538.02 lps) at 0.5 IWC (127.3 Pa)	55,200 Btu/hr (16.18 kW) 1173 scfm (553.59 lps) at 0.5 IWC (127.3 Pa)	18,000 Btu/hr (5.28 kW) 555 scfm (261.93 lps) at 0.47 IWC (119.7 Pa)	18,000 Btu/hr (5.28 kW) and 550 scfm (259.57 lps) @ 0.4 IWC (101.8 Pa)
Fan-off delay cooling	0 seconds cooling	0 seconds cooling	0 seconds cooling	0 seconds cooling
Fan-off delay heating	90 seconds heating	0 seconds heating	0 seconds heating	0 seconds heating

Test Equipment Laboratory Setup

Tests were performed at Intertek®, an AHRI-certified laboratory, located in the United States. The laboratory is used by manufacturers to certify air conditioners and heat pumps for AHRI equipment efficiency testing for the U.S. Department of Energy (DOE) compliance and enforcement program to meet energy conservation standards required by the Energy Policy and Conservation Act of 1975 (as amended) [8]. The test facility consists of climate-controlled indoor and outdoor chambers where ducts, evaporator, condenser, furnace or hydronic heating equipment and forced air units are located. The HVAC systems and standard test equipment were assembled and installed in the test chambers by laboratory technicians. The AHRI 210/240 cooling verification tests were performed according to ANSI/AHRI 2008 Standard for Performance Rating of Unitary Air-Conditioning and Air-Source Heat Pump Equipment Standard 210/240 and ANSI/ASHRAE Standard 37-2009 [2, 4]. Thermal Efficiency verification tests were performed according to ANSI Z21.47-5th Edition 2006/CSA 2.3-5th Edition 2006 [9]. The psychrometric room meets ASHRAE 41.2-1987 standard specifications [5]. Calibration for all equipment at the laboratory test this facility is conducted in accordance with ISO 17025 requirements by an ILAC accredited calibration provider. Gas furnace heating equipment performance and AFUE tests were performed per ANSI Z21.47 specifications.

The DX cooling laboratory tests were performed under non-steady state field conditions to measure base cooling energy use, sensible capacity, and efficiency with no fan-off delay or fixed 60-second delay for the 3-ton packaged unit #4 or no delay and 90-second delay for the 3-ton split-system unit #3. Non-steady state cooling tests were also performed with the Smart EFC® providing a variable fan-off delay based on the duration of the cooling on/off cycle. Gas furnace heating lab tests were performed to measure base heating energy use, capacity, and efficiency with fixed 90-second and 120-second fan-off delays for units #3 and #4. For unit #3, non-steady state heating tests were performed with the Smart EFC® providing increased fan speed from low-to-high or medium-to-high after 4 minutes of furnace operation and variable fan-off delay based on the duration of the heating on/off cycle. Lab tests of the 1.5-ton split-system heat pump unit #5 and 1.5-ton split-system hydronic unit #6 were performed under non-steady state conditions to measure base energy use, sensible cooling or heating capacity and efficiency with no delay or 65-second fixed delay for unit #5 or 60 seconds for unit #6 after the cooling or heating system turned off. For unit #5 and #6, non-steady state cooling and heating tests were also performed with the Smart EFC® providing a variable fan-off delay based on the cooling or heating on/off cycle.

Cooling Test Data and Energy Savings Analysis

The Intertek® laboratory performed 27 split-system and packaged unit cooling tests and 24 heat pump cooling tests with and without the Smart EFC®. Tests were performed at 75°F (29.3°C) return air DB and 62°F (16.7°C) return air WB temperatures and 95°F (35°C) DB outdoor air temperature. Tests measured the additional sensible cooling capacity provided by the Smart EFC® extended variable fan-off delay compared to the baseline system with no delay or a fixed fan-off delay. The laboratory tests measured energy input and sensible cooling capacity output (Btu or Joules) with and without the EFC® for compressor operating times from 2 to 50 minutes. The laboratory tests also measured total sensible cooling capacity for 60 minutes at the same conditions.

Table 3 and **Figures 1** and **2** provide the following cooling tests for unit #3: 1) no delay wet coil base, 2) 90-second delay dry coil base, 3) no delay dry coil base, and 4) Smart EFC® variable delay.[5] Cooling savings vary from 6.1 to 32% compared to no delay base, and 3.8 to 16.6% compared to 90-second delay base. Average Smart EFC® cooling savings are 16.1% versus no delay base and 10.1% versus 90-second delay base.

Table 3: Intertek® Cooling Tests Unit #3 – Smart EFC® v. No-Delay and 90-Second Delay

Compressor on time (minutes)	**5**	**5**	**10**	**15**	**30**	**Ave.**
Base no delay wet coil tests	**201**	**202**	**203**	**204**	**205**	
No delay sensible cooling (Btu) [a]	1,006	1,396	3,264	5,381	10,995	4,409
No delay AC energy use (kWh) [b]	0.265	0.271	0.544	0.828	1.673	0.717
No delay sensible efficiency (EER*) [c=a/b/1000]	3.79	5.14	6.00	6.49	6.57	5.60
Base 90-second delay dry coil tests						
90-sec. delay sensible cooling (Btu) [d]	1,283	1,553	3,465	5,598	11,285	4,637
90-sec. delay AC energy use (kWh) [e]	0.276	0.281	0.553	0.836	1.677	0.725
90-sec delay sensible efficiency (EER*) [f=d/e/1000]	4.65	5.52	6.27	6.69	6.73	5.97
90-sec delay fan energy (kWh) [g]	0.011	0.011	0.011	0.011	0.011	0.011
Base no delay dry coil (>30 min between tests)						
No delay dry coil sensible cooling (Btu) [h]	857	1,109	2,965	5,094	10,791	4,163
No delay dry coil energy use (kWh) [i]	0.264	0.270	0.541	0.825	1.666	0.713
No delay dry coil efficiency (EER*) [j=h/i/1000]	3.24	4.11	5.48	6.17	6.48	5.10
EFC® tests	**1**	**2**	**3**	**4**	**5**	
EFC® sensible cooling (Btu) [k]	1,602	1,893	3,837	6,186	11,864	5,076
EFC® AC energy use (kWh) [l]	0.287	0.293	0.564	0.855	1.696	0.739
EFC® sensible efficiency (EER*) [m=k/l/1000]	5.58	6.47	6.80	7.23	7.00	6.62
EFC® fan energy vs No delay (kWh) [n]	0.023	0.023	0.023	0.030	0.030	0.026
EFC® savings v. no delay wet coil base [o=1-c/m]	**32%**	**20.5%**	**11.9%**	**10.2%**	**6.1%**	**16.1%**
EFC® fan energy vs. 90-sec. (kWh) [p=n-g]	0.011	0.011	0.011	0.019	0.019	0.014
EFC® savings v. 90-sec. base [q=1-f/m]	**16.6%**	**14.7%**	**7.8%**	**7.5%**	**3.8%**	**10.1%**
EFC® AC-only dry coil v. no-delay wet coil [r=1-c/j]	**-17.0%**	**-25.2%**	**-9.5%**	**-5.2%**	**-1.4%**	**-11.7%**

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[5] AC systems operating with no fan-off delay leave water on the evaporator coil for successive AC cycles, if the AC off cycle time is less than 15 to 30 minutes (hereafter referred to as initial “wet coil” conditions). AC systems with fixed 30- to 90-second fan-off delays leave less water on the coil for successive AC cycles (hereafter referred to as initial “dry coil” conditions). If the AC off cycle is greater than 30 minutes, then the AC system will generally operate with initial dry coil conditions with the exception of high humidity conditions where the AC system has not been previously operating.

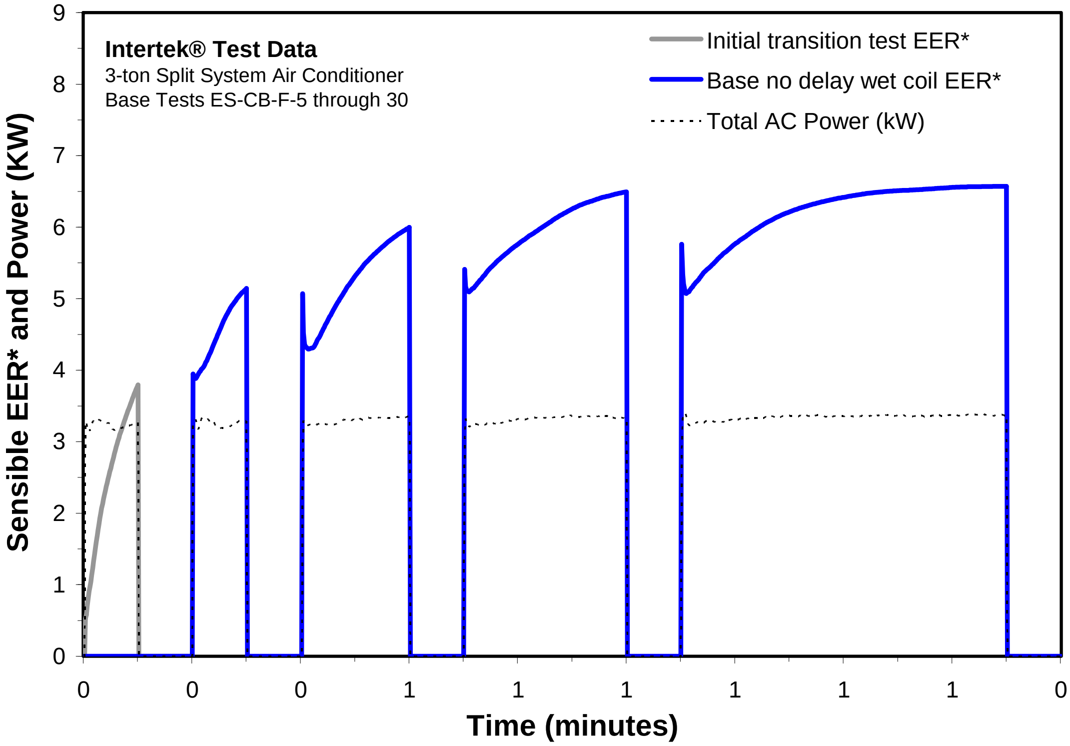

Figure 1: Intertek® Cooling Tests 3-ton Unit #3 - No Delay Wet Coil Base

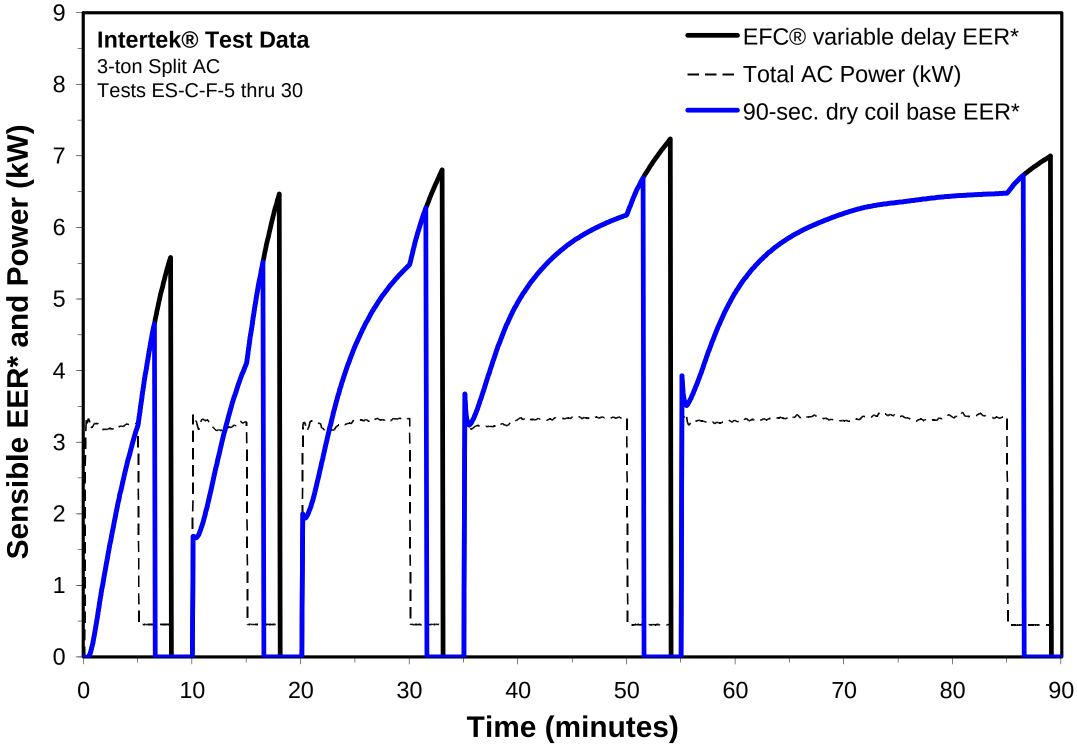

Figure 2: Intertek® Cooling Tests 3-ton Unit #3 – Smart EFC® v. 90-sec. Dry Coil Base Delay

The bottom row of **Table 3** provides negative savings of -1.4% to -25.2% (row r) for EFC® AC-only compared to no-delay wet coil base for successive tests with off cycles less than 30 minutes. The negative AC-only savings indicate that AC systems with the Smart EFC® deliver less sensible cooling and require slightly more compressor power to satisfy the cooling thermostat compared to AC systems with no fan-off delay for successive tests with off cycles less than 30 minutes. The EFC® AC-only negative savings are caused by two phenomena: 1) evaporating water from the evaporator coil to the conditioned space at the end of each AC-only cycle increases humidity in the conditioned space and reduces Sensible Heat Ratio (SHR); and 2) successive Smart EFC® tests start with an initial dry coil which reduces sensible cooling at the beginning of the AC-only cycle. The negative EER* impact is -1.4% for the 30-minute cycle and approaches zero for cycles of 60-minutes or longer.

Table 4 and **Figure 3** provide field tests of the 5-ton AC unit #2 with the Smart EFC® FDD. Tests were performed at average OAT of 93.2 +/- 0.06°F and 21% total system duct leakage @ 25 Pascal. **Table 4** shows the Smart EFC® providing normalized cooling savings ranging from 9.7 to 24.4% (row p) compared to no-delay wet coil base tests. Normalized savings are adjusted based on the EFC® AC-only sensible capacity (row i) required to match base no delay wet coil sensible capacity (row b) and Smart EFC® normalized energy (row n) to match base no delay wet coil normalized capacity. The Smart EFC® EER* negative impact is -4.4% to +1.7% (row k) for EFC® AC-only compared to no-delay wet coil base for successive tests. The +1.7% indicates an initial dry coil at 30 minutes off time. The average difference between field and laboratory test results is -0.2 +/- 1.2% based on **Equation 2** (row q) indicating that the Smart EFC® FDD performs as good or better than the EFC® product tested at Intertek®.

Table 4: Field Tests 5-ton Unit #2 – Smart EFC® FDD v. No-Delay Base with 21% Duct Leakage

Compressor on time (minutes)	**6**	**6**	**10**	**15**	**30**	**Ave.**
Base no delay wet coil tests	**11**	**12**	**13**	**14**	**15**	
Base PLR	0.085	0.086	0.150	0.229	0.482	0.207
Base sensible cooling (Btu) [a]	2,626	2,654	4,617	7,051	14,810	6,352
Base AC energy use (kWh) [b]	0.459	0.458	0.774	1.168	2.368	1.05
Base sensible efficiency (EER*) [c=a/b/1000]	5.72	5.80	5.97	6.04	6.25	5.96
Smart EFC® FDD tests	**16**	**17**	**18**	**19**	**20**	
EFC® FDD sensible cooling (Btu) [d]	3,824	3,812	5,904	8,544	16,566	7,730
EFC® FDD AC energy use (kWh) [e]	0.497	0.497	0.806	1.235	2.392	1.09
EFC® FDD sensible efficiency (EER*) [f=d/e/1000]	7.69	7.67	7.32	6.92	6.93	7.31
EFC® FDD preliminary savings v. no delay [g=1-c/f]	25.6%	24.4%	18.6%	12.7%	9.7%	18.2%
EFC® extra fan energy (kWh) [h]	0.045	0.045	0.053	0.057	0.062	0.052
EFC® AC-only sensible cooling w/o delay [i]	2,475	2,508	4,465	7,017	14,816	6,256
EFC® AC-only energy (kWh) [j=e-h]	0.452	0.451	0.753	1.178	2.330	1.033
EFC® AC-only sensible EER* (Btu/W) [k=i/j/1000]	5.48	5.56	5.93	5.96	6.36	5.86
EFC® AC on cycle EWV impact on EER* [k]	**-**	**-4.4%**	**-0.7%**	**-1.4%**	**1.7%**	**-1.2%**
EFC® extra cooling to match base [l=a-i]	150	146	152	34	-6	95
EFC® normalized sensible capacity (Btu) [m=d-i+b]	3,974	3,958	6,057	8,578	16,560	7,825
EFC® normalized energy (kWh) [n=j*b/i+h]	0.525	0.523	0.832	1.240	2.391	1.102
EFC® normalized sensible EER* (Btu) [o=m/n/1000]	7.57	7.56	7.28	6.91	6.93	7.25
EFC® cooling savings [p=1-d/g]	**24.4%**	**23.3%**	**18.1%**	**12.7%**	**9.7%**	**17.6%**
Lab test **Eq. 2** savings [q = 0.0468*PLR$^{-0.6928}$]	25.7%	25.5%	17.4%	13.0%	7.8%	17.9%
Field minus lab test **Eq. 2** difference [r=p-q]	-1.3%	-2.2%	0.7%	-0.3%	1.9%	-0.2%

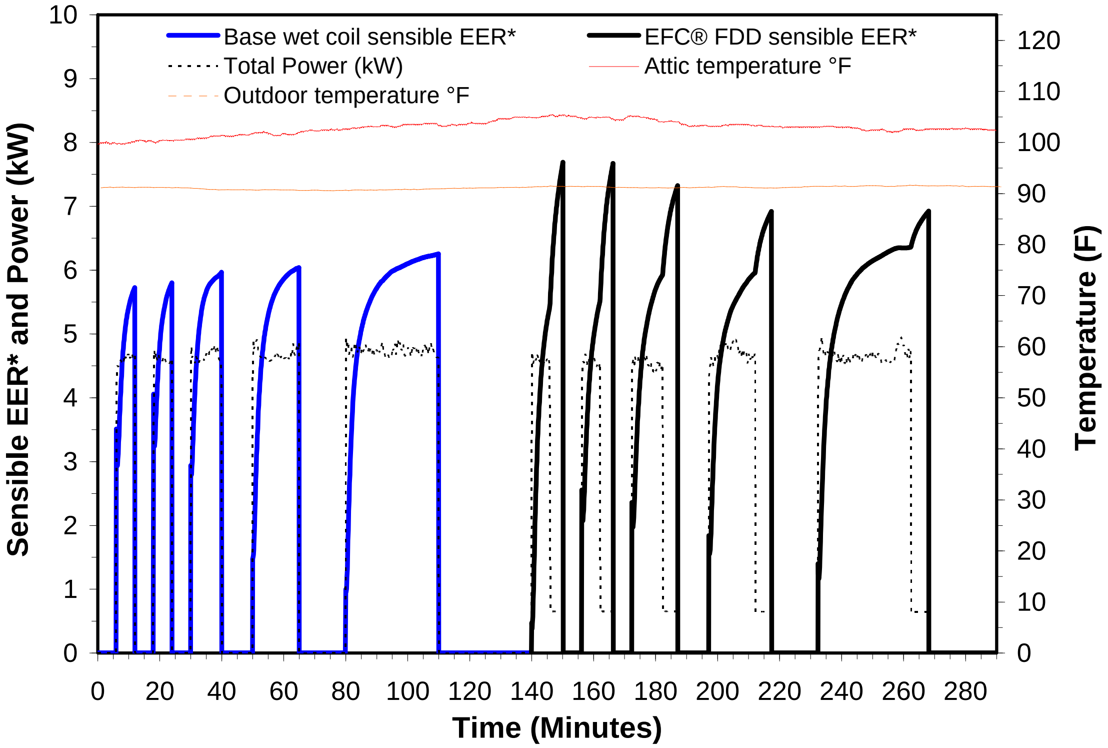

Figure 3: Field Tests 5-ton Unit #2 – Smart EFC® FDD v. No-Delay Base with 21% Duct Leakage

The ratio of sensible cooling capacity for each test divided by the total sensible cooling capacity for 60 minute tests is defined as the cooling Part Load Ratio (PLR) as shown in **Equation 1**. The cooling PLR is used to normalize the cooling savings for each group of tests.[6]

Equation 1 $$PLR_c = \frac{Q_{c_o}}{Q_{c_r}}$$

Where, PLR_c = cooling Part Load Ratio,

Q_{c_o} = delivered sensible cooling capacity measured for each test (Btu or Joules), and

Q_{c_r} = total sensible capacity measured at same conditions for 60 minutes (Btu or Joules).

Figure 4 provides test data of the Smart EFC® cooling energy savings versus cooling PLR for the dry coil base and wet coil base. **Figure 4** provides three regression equations for calculating EFC® cooling energy savings. **Eq. 2** is used to calculate EFC® cooling savings versus the dry coil base.

Equation 2 $$\Delta\eta_c = 0.0468\,(PLR_c)^{-0.6928}$$

Where, $\Delta\eta_c$ = Smart EFC® cooling savings versus dry coil base.

Eq. 3 is used to calculate EFC® cooling energy savings versus the no-delay wet coil base.

Equation 3 $$\Delta\eta_c = 0.0418\,(PLR_c)^{-0.5711}$$

Where, $\Delta\eta_c$ = EFC® cooling savings versus wet coil base.

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[6] Weighted average test results are based on tests performed at approximately the same PLR where the baseline is either zero or a fixed fan-off time delay for the same AC unit.

The relationship between the Smart EFC® impact on AC-only EER* and PLR compared to initial wet coil base conditions is provided in the following power function regression equation.

Equation 4 $\Delta\eta_a = -0.009\left(PLR_s\right)^{-1.095}$

Where, $\Delta\eta_a$ = EFC® adjustment for AC-only energy savings compared to no-delay wet coil based on Intertek® test data provided in the bottom of **Table 3** (row r).

Eq. 4 is used in the DOE2 post processor to adjust Smart EFC® savings in subsequent time steps to account for: 1) water evaporated from the coil to the conditioned space at the end of each AC-only cycle which increases humidity in the conditioned space and reduces the Sensible Heat Ratio (SHR); and 2) initial dry coil conditions during successive Smart EFC® tests which reduce sensible cooling at the beginning of the AC-only cycle. The mass and energy balance associated with these two phenomena are determined using the above regression equations in the DOE2 post processor to adjust EFC® savings in subsequent time steps based on PLR.

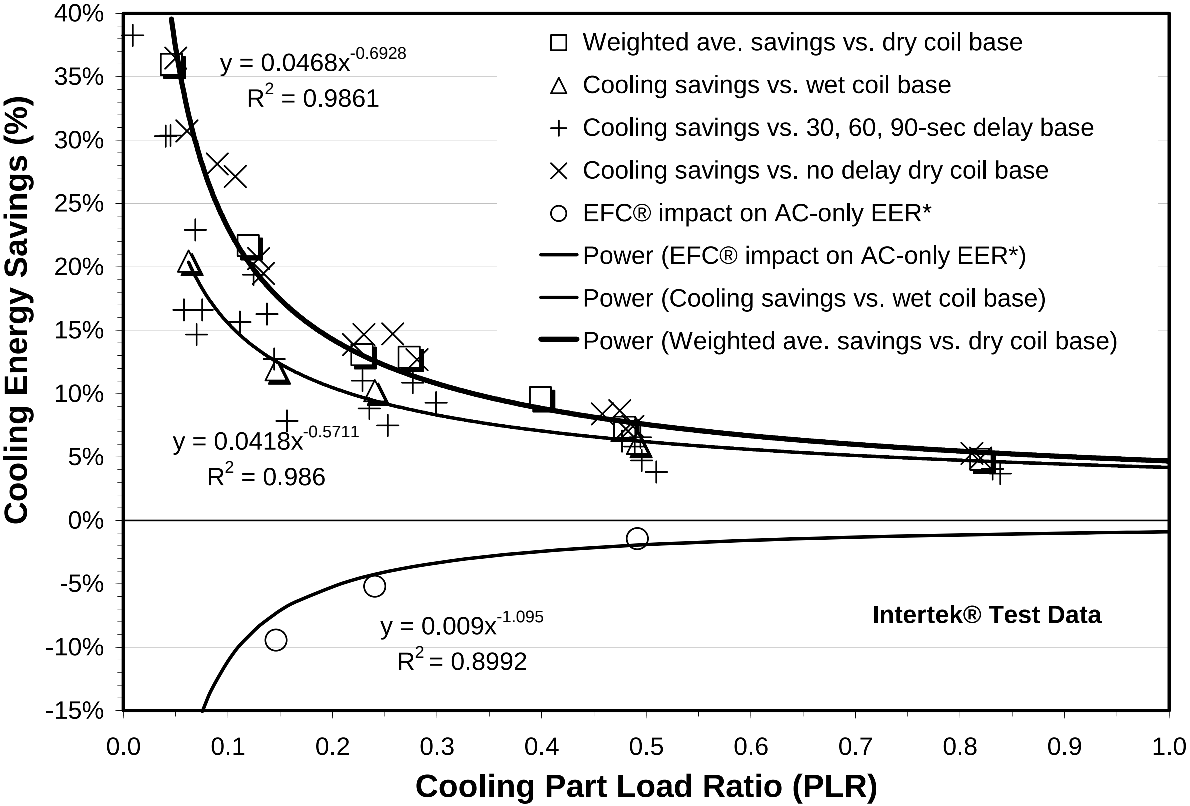

Figure 4: Cooling Energy Savings versus Part Load Ratio for Smart EFC®

Laboratory and field tests demonstrate that the Smart EFC® improves energy efficiency by delivering more cooling capacity and providing longer off times. The EFC® also prevents evaporator coil icing by evaporating water from the coil at the end of each AC cycle. This prevents ice formation when the evaporator coil temperature is below freezing which can be caused by low airflow, dirty air filters, low refrigerant charge, low cooling setpoint, and refrigerant restrictions. Coil icing can reduce evaporator airflow by 17 to 37%, reduce efficiency by 4% to 12%, and cause continuous AC operation [12].

Data from a sample of 5,582 AC units in California showing 77% of air conditioners with zero base fan-off delay, 11.9% with 30-second base delay, 7.8% with 60-second base delay, and 3.3% with 90-second base delay [7]. These values are used to determine weighted average cooling savings based on field and laboratory tests of the six AC units and different base fan-off delays.

Building energy simulation software, post processors, and the Database for Energy Efficiency Resources (DEER) residential single-family, multi-family, and mobile home building prototypes were used to evaluate the baseline HVAC energy use and peak demand for each building prototype and 16 California climate zones [11]. The average annual EFC® cooling energy savings are 11.3 ± 2.7% and the weighted average cooling PLR is 0.21 based on building simulations and housing stock weights for each climate zone from California housing stock data and US Census data [7, 10, 13].

Gas Furnace Heating Test Data and Energy Savings Analysis

The laboratory performed 48 split- and packaged gas furnace heating tests (24 baseline tests and 24 measure tests). The tests were performed at 72°F (22.2 C) return air DB and 53°F (11.7 C) return air WB temperatures and 47°F (8.3 C) DB outdoor air temperature. The laboratory tests measured the additional heating capacity provided by the EFC® using an extended fan-off time delay which varies as a function of the heat-source operational time compared to the baseline system with no time delay or a fixed fan-off time delay. The laboratory tests measured heating capacity output (Btu or Joules) with and without the Smart EFC® for furnace operational times varying from 5 to 30 minutes. The laboratory tests also measured total heating capacity for 60 minutes at the same conditions.

Table 5 provides the following Intertek® gas furnace heating tests for the 3-ton packaged unit #4: 1) 90-second base, 2) 120-second delay base, and 3) Smart EFC® FDD variable delay. Heating energy savings vary from 5.6 to 38.3% with 90-second delay base, and savings vary from 4.2 to 24.6% for 120-second delay base. Average EFC® FDD heating energy savings are 20.3% versus the 90-second delay base and 14.2% versus the 120-second delay base.

The ratio of heating capacity for each test divided by the total heating capacity for 60 minute tests is defined as the heating Part Load Ratio (PLR) as shown in **Equation 6**. The heating PLR is used to normalize the gas furnace heating energy savings for groups of tests.

Equation 6

$$PLR_h = \frac{Q_{h_o}}{Q_{h_r}}$$

Where, PLR_h = heating part load ratio of delivered heating capacity for each test divided by the total heating capacity of the equipment (dimensionless),

Q_{h_o} = delivered heating capacity measured for each test (Btu or Joules), and

Q_{h_r} = total heating capacity measured at same conditions for 60 minutes (Btu or Joules).

Table 5: Intertek® Gas Furnace Heating Tests Unit #4 – EFC® FDD v. 90- and 120-Second Delay

Furnace on time (minutes)	**3**	**7**	**8**	**15**	**30**	**Ave.**
Base 90-sec. delay tests	**109**	**111**	**113**	**115**	**117**	
Base 90-sec. heating energy (Btu) [a]	875	3,461	4,185	9,559	21,619	7,940
Base 90-sec. gas furnace energy use (kWh) [b]	3,026	7,774	8,952	16,081	32,695	13,706
Base 90-sec. heating efficiency (EER*) [c=a/b]	28.9%	44.5%	46.8%	59.4%	66.1%	49.2%
Base 120-second delay tests	**51**	**53**	**55**	**57**	**59**	
120-sec. delay heating energy (Btu) [c]	1,070	3,755	4,485	9,887	21,952	4,637
120-sec. delay gas furnace energy use (kWh) [d]	3,026	7,774	8,952	16,081	32,695	0.725
120-sec delay heating efficiency (EER*) [e=d/e]	35.3%	48.3%	50.1%	61.5%	67.1%	5.97
EFC® gas furnace heating tests	**52**	**54**	**56**	**58**	**60**	
EFC® heating energy (Btu) [f]	1,419	4,564	5,339	10,826	22,907	5,076
EFC® gas furnace energy use (kWh) [g]	3,026	7,774	8,952	16,081	32,695	0.739
EFC® heating efficiency (EER*) [h=f/g]	46.9%	58.7%	59.6%	67.3%	70.1%	6.62
EFC® fan energy vs 90-sec. delay (kWh)	0.011	0.017	0.018	0.018	0.018	0.026
EFC® savings v. 90-sec. delay [j=1-c/h]	**38.3%**	**24.2%**	**21.6%**	**11.7%**	**5.6%**	**20.3%**
EFC® fan energy vs. 120-sec. (kWh)	0.008	0.014	0.014	0.014	0.014	0.014
EFC® savings v. 120-sec. Base [k=1-e/h]	**24.6%**	**17.7%**	**16.0%**	**8.7%**	**4.2%**	**14.2%**

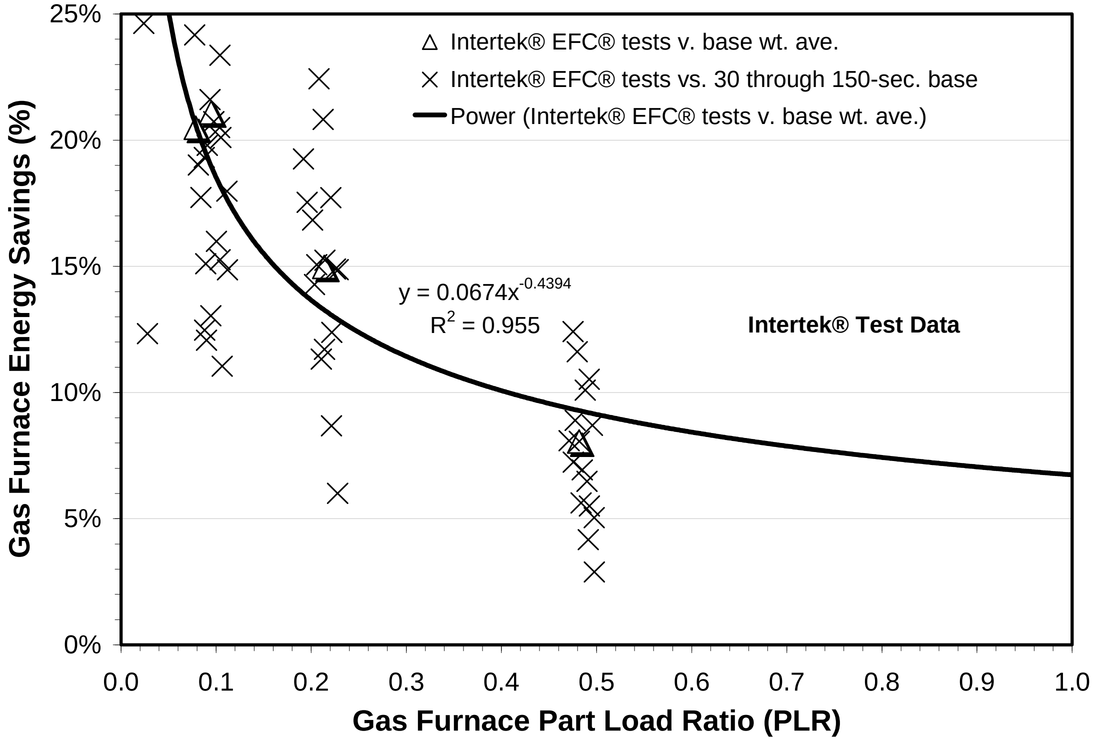

Figure 5: Intertek® Gas Furnace Heating Tests – Smart EFC® Savings versus Part Load Ratio

Laboratory test data of the gas furnace heating energy savings versus PLR are shown in **Figure 5**. Gas furnace heating energy savings are calculated using regression **Equation 7** based on the PLR.

Equation 7 $\Delta\eta_h = 0.0674\ (PLR_h)^{-0.4394}$

Where, $\Delta\eta_h$ = Smart EFC® FDD gas furnace heating savings compared to baseline.

Table 6 and **Figure 6** provide two sets of 10-hour field tests of the gas furnace unit #2 controlled by a thermostat. Each set of tests was performed with 6% duct leakage at 25 Pascal: The base test (black curve) includes a 120-second fixed fan-off delay and the default fan speed provides 1080 cfm (509.7 lps) airflow. The Smart EFC® FDD test includes a variable fan-off delay and approximately 4 minutes after each thermostat call for heating the EFC® energizes the fan relay to High Speed Fan (HSF) which provides 1154 cfm (544.6 lps) airflow.[7] Prior the fan operates at default heating fan speed.

Table 6 (row x) indicates normalized gas savings of 17.9% for the Smart EFC® FDD HSF based on normalized EFC® gas usage of 314,328 Btu (row g) versus base gas usage of 382,982 Btu (row e).[8] Normalized savings based on furnace on time are 18.1% (row d). The Smart EFC® provides longer off times and 15 heating cycles consuming 314,328 (row g) Btu of non-normalized gas usage with average furnace operation of 13.1 minutes and average thermostat temperature of 72.7°F (row s) and 33.7°F delta T (row t). The base has 18 heating cycles with average furnace operation of 12.5 minutes and base thermostat temperature of 72.4F (row p) and 31.5F delta T (row q). The 17.9% normalized gas savings (row x) are 23% greater than the 14.6% calculated savings based on **Eq. 7**

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[7] The furnace factory default fan-off time delay is 90-seconds. The default heating medium fan speed delivers 1080 cfm (509.7 lps) and the High Speed Fan (HSF) normally used for cooling delvers 1154 cfm (544.6 lps). Approximately 93.3% of forced air units operate the fan at high speed when the fan relay is energized either by itself or with the furnace operating simultaneously, and only 6.7% operate the fan at a low speed when the fan relay is energized by itself.

[8] Smart EFC® HSF normalized gas usage of 314,328 Btu is based on non-normalized EFC® gas usage of 336,584 Btu times ratio of 31.5F delta T for base divided by 33.7F delta T for EFC®.

indicating that calculated savings are conservative. The EFC® FDD delivers 19.5% savings (row y) based on 72.3% efficiency (row o) versus 58.2% base efficiency (row k).

Table 6: Gas Furnace Unit #2 10-Hour Tests – Smart EFC® FDD HSF vs. 120-sec. Base Delay

Description	**Row**	**Total**
Base furnace on time (minutes)	a	233.3
EFC® furnace on time (minutes)	b	204.6
EFC® normalized furnace on time (minutes)	c = b*(s/p)	191.0
EFC® normalized savings based on furnace on time (%)	**d=1-(c/a)**	**18.1%**
Base furnace energy input (Btu)	e	382,982
EFC® furnace energy input (Btu)	f	336,585
Normalized base furnace energy input based on delta T (Btu)	g =e*[s/p]	314,238
Base furnace off time (minutes)	h	382.3
EFC® furnace Off Time (minutes)	i	411.0
Base heating (Btu)	j	222,811
Base heating efficiency (%)	k=j/e	58.2%
EFC® heating (Btu)	l	227,093
EFC® heating efficiency (%)	m=l/f	67.5%
EFC® normalized heating (Btu)	n = l*[s/p]	243,243
EFC® Normalized heating Efficiency (%)	o=n/f	72.3%
EFC® additional heating energy (Btu)	p=n-j	20,432
Base outdoor air temp. (°F)	o	40.9
Base indoor air temp. (°F)	p	72.4
Base average outdoor minus indoor air temp. delta T_{BASE} (°F)	q=p-0	31.5
EFC® ave. outdoor air temp. (°F)	r	38.9
EFC® average indoor air temp. (°F)	s	72.7
EFC® average outdoor minus indoor air temp. delta T_{EFC} (°F)	t=s-r	33.7
EFC® furnace savings unadjusted for delta T	**u =1-[f/e]**	**12.1%**
EFC® average Part Load Ratio (PLR)	v	0.183
EFC® heating savings based on Eq. 7 $\Delta\eta_h = 0.0674(PLR_h)^{-0.4394}$	w	14.2%
EFC® normalized heating savings based on delta T (%)	**x=1-[g/e]**	**17.9%**
EFC® normalized heating savings based on efficiency and delta T (%)	**y=1-[k/o]**	**19.5%**

Data from a sample of 5,582 gas furnace units in California indicate 2.6% of gas furnaces with 45-second fan-off delays, 8.3% with 60-second delays, 1.3% with 75-second delays, 57% with 90-second delays, 24% with 120-second delays, and 6.7% with 150-second delays [7]. Data from a sample of 5206 units indicate 93.3% have base high-speed fan control 6.7% do not [7]. Assuming weighting factors of 69.3% for 90-second delay and 30.7% for 120-second delay, the weighted average gas furnace heating savings are 18.4% based on data in **Table 5**. Based on eQuest simulations, the average annual heating PLR values range from 0.11 to 0.2 and the weighted average heating PLR 0.14 [7]. The average annual EFC® heating savings are 15.7 ± 1.7% based **Equation 7** and housing stock weights for each climate zone from California housing data and US Census data [7, 10, 13].

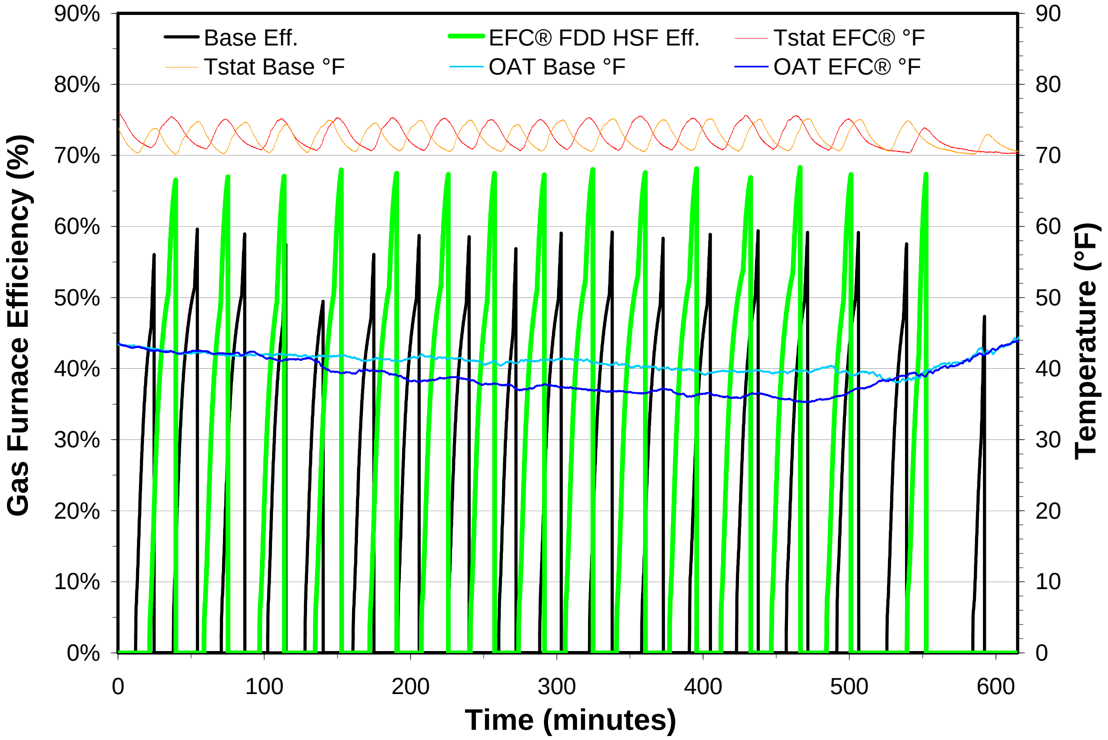

Figure 6: Gas Furnace Unit #2 10-Hour Tests – Smart EFC® FDD HSF vs. 120-sec. Base Delay

Heat Pump Heating Test Data and Energy Savings Analysis

The laboratory performed 48 split-system Heat Pump (HP) heating tests (24 baseline tests and 24 measure tests). The tests were performed at 17°F (-8.3 C), 35°F (1.7 C), 47°F (8.3 C), and 62°F (16.7 C) outdoor temperatures and 70°F (21.1 C) DB and 55°F (12.8 C) WB indoor temperatures. Laboratory tests measured the Smart EFC® additional heating capacity, and also measured total HP heating capacity for 60 minutes at the same conditions.[9]

Table 7 provides the following Intertek® HP heating tests at 47°F (8.3°C) OAT for the 1.5-ton split-system HP unit #5: 1) no delay base, 2) 65-second delay base, and 3) Smart EFC® variable delay. Smart EFC® heating energy savings vary from 3.7 to 71% compared to no delay or 65-second base delay and PLR values ranging from 0.02 to 0.83 based on 48 laboratory tests (not all test data are shown). EFC® heating energy savings vary from 5.1 to 56.7% versus the no delay base, and EFC® savings vary from 3.7 to 30.6% versus the 65-second delay base. Average Smart EFC® HP heating energy savings are 24.7% versus the no delay base and 15.4% versus the 65-second delay base.

The ratio of heating capacity for each test divided by the total heating capacity for 60 minute tests at the same test conditions is defined as the Part Load Ratio (PLR) as shown in **Equation 8**. The PLR is used to normalize HP heating energy savings for each group of tests. Laboratory test data of the EFC® heating energy savings versus PLR are shown in **Figure 7**. EFC® FDD HP heating energy savings are calculated using regression **Eq. 8** based on the PLR (from **Figure 7**).

Equation 8 $\Delta\eta_h = 0.0526\left(PLR_h\right)^{-0.4499}$

Where, $\Delta\eta_h$ = Smart EFC® heat pump heating savings compared to base.

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[9] Heat pump input Btu values are based on measured kWh times 3412 Btu/h.

Table 7: Intertek® Heat Pump Heating Tests Unit #5 – Smart EFC® v. 0- and 65-Second Delay

Heat pump on time (minutes)	**2**	**5**	**10**	**20**	**30**	**50**	**Ave.**
Base 0-sec. delay tests	**125**	**126**	**127**	**128**	**129**	**130**	
Base no delay HP heating energy (Btu) [a]	36	256	953	2,974	5,268	9,863	3,225
Base no delay HP input (kWh) [b]	0.04	0.11	0.23	0.47	0.71	1.20	0.46
Base no delay HP efficiency [c=a/b/3412]	0.24	0.68	1.24	1.87	2.18	2.41	1.44
EFC® HP heating energy (Btu) [d]	91	437	1,330	3,531	5,862	10,481	3,622
EFC® HP input (kWh) [e]	0.05	0.12	0.23	0.48	0.72	1.21	0.47
EFC® HP heating efficiency [f=d/e/3412]	0.56	1.10	1.66	2.17	2.39	2.54	1.74
EFC® fan energy vs no delay (kWh)	0.004	0.006	0.009	0.011	0.010	0.010	0.008
EFC® HP savings v. no delay [g=1-c/f]	**56.7%**	**38.0%**	**25.5%**	**13.9%**	**8.8%**	**5.1%**	**24.7%**
Base 65-second delay tests	**131**	**132**	**133**	**134**	**135**	**136**	
Base 65-sec. delay HP energy (Btu) [h]	95	366	1,135	3,212	5,522	10,126	3,410
Base 65-sec. delay HP input (kWh) [i]	0.05	0.11	0.23	0.47	0.71	1.20	0.46
Base 65-sec. delay HP efficiency [j=h/i/3412]	0.59	0.94	1.45	2.01	2.27	2.47	1.62
EFC® HP heating energy (Btu) [k]	148	513	1,430	3,642	5,981	10,605	3,720
EFC® HP input (kWh) [l]	0.05	0.12	0.24	0.48	0.72	1.21	0.47
EFC® HP heating efficiency [m=k/l/3412]	0.85	1.25	1.76	2.22	2.42	2.56	1.84
EFC® fan energy vs. 65-sec. (kWh)	0.008	0.014	0.014	0.014	0.014	0.014	0.013
EFC® HP savings v. 65-sec. base [m=1-j/m]	**30.6%**	**24.6%**	**17.6%**	**9.8%**	**6.3%**	**3.7%**	**15.4%**

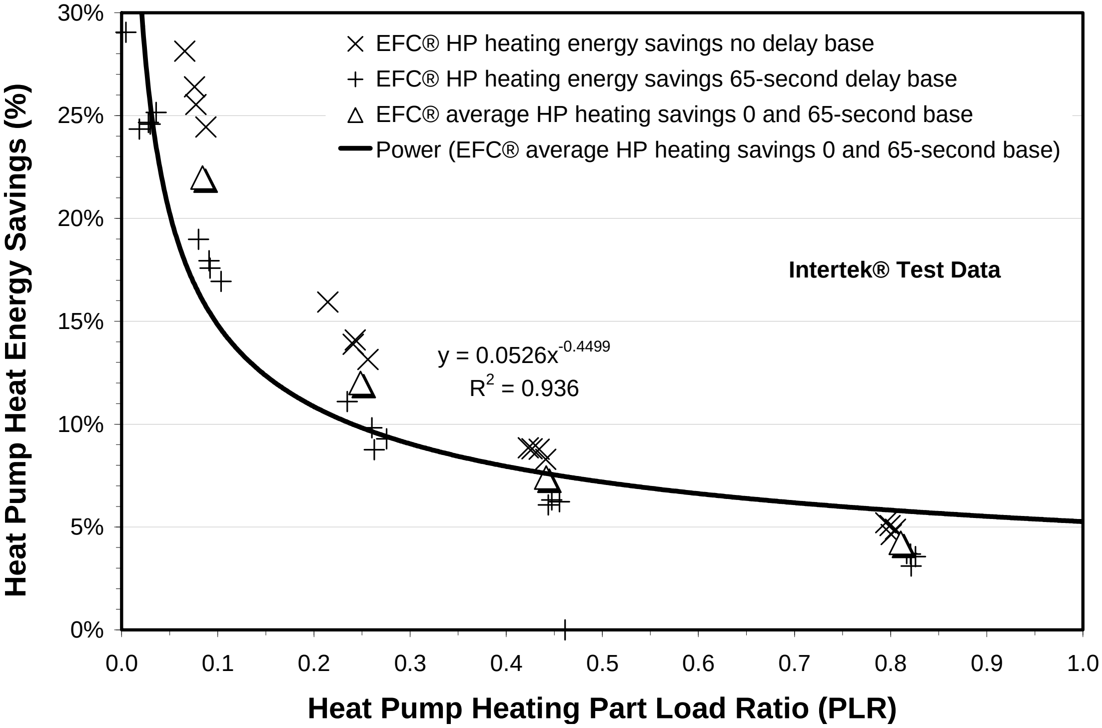

Figure 7: Intertek® HP Heating Tests – Smart EFC® FDD Heating Savings versus PLR

Figure 7 shows the Smart EFC® FDD HP heating savings varying from 3.1 to 29% compared to baseline fan-off delays of zero or 65 seconds and PLR values ranging from 0.05 to 0.83 based on 48 lab tests. Data from a sample of 3,114 heat pump units in California indicate 78% of heat pump heating units have no delay and 22% have 65-second fan-off delays [7]. Based on the eQuest simulations, the average annual heating PLR values range from 0.09 to 0.27 and the weighted average heating PLR 0.13 [7]. The average annual EFC® heat pump heating energy savings are 9.7 ± 1.6% based on **Equation 8** and housing stock weights for each climate zone from California housing stock data and US Census data [7, 10, 13].

Hydronic Heating Test Data and Energy Savings Analysis

The laboratory performed 20 split-system hydronic hot water heating tests. The tests were performed at 47°F (8.3 C) outdoor temperatures with 130°F (54.4 C) and 140°F (60 C) hot water temperature and 70°F (21.1 C) DB and 55F (12.8 C) WB indoor temperatures. The laboratory tests measured the additional heating capacity provided by the EFC® using an extended fan-off time delay which varies as a function of the hydronic heating operating time compared to the baseline system with no time delay or a fixed 60-second time delay. The laboratory tests also measured total hydronic heating capacity for 60 minutes at the same conditions.

Table 8 provides the following Intertek® hydronic heating tests at 130°F for the 1.5-ton split-system unit #6: 1) no delay base, 2) 60-second delay base, and 3) EFC® variable delay. EFC® hydronic heating energy savings vary from 4.2 to 66% with no delay base, and savings vary from 2.3 to 28.7% for 60-second delay base. Average EFC® heating energy savings are 24.6% versus the no delay base and 12.1% versus the 60-second delay base. The PLR is used to normalize the EFC® hydronic heating energy savings for each group of tests. Laboratory test data of the EFC® hydronic heating energy savings versus PLR are shown in **Figure 8**. EFC® hydronic heating savings are calculated using regression **Eq. 9** based on the PLR (from **Figure 8**).

Equation 9

$$\Delta\eta_h = 0.0392(PLR_h)^{-0.6023}$$

Where, $\Delta\eta_h$ = EFC® hydronic heating savings versus base.

Table 8: Intertek® Hydronic Heating Tests Unit #6 at 130°F –EFC® v. 0- and 60-Second Delay

Hydronic heating on time (minutes)	**2**	**5**	**10**	**20**	**30**	**50**	**Ave.**
Base 0-sec. delay tests	**173**	**174**	**175**	**176**	**177**	**178**	
Base no delay HYD heating energy (Btu) [a]	122	512	1,869	4,260	6,325	10,834	3,987
Base no delay HYD input (Btu) [b]	970	2,365	4,584	9,223	14,102	23,893	9,189
Base no delay HYD heating efficiency [c=a/b]	12.6%	21.6%	40.8%	46.2%	44.9%	45.3%	35.2%
Base 60-second delay tests	**179**	**180**	**181**	**182**	**183**	**184**	
Base 60-sec. delay HYD energy (Btu) [d]	256	674	2,099	4,458	6,540	11,040	4,178
Base 60-sec. delay HYD input (Btu) [e]	970	2,365	4,584	9,223	14,102	23,893	9,189
Base 60-sec. delay heating efficiency [f=d/e]	26.4%	28.5%	45.8%	48.3%	46.4%	46.2%	0.40
EFC® HYD heating energy (Btu) [g]	360	839	2,379	4,709	6,854	11,303	4,407
EFC® HYD input (Btu) [h]	970	2,365	4,584	9,223	14,102	23,893	9,189
EFC® HYD heating efficiency [i=g/h]	37.1%	35.5%	51.9%	51.1%	48.6%	47.3%	0.45
EFC® fan energy vs no delay (kWh)	0.007	0.009	0.010	0.010	0.012	0.010	0.010
EFC® HYD savings v. no delay [j=1-c/i]	**66%**	**39%**	**21.4%**	**9.5%**	**7.7%**	**4.2%**	**24.6%**
EFC® fan energy vs. 60-sec. (kWh)	0.007	0.009	0.010	0.009	0.012	0.010	0.009
EFC® HYD savings v. 60-sec. base [k=1-f/i]	**28.7%**	**19.7%**	**11.8%**	**5.3%**	**4.6%**	**2.3%**	**12.1%**

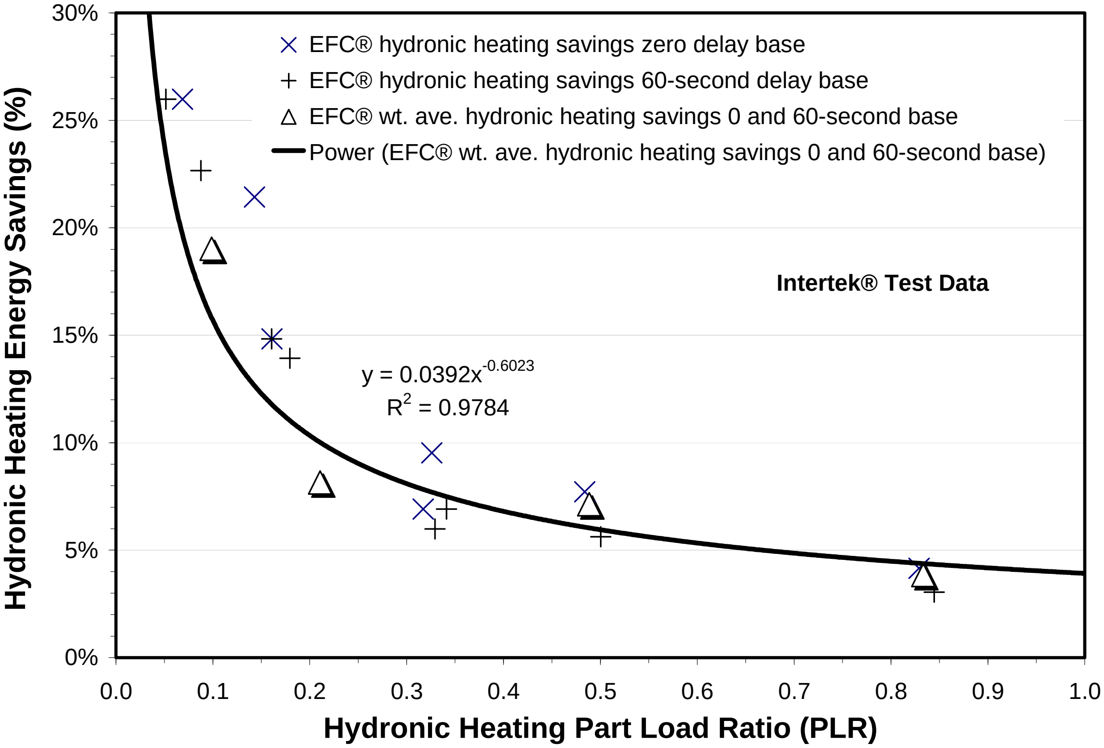

Figure 8: Intertek® Hydronic Heating Tests – Smart EFC® FDD Savings versus Part Load Ratio

Figure 8 shows the Smart EFC® FDD hydronic heating savings varying from 2.3 to 26% compared to baseline fan-off delays of zero or 60 seconds and PLR values ranging from 0.056 to 0.85 based on 20 lab tests. Data from a sample of 1,291 hydronic units in California indicate 72.3% have no delay, 17.6% have 30-second delays, and 10.1% have 60-second fan-off delays [7]. Based on the eQuest simulations, the average annual heating PLR values range from 0.09 to 0.20 and the weighted average heating PLR 0.12 [7]. The average annual EFC® heating energy savings are 17.9 ± 1.7% based on **Equation 9** and housing stock weights for each climate zone from California housing stock data and US Census data [7, 10, 13].

Discussion

The Smart EFC® recovers latent energy from the AC evaporator coil by operating the fan after the compressor turns off to evaporatively cool the conditioned space and satisfy the cooling thermostat setpoint longer and lengthen the off cycle. For heating systems, the Smart EFC® operates the fan after the heating system turns off to satisfy the heating thermostat setpoint longer and lengthen the off cycle. These tests results indicate that mild climates with frequent on-off cycles can realize greater savings than hot climates with longer cycles. Laboratory and field tests demonstrate that the EFC® can prevent evaporator coil icing by continuing to operate the fan and evaporate cold-water condensate from the coil at the end of each cooling cycle which prevents ice formation when the evaporator coil temperature is below freezing. This helps maintain thermal comfort, efficiency and equipment life per the ACCA Standard 4 and Standard 5 HVAC Quality installation and maintenance standards [6].

Intertek® tests of the AC unit #3 found Smart EFC® FDD cooling savings ranging from 3.8 to 32% with average savings of 16.1% versus the no delay base and 10.1% versus the 90-second delay base. Field measurements of the 5-ton AC unit #2 with 21% duct leakage and the same unit with the Smart EFC® found normalized cooling energy savings of 18.2% based on 20 tests. Intertek laboratory tests of gas furnace unit #4 found Smart EFC® FDD heating savings ranging from 4.2 to 38% and average savings of 17.3%. Field measurements of gas furnace unit #2 with 21% duct leakage and the same system with the Smart EFC® found average normalized heating savings of 19.5% based on 15 EFC®

cycles over 10 hours and 18 base cycles over 10-hours. Intertek® laboratory tests of heat pump unit #5 found heating energy savings ranging from 3.7 to 56.7% with average savings of 20.1% based on 48 tests. Intertek® laboratory tests of hydronic unit #6 found heating energy savings ranging from 2.3 to 66% with average savings of 18.4% based on 20 tests. According to the US EIA, California uses approximately 0.74 quadrillion Btu (quads) or 0.79 exajoules (EJ) per year for space cooling and heating [1]. Assuming the EFC® can save 11.3% on cooling and 14.7% on heating, the potential annual energy savings are 0.096 quadrillion Btu (quads) or 0.1 exajoules (EJ) in California or 4.1% of US EIA total estimated annual energy use in California of 2.4 quads or 2.53 EJ.

Conclusions

Laboratory and field tests of the Smart EFC® FDD provide evidence to support cooling and heating energy efficiency savings claims. Cooling tests demonstrate improved thermal comfort by exceeding thermostat set points and providing longer off-cycle times from variable fan-off delays based on cooling or heating on/off cycles. Test results indicate that mild climates with frequent on-off cycles can realize greater savings than hot climates, but HVAC systems operating in either type of climate can realize increased efficiency and energy savings. The laboratory and field tests also demonstrate that the EFC® can prevent evaporator coil icing by continuing to operate the fan and evaporate cold-water condensate from the coil at the end of each cooling cycle which prevents ice formation when the evaporator coil temperature is below freezing.

Based on building simulations, market share data, housing stock data, laboratory tests, and field tests the Smart EFC® FDD cooling energy savings are 11.3 ± 2.7%, gas furnace heating energy savings are 15.7 ± 1.7%, HP heating energy savings are 9.7 ± 1.6%, and hydronic heating energy savings are 17.9 ± 1.6%. California uses approximately 0.74 quadrillion Btu (quads) or 0.79 exajoules (EJ) per year for space cooling and heating. Assuming the Smart EFC® can save 11.3% on cooling and 14.7% on heating, the estimated potential annual energy savings are 0.096 quadrillion Btu (quads) or 0.1 exajoules (EJ) or 4.1% of the total estimated annual energy use in California of 2.4 quads or 2.53 EJ.

Acknowledgements

Laboratory tests performed at Intertek in Plano, TX and field tests were performed in Reno NV, with funding from GreenFan® Inc. Building energy simulations were performed by Pete Jacobs of Building Metrics Inc.

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