INTERTEK PERFORMANCE EVALUATION OF AN EFFICIENT FAN CONTROLLER (EFC) INSTALLED ON SPLIT AND PACKAGE AIR CONDITIONERS WITH GAS FURNACES

08/04/2015 Intertek Project No. G101756555
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Report Scope:

This report summarizes the performance evaluation of an Efficient Fan Controller (smart EFC or EFC) energy efficiency measure for Heating, Ventilating, Air Conditioning (HVAC) systems. The EFC was installed on a 13-SEER 3-ton split-system and a 13 SEER 3-ton packaged HVAC unit. Both units have an 80% AFUE rated gas furnace. Testing was conducted at the Intertek laboratory in Plano, Texas. Testing was performed by Intertek technicians managed by Gilbert Taracena and Craig Grider. Intertek is an Air-Conditioning Heating Refrigeration Institute (AHRI) certified test laboratory and has been certified for more than 50 years (http://www.intertek.com/hvac/associations/ahri/).

Product Description as Tested:

The EFC is a microprocessor-based device that monitors the duration of either the air conditioning compressor or furnace operation and varies the duration of the indoor evaporator or furnace fan operation depending on the length of time the AC compressor or furnace operated (referred to as “time delay” or “fan-off delay”). For existing systems in heating mode after four minutes of furnace operation, the EFC is designed to increase fan speed from low-to-high or medium-to-high speed and deliver more heating capacity using the same amount of natural gas input and slightly more fan energy. For a given heating load, the EFC reduces gas use by delivering increased heating capacity for the same amount of gas input to satisfy the space heating thermostat sooner and extend furnace off time. The EFC activates the fan signal from the thermostat as though the fan switch was toggled to the "on" position. If the default fan speed controlled by the fan switch is set to the same speed as heating, then the EFC will only save heating energy based on extended fan operation after the furnace turns off (see **Table 14** and **Table 15**). Increasing airflow to high speed during furnace operation supplies more heating capacity to satisfy the space heating thermostat sooner, reduce furnace operation, and save gas energy. The EFC improves HVAC efficiency and saves energy by providing longer variable fan-off time delays based on HVAC system type, mode of operation, duration of cooling or heating operation and EFC Fault Detection Diagnostics (FDD). The EFC recovers and delivers more sensible cooling or heating capacity to the space to exceed thermostat setpoint temperatures, lengthen off-cycles, and reduce on-cycles.

Description of Test Units

The test equipment schematic is shown in **Figure 1**. Test unit characteristics are described in **Table 1**. The rated cooling capacity of the 3-ton split-system HVAC unit is 33,800 Btu per hour (Btu/hr) and the rated heating capacity is 54,000 Btu/hr. The default cooling time delay is either 0 seconds or 90 seconds after the air conditioning compressor turns off, and the default heating time delay is 120 seconds after the furnace turns off. The rated cooling capacity of the 3-ton packaged HVAC unit is 35,800 Btu per hour and the rated heating capacity is 55,200 Btu per hour. The 3-ton packaged unit default cooling time delay is either 0 seconds or 60 seconds after the air conditioning compressor turns off, and the heating time delay is 120 seconds after the furnace turns off.

Figure 1: Test Equipment Schematic

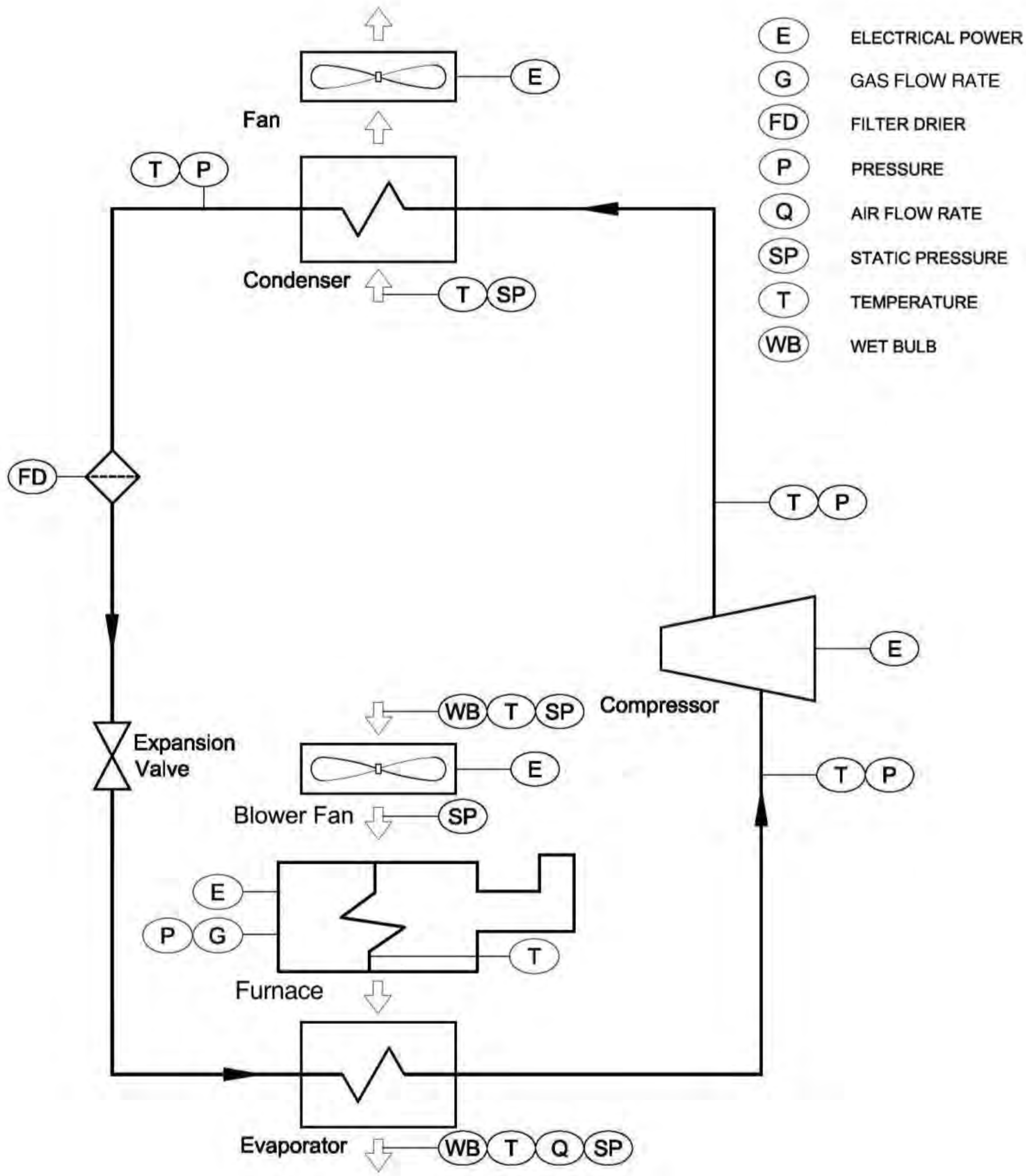

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Table 1: Description of Test Units – 3-ton Split-System HVAC Unit and 3-ton Packaged Unit

Unit Description	3-ton Split-System HVAC Unit	3-ton Packaged HVAC Unit
ID Model Number	CNRHP3617ATA	GPG1336070M41BA
Input Voltage	208/230 VAC	208/230 VAC
Input Frequency	60 HZ	60 HZ
Phase	1 Phase	1 Phase
Type	Ducted Evaporator	Packaged Unit
Rated Cooling Capacity	33800 Btu/hr 1200 scfm at 0.5 IWC 25660 Btu/hr sensible	35800 Btu/hr 1188 scfm at 0.5 IWC 28547 Btu/hr sensible
OD Model Number	24ABS336A300	GPG1336070M41BA
Fan Speed and RPM	Low 1050, Medium 1080, High 1100 RPM	Low 850, Medium 980, High 1040 RPM
Fan Time Delay Cooling	0 or 90 seconds Cooling	0 or 60 seconds Cooling
Fan Time Delay Heating	120 seconds Heating	120 seconds Heating
Frequency and Phase	60 HZ and Single Phase	60 HZ and Single Phase
Refrigerant Charge	R22 86.4 Ounces	R410A 70 Ounces
Type	Air Cooled Condenser	Air Cooled Condenser
Furnace Model Number	58STA070-12	GPG1336070M41BA
Rated Heating Capacity	54000 Btu/hr 1140 scfm at 0.5 IWC	55200 Btu/hr and 1073 scfm @ 0.5 IWC

Location and Dates of Tests:
Tests were performed at the Intertek Laboratory in Plano, Texas, from 01/05/2015 through 01/17/15.

Test Methods:
Each unit was tested under AHRI 210/240 test conditions and ANSI Z21.47 to verify manufacturer published efficiency ratings. 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. Verification tests were conducted according to **Table 2** (ANSI/AHRI Standard 210/240-2008, Table 11) and **Table 3**.[1] Thermal Efficiency verification tests were performed according to ANSI Z21.47-5th Edition 2006/CSA 2.3-5th Edition 2006.[2]

Each unit was tested in cooling mode under non-steady state field conditions to measure sensible cooling capacity and efficiency with no time delay or fixed time delay of 60 seconds for the packaged unit or 90 seconds for the split-system after the air conditioning compressor turned off. Non-steady state cooling tests were performed with the patented EFC product providing a variable time delay on the evaporator fan

[1] ANSI/AHRI 2008 Standard for Performance Rating of Unitary Air-Conditioning and Air-Source Heat Pump Equipment Standard 210/240. American National Standards Institute. Air-Conditioning Heating and Refrigeration Institute.
[2] ANSI Z21.47-5th Edition 2006/CSA 2.3-5th Edition 2006– Standard for Gas-Fired Central Furnaces. American National Standards Institute.

depending on length of time the compressor operated.

Each unit was tested in heating mode under non-steady state field conditions to measure the sensible heating capacity and efficiency with fixed time delay of 120 seconds after the gas furnace turned off. Non-steady state heating tests were performed with the patented EFC product providing increased fan speed from low-to-high or medium-to-high speed after 4 minutes of furnace operation and variable time delay on the fan after the furnace turns off depending on length of time the furnace operated.

Non-steady state testing of EFC did not include an evaluation of SEER or AFUE impacts.

Table 2: ANSI/AHRI 210/240 Table 11. Minimum External Static Pressure for Ducted Systems Tested with an Indoor Fan Installed

Table 11. Minimum External Static Pressure for Ducted Systems Tested with an Indoor Fan Installed

Rated Cooling[1] or Heating[2] Capacity		Minimum External Resistance[3]			
		All Other Systems		Small-Duct, High-Velocity Systems[4,5]	
Btu/h	kW	in H_2O	Pa	in H_2O	Pa
Up thru 28,800	Up thru 8.44	0.10	25	1.10	275
29,000 to 42,500	8.5 to 12.4	0.15	37	1.15	288
43,000 and Above	12.6 thru 19.0	0.20	50	1.20	300

(1) For air conditioners and heat pumps, the value cited by the manufacturer in published literature for the unit's capacity when operated at the A or A_2 Test conditions.
(2) For heating-only heat pumps, the value the manufacturer cites in published literature for the unit's capacity when operated at the H1 or $H1_2$ Test conditions.
(3) For ducted units tested without an air filter installed, increase the applicable tabular value by 0.08 in H_2O [20 Pa].
(4) See Definition 1.35 of Appendix C to determine if the equipment qualifies as a small-duct, high-velocity system.
(5) If a closed-loop, air-enthalpy test apparatus is used on the indoor side, limit the resistance to airflow on the inlet side of the indoor blower coil to a maximum value of 0.10 in H_2O [25 Pa]. Impose the balance of the airflow resistance on the outlet side of the indoor blower.

Table 3: ANSI/AHRI 210/240 Table 3. Cooling Mode Test Conditions

Table 3. Cooling Mode Test Conditions for Units Having a Single-Speed Compressor and a Fixed-Speed Indoor Fan, a Constant Air Volume Rate Indoor Fan, or No Indoor Fan

Test Description	Air Entering Indoor Unit Temperature				Air Entering Outdoor Unit Temperature				Cooling Air Volume Rate
	Dry-Bulb		Wet-Bulb		Dry-Bulb		Wet-Bulb		
	°F	°C	°F	°C	°F	°C	°F	°C	
A Test - required (steady, wet coil)	80.0	26.7	67.0	19.4	95.0	35.0	75.0(1)	23.9(1)	Cooling Full-load (2)
B Test - required (steady, wet coil)	80.0	26.7	67.0	19.4	82.0	27.8	65.0(1)	18.3(1)	Cooling Full-load (2)
C Test - optional (steady, dry coil)	80.0	26.7	(3)		82.0	27.8	–		Cooling Full-load (2)
D Test - optional (cyclic, dry coil)	80.0	26.7	(3)		82.0	27.8	–		(4)

Notes:

(1) The specified test condition only applies if the unit rejects condensate to the outdoor coil.
(2) Defined in section 6.1.3.3.1.
(3) The entering air must have a low enough moisture content so no condensate forms on the indoor coil. (It is recommended that an indoor wet-bulb temperature of 57.0 °F [13.9 °C] or less be used.)
(4) Maintain the airflow nozzles static pressure difference or velocity pressure during the ON period at the same pressure difference or velocity pressure as measured during the C Test.

Test Matrix:

A Test - required (steady, wet-coil)
A Test - customer specified scheduled airflow at 0.4" WC
B Test - required (steady, wet-coil)
C Test - optional (steady, dry-coil)
D Test - optional (cyclic, dry-coil)

Test Equipment Calibration

The psychrometric room is designed to ASHRAE 37 specifications.[3] Calibration for all equipment on this facility is completed annually, and is maintained under one Intertek ID number. Individual calibration records can be made available upon request. All calibration is conducted in accordance to ISO 17025 requirements by an ILAC accredited calibration provider. Intertek gas furnace heating equipment performance and AFUE tests are performed per ANSI Z21.47 specifications.

AHRI and ANSI Performance Evaluation Results

AHRI and ANSI steady-state test parameters and results are summarized in **Figure 3** through **Figure 6**. Detailed test data and results are provided in Excel workbooks.

EFC Performance Evaluation Results

The baseline and EFC non-steady state test parameters and test results for the 3-ton split-system and 3-ton packaged unit in cooling and heating mode are summarized in **Table 4** through **Table 14** and **Figure 7** through **Figure 17**. Detailed test data and results are provided in Excel workbooks.

[3] ANSI/ASHRAE STANDARD 37-2009. 2009. Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment

Figure 2: AHRI 210/240 Baseline Performance Test of 3-ton Split System in Cooling Mode

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SEASONAL ENERGY EFFICIENCY RATIO (SEER) Version C, 2012-02-08, TRS

Section 4.1.1

DOE 10 CFR 430 Appendix M, AHRI 210/240 - 2006

PROJECT / UUT INFORMATION

Client:	GreenFan, Inc.		Manufacturer:	NA	
Project:	GreenFan, Inc.		Model:	24ABS336A003	
Task:	SEER		Serial Number:	3309E02884	
Compressor Type:	Single-Speed	[-]	Blower Type:	Fixed-Speed	[-]
	12.35				
	13.00				

TEST DATA

Test	ID Condition [DB / WB]	OD Condition [DB / WB]		Capacity) [Btu/hr]	Power [W]	Test Report Filename [*]
A	80 / 67	95 / 75*	Req	35607	3163	318-2 A
B	80 / 67	82 / 65*	Req	36889	2794	318-2 B
C	80 / < 57	82 / 65*	Opt	33374	2763	318-2 C
D	80 / < 57	82 / 65*	Opt	Cd =	0.087	318-2 D

SEER CALCULATION

Bin#	Tj	nj/N	BL(Tj)	Speed	qc(Tj)/N	ec(Tj)/N
1	67	0.214	-	-	-	-
2	72	0.231	-	-	-	-
3	77	0.216	-	-	-	-
4	82	0.161	-	-	-	-
5	87	0.104	-	-	-	-
6	92	0.052	-	-	-	-
7	97	0.018	-	-	-	-
8	102	0.004	-	-	-	-
				Totals:	0.00	0.00

		% Rated	% Minimum
SEER:	12.63	97.14%	102.26%

Figure 3: ANSI Z21.47 Baseline Thermal Efficiency Test of 3-ton Split System in Heating Mode

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Thermal Efficiency Test - ANSI Z21.47

Date	Manufacturer	Model	Test Number	Report Number
January 29, 2015	NA	58STA070-12	G101756555	101756555DAL-005B
Unit Type:	Nameplate Input, Btu/hr.	Certified Input, Btu/hr.	Tested Input, Btu/hr.	Input Deviation
Furnace	66,000	66,000	64927.11	1.63%
Type	Certified Thermal Efficiency Rating			Efficiency Deviation
Single Stage	80	82.10		-2.63%

Report Prepared by

Report Reviewed by

Humidity	Barometric	Flue/duct	Gas Manifold	Gas Line	Volts	Amps	Watts	Hertz	Calorimeter
28.9	29.81	0.322	3.96	7.03	115	4.99	482	60	994.02

Oxygen	CO	CO2	Air Free	Flow CFH	Flow Total	Flow Cycle	Heating Input	Flue Temp	Ambient
7.28	37	7.66	57.48	-	-	-	64927.11	355.29	79.41

Air required for complete combustion, SCF per 1,000 Btu of gas burned;

A = 9.4

Carbon Dioxide in flue gases, percent of total dry constituents in the flue gases

C = 7.66

Relative humidity of air supplied for combustion, percent/100;

h = 0.289

Dry Constituents in flue gases from stoichiometric combustion, SCF per 1,000 Btu of gas burned;

P = 8.47

Total constituents in flue gases from stoichiometric combustion, SCF per 1,000 Btu of gas burned;

T = 10.42

Flue gas temperature, degree R;

Tf = 887.74

Room temperature, degree R;

Tr = 611.86

Ultimate carbon dioxide of flue gas, percent;

U = 11.9

Cubic Feet	CF (f^3)		1
Time	min	0 sec	53.77
Gas pressure	in. wc		7.02
Ambient Pressure	in. Hg		29.81
Current Gas Temperature	°F		77.9
Calibrated Atmospheric Pressure	in. Hg		30.00
Calibrated Gas Temperature	°F		60.00
Manifold Pressure	in. wc		3.97

Calorimeter Reading	994.90
Correction Factor	0.9975
BTU/hr	64927.11
Manufacture Declared BTU/hr	66000.00
Percentage	1.63%

V1	66.95	CFH
P1	14.90	PSIA
T1	537.57	°F
V2	65.26	CFH
P2	14.73	PSIA
T2	519.67	°F

KEY
T1 - Current Gas Temperature (Rankines)
T2 - Calibrated Gas Temperature (Rankines)
V1- Clocked cf/h (meter)
V2- Calculated cf/h
P1- Current Ambient Pressure + Gas pressure (meter)
P2- Calibrated Atmospheric Pressure

Gas Meter	
ID# 1205	
Calibration Conditions	
°F	60
inHg	30

Figure 4: AHRI 210/240 Baseline Performance Test of the 3-ton Packaged Unit in Cooling Mode

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SEASONAL ENERGY EFFICIENCY RATIO (SEER) Version C, 2012-02-08, TRS

Section 4.1.1

DOE 10 CFR 430 Appendex M, AHRI 210/240 - 2006

PROJECT / UUT INFORMATION

Report Number:			AHRI Number:	NA	
Client:	GreenFan, Inc.		Manufacturer:	NA	
Project:			Model:	GPG1336070M41BA	
Task:	Seer Calculation		Serial Number:	1412149903	
Compressor Type:	Single-Speed	[-]	Blower Type:	Fixed-Speed	[-]
Minimum SEER:	12.35	[-]			
Rated SEER:	13	[-]			

TEST DATA

Test	ID Condition [DB / WB]	OD Condition [DB / WB]		Capacity) [Btu/hr]	Power [W]	Test Report Filename [*]
A	80 / 67	95 / 75*	Req	-	-	
B	80 / 67	82 / 65*	Req	39031	2968	
C	80 / < 57	82 / 65*	Opt	-	-	
D	80 / < 57	82 / 65*	Opt	Cd =	0.026	

SEER CALCULATION

Bin#	Tj	nj/N	BL(Tj)	Speed	qc(Tj)/N	ec(Tj)/N
1	67	0.214	-	-	-	-
2	72	0.231	-	-	-	-
3	77	0.216	-	-	-	-
4	82	0.161	-	-	-	-
5	87	0.104	-	-	-	-
6	92	0.052	-	-	-	-
7	97	0.018	-	-	-	-
8	102	0.004	-	-	-	-
				Totals:	0.00	0.00

		% Rated	% Minimum
SEER:	**12.98**	99.84%	105.10%

Figure 5: ANSI Z21.47 Baseline Thermal Efficiency Test of 3-ton Packaged Unit in Heating Mode

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Thermal Efficiency Test - ANSI Z21.47

Date	Manufacturer	Model	Test Number	Report Number
February 25, 2015	NA	GPG1336070M41BA	G101756555	101756555DAL-005D

Unit Type:	Nameplate Input, Btu/hr.	Certified Input, Btu/hr.	Tested Input, Btu/hr.	Input Deviation
Furnace	69,000	69,000	68573.00	0.62%

Type	Certified Thermal Efficiency Rating		Efficiency Deviation
Single Stage	80	81.04	-1.30%

Report Prepared by — Report Reviewed by

Humidity (%RH)	Barometric (inHg)	Flue/duct (inWC)	Gas Manifold (inWC)	Gas Line (inWC)	Volts	Amps	Watts	Hertz	Calorimeter (BTU/ft³)
21.53	29.45	0.39	3.94	8.15	230	1.68	379	60	997.61

Oxygen %	CO PPM	CO2 %	Air Free CO PPM	Flow CFH	Flow Total	Flow Cycle	Heating Input (BTU/hr)	Flue Temp (F)	Ambient (F)
8.21	8.1	7.22	13.19				68573	369.56	72.35

Air required for complete combustion, SCF per 1,000 Btu of gas burned;
A = 9.4
Carbon Dioxide in flue gases, percent of total dry constituents in the flue gases
C = 7.22
Relative humidity of air supplied for combustion, percent/100;
h = 0.2153
Dry Constituents in flue gases from stoichiometric combustion, SCF per 1,000 Btu of gas burned;
P = 8.47
Total constituents in flue gases from stoichiometric combustion, SCF per 1,000 Btu of gas burned;
T = 10.42
Flue gas temperature, degree R;
Tf = 902.01
Room temperature, degree R;
Tr = 604.8
Ultimate carbon dioxide of flue gas, percent;
U = 11.9

Cubic Feet	**CF (f^3)**			**1**
Time	**min**	**0**	**sec**	**52.72**
Gas Meter Type	**Dry**			
Gas pressure	**in. wc**			**8.13**
Ambient Pressure	**in. Hg**			**29.46**
Current Gas Temperature	**°F**			**76.26**
Calibrated Atmospheric Pressure	**in. Hg**			**30.00**
Calibrated Gas Temperature	**°F**			**70.00**
Manifold Pressure	**in. wc**			**3.95**

Calorimeter Reading	996.54
Correction Factor	0.9977
HHV (Saturated or Dry)	**Saturated**
BTU/hr	68573.79
Manufacture Declared BTU/hr	69000.00
Percentage	0.62%

Sensible Cooling and Heating Capacity and Efficiency Calculations

Sensible cooling and heating capacity for the split-system or packaged HVAC systems with either no time delay or fixed time delay and EFC variable time delay are measured in British thermal units (Btu).[4] The sensible cooling capacity is based on the measured airflow rate in cubic feet per minute (cfm), specific volume (ft^3/lbm), and difference between the return air specific heat (Btu/lbm·°F) times temperature (°F) and the supply air specific heat times temperature per ASHRAE 37 (7.3.3.1, p. 11). **Equation 1** is used to calculate the non-steady state sensible cooling capacity for the air conditioner.

Equation 1 $$Q_{sc} = \sum_{t=0}^{n} q_{sc_t} \left[\frac{t}{3600} \right]$$

Where, Q_{sc} = non-steady-state sensible cooling capacity for the air conditioner (Btu),

t = time measurement interval (5 seconds),

n = number of measurement intervals for test (integer),

$q_{sc_t} = \dfrac{60\dot{V}(c_{p1}T_{a1} - c_{p2}T_{a2})}{\nu_2(1+W_n)}$ = sensible cooling capacity per time interval (Btu/hr) [W],

$\dot{V}$ = volumetric supply airflow leaving indoor side (cfm) [m^3/s],

W_n = humidity ratio of supply air at nozzle (lbm of water vapor per lbm of dry air) [kg_{wv}/kg_{da}],

ν_n = specific volume of supply air at nozzle (ft^3/lbm) [m^3/kg],

T_{a1} = drybulb temperature of return air entering indoor side (°F) [°C],

T_{a2} = drybulb temperature of supply air leaving indoor side (°F) [°C],

$c_{p1} = 0.24 + 0.444\, W_1$ = specific heat of return air entering indoor side (Btu/lbm·°F) [J/kg·°C], and

$c_{p2} = 0.24 + 0.444\, W_2$ = specific heat of supply air leaving indoor side (Btu/lbm·°F) [J/kg·°C].

Total cooling capacity is calculated as follows per ASHRAE 37.

$q_{tc} = \dfrac{60\dot{V}(h_{a1} - h_{a2})}{\nu_n(1+W_2)}$ = non-steady state total cooling capacity (Btu/hr) [W],

h_{a1} = enthalpy of return air entering indoor side (Btu/lbm) [J/kg] and

h_{a2} = enthalpy of supply air leaving indoor side (Btu/lbm) [J/kg].

For split systems where the test equipment indoor section is located in the indoor test room, then duct losses are accounted for as follows per ASHRAE 37 (section 7.3.3.3, p. 12).

$$q_{loss} = UA_d(T_{ai} - T_{a2})$$

Where, q_{loss} = duct loss (Btu/h) [W] added to sensible or total cooling per ASHRAE 37, but not included in the Intertek tests to remove duct losses from cooling capacity calculations,

UA_d = product of overall heat transfer coefficient and surface area for ducts located in indoor or outdoor test room, (Btu/h °F) [W/°C], and

T_{ai} = drybulb temperature of indoor test room (°F) [°C].

For packaged units where test equipment is located in the outdoor test room, then duct losses are

[4] The British thermal unit (Btu) is 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.

accounted for as follows per ASHRAE 37 (section 7.3.3.3, p. 12).

$$q_{loss} = UA_d\,(T_{a1} - T_{ao})$$

Where, T_{ao} = drybulb temperature of indoor test room (°F) [°C].

The non-steady-state sensible cooling efficiency (η_{sc}) is defined as the sensible cooling capacity (Btu/hr) divided by the electric power consumption (Watts) of the air conditioner (including compressor, fans, and controls). **Equation 2** is used to calculate the non-steady-state sensible cooling efficiency.

Equation 2 $$\eta_{sc} = \sum_{t=0}^{n} \frac{q_{sc_t}}{e_t}$$

Where, η_{sc} = non-steady-state sensible cooling efficiency (Btu/Watt-hour or Btu/Wh), and

e_t = electric power consumption per time interval for the air conditioner (Wh).

Non-steady state cooling tests were performed with no time delay or fixed time delay and EFC variable time delay to measure the sensible cooling capacity and efficiency. The non-steady-state sensible cooling capacity improvement for the EFC is calculated using **Equation 3**.

Equation 3 $$\Delta Q_{sc} = \left[\frac{Q_{sc_e}}{Q_{sc_o}} - 1 \right] 100$$

Where, ΔQ_{sc} = sensible cooling capacity improvement with EFC (%),

Q_{sc_e} = sensible cooling capacity with EFC (Btu), and

Q_{sc_o} = baseline sensible cooling capacity without EFC (Btu).

The non-steady-state sensible cooling efficiency improvement for EFC is calculated using **Equation 4**.

Equation 4 $$\Delta \eta_{sc} = \left[\frac{\eta_{sc_e}}{\eta_{sc_o}} - 1 \right] 100$$

Where, $\Delta \eta_{sc}$ = sensible cooling efficiency improvement with EFC (%),

η_{sc_e} = sensible cooling efficiency with EFC (Btu/Wh), and

η_{sc_o} = sensible cooling efficiency without EFC (Btu/Wh).

The baseline cooling energy to match the EFC sensible cooling capacity is calculated using **Equation 5**.

Equation 5 $$E_{c_m} = \left[\frac{Q_{sc_e}}{\eta_o\,(1000\ W/kW)} \right]$$

Where, E_{c_m} = baseline energy required to match EFC cooling capacity (kWh),

Q_{sc_e} = sensible cooling capacity with EFC (Btu), and

η_o = baseline sensible efficiency without EFC (Btu/Wh).

Cooling energy savings with the EFC are achieved by providing longer variable fan-off time delays based on the duration of the cooling system operating time in order to recover and supply more sensible cooling to the space to exceed the thermostat setpoint temperature and lengthen air conditioning off-cycles producing fewer cooling on-cycles. The cooling energy savings are calculated using **Equation 6.** This is the energy required by the baseline system to match the extra cooling capacity supplied with the EFC .

Equation 6 $$\Delta E_C = E_{c_m} - E_{c_e} = \frac{Q_{c_e} - Q_{c_o}}{\eta_{sc_o}\,(1000\ \text{W/kWh})} + E_{c_o} - E_{c_e}$$

Where, ΔE_C = cooling energy savings with EFC compared to baseline (kWh),

Q_{c_o} = cooling capacity supplied by baseline system (Btu),

Q_{ce} = cooling capacity supplied with EFC (Btu),

E_{c_o} = baseline energy consumption (kWh), and

E_{c_e} = energy consumption with EFC (kWh).

The cooling savings percentage is calculated using **Equation 7**.

Equation 7 $$\Delta e_{CS} = \left[1 - \frac{\eta_{sc_o}}{\eta_{sc_e}}\right]100$$

Where, Δe_{CS} = cooling savings with EFC (%)**.**

An example calculation is provided for the 10-minute cooling test 3 (see **Table 4**) using **Equations 4** through **7**. With the no time delay baseline, the split-system air conditioner uses 0.541 kWh to supply 2965 Btu of sensible cooling to the space with an efficiency of 5.48 Btu/Wh. With the EFC, the air conditioner uses 0.564 kWh to supply 3827 Btu of sensible cooling to the space with an efficiency of 6.80 Btu/Wh. The cooling efficiency improvement with the EFC is calculated using **Equation 4**.

Example Eq. 4 $$\Delta\eta_{SC} = \left[\frac{\eta_{sc_e}}{\eta_{sc_o}} - 1\right]100 = \left[\frac{6.8}{5.48} - 1\right]100 = 19.5\%$$

Where, $\Delta\eta_{SC}$ = test 3 sensible cooling efficiency improvement with EFC = 19.5%

η_{sc_e} = test 3 sensible cooling efficiency with EFC = 6.8 Btu/Wh, and

η_{sc_o} = test 3 sensible cooling efficiency without EFC = 5.48 Btu/Wh.

The test 3 cooling energy required to match the EFC sensible cooling capacity at the baseline efficiency is calculated using **Equation 5**.

Example Equation 5 $$E_{c_m} = \left[\frac{Q_{sc_e}}{\eta_o(1000)}\right] = \left[\frac{3837}{5.48\,(1000)}\right] = 0.70\ \text{kWh}$$

Where, E_{c_m} = baseline energy required to match EFC capacity = 0.70 kWh,

Q_{sc_e} = test 3 sensible cooling capacity with EFC = 3837 Btu, and

η_O = test 3 baseline sensible efficiency without EFC = 5.48 Btu/W.

The test 3 cooling energy savings with EFC are calculated using **Equation 6**.

Example Eq. 6 $$\Delta E_C = \frac{Q_{c_e} - Q_{c_o}}{\eta_{sc_o}\,(1000\ \text{W/kWh})} + E_{c_o} - E_{c_g} = \frac{3837 - 2965}{5.48\ (1000)} + 0.541 - 0.564 = 0.137\ \text{kWh}$$

Where, ΔE_C = test 3 cooling energy savings with EFC compared to baseline = 0.137 kWh,

Q_{c_o} = test 3 cooling capacity supplied by baseline system = 2965 Btu,

Q_{c_e} = test 3 cooling capacity supplied with EFC = 3837 Btu,

E_{c_o} = test 3 baseline energy consumption = 0.541 kWh, and

E_{c_e} = test 3 energy consumption with EFC = 0.564 kWh.

The test 3 cooling percentage savings with EFC are calculated using **Equation 7**.

Example Equation 7 $$\Delta e_{cs} = 1 - \frac{\eta_{sc_o}}{\eta_{sc_g}} \times 100 = 1 - \frac{5.48}{6.805} \times 100 = 19.5\%$$

Where, Δe_{cs} = test 3 sensible cooling efficiency improvement with EFC = 19.5%,

η_{sc_o} = test 3 baseline sensible cooling efficiency = 5.48 Btu/Wh, and

η_{sc_e} = test 3 sensible cooling efficiency with EFC = 6.805 Btu/Wh.

The sensible heating capacity is based on the measured airflow rate (cfm), specific volume (ft^3/lbm), and difference between the supply air specific heat (Btu/lbm·°F) times temperature (°F) and the return air specific heat times temperature per ASHRAE 37. **Equation 8** is used to calculate the non-steady state sensible heating capacity.[5]

Equation 8 $$Q_h = \sum_{t=0}^{n} q_{h_t} \left[\frac{t}{3600} \right]$$

Where, Q_h = non-steady-state sensible heating capacity for heating system (Btu),

$q_{h_t} = \dfrac{60\dot{V}(c_{p2}T_{a2} - c_{p1}T_{a1})}{\nu_2(1+W_n)}$ = sensible heating capacity per time interval (Btu/hr) [W],

T_{a2} = dry bulb temperature of supply air leaving the indoor side heat source (F), and

T_{a1} = dry bulb temperature of return air entering the indoor side heat source (F).

The heating efficiency (η_h) is defined as the non-steady-state sensible heating capacity (Btu/hr) divided by the heat source energy consumption (Btu/hr) per time interval.
Equation 9 is used to calculate the heating efficiency for the heating system.

Equation 9 $$\eta_h = \sum_{t=0}^{n} \frac{q_{h_t}}{e_{h_t}} = \frac{Q_h}{E_h}$$

Where, η_h = heating efficiency (dimensionless),

q_{h_t} = non-steady state heating capacity per time interval (Btu/hr),

e_{h_t} = non-steady-state heating energy consumption per time interval (Btu/hr),

Q_h = sensible heating capacity supplied by heating system (Btu), and

E_h = heat source energy consumption (Btu).

Furnace heating energy consumption is equal to total Btu consumption as shown in **Equation 10**.

[5] Sensible heating capacity supplied to the space increases the sensible drybulb temperature controlled by the thermostat.

Equation 10 $$Q_e = \sum_{t=0}^{n} e_t \left[\frac{t}{3600} \right]$$

Where, Q_e = heat source energy consumption (Btu), and

$e_t = \bar{c}\dot{V}_t$ = non-steady state energy consumption (Btu) per time interval for the furnace as measured by the Intertek calorimeter and Intertek natural gas volumetric flow meter (cubic feet),

$\bar{c}$ = average heat rate of natural gas (Btu/ft^3) at ambient temperature and pressure as measured by the Intertek calorimeter, and

$\dot{V}_t$ = volumetric flow of natural gas (ft^3) per time interval as measured by the Intertek natural gas flow meter (cubic feet).

The heating efficiency improvement for the EFC is calculated using **Equation 11**.

Equation 11 $$\Delta\eta_h = \left[\frac{\eta_{h_e}}{\eta_{h_o}} - 1 \right] 100$$

Where, $\Delta\eta_{sc}$ = heating efficiency improvement with EFC (%),

η_{h_e} = heating efficiency with EFC (dimensionless), and

η_{h_o} = heating efficiency without EFC (dimensionless).

The baseline heating energy to match the EFC heating capacity is calculated using **Equation 12**.

Equation 12 $$E_{h_m} = \left[\frac{Q_{h_e}}{\eta_{h_o}} \right]$$

Where, E_{hm} = energy required to match EFC heating capacity (Btu) at baseline efficiency,

Q_{he} = heating capacity supplied by furnace with EFC (Btu),

η_{h_o} = heating efficiency without EFC (dimensionless).

Heating energy savings with the EFC are achieved by providing greater furnace heating capacity with high-speed fan operation (where applicable) and longer variable fan-off time delays based on furnace operational time to recover and supply more heat to the space to exceed the thermostat setpoint temperature and lengthen furnace off-cycles producing less frequent or shorter furnace on-cycles. The heating energy savings are calculated using **Equation 13**. This is the energy required by the baseline system to match the extra heating capacity supplied with the EFC minus energy consumption with the EFC.

Equation 13 $$\Delta E_h = E_{h_m} - E_{he} = \frac{Q_{h_e} - Q_{h_o}}{\eta_{h_o}} + E_{h_o} - E_{h_e}$$

Where, ΔE_h = furnace heating energy savings with EFC compared to baseline (Btu),

Q_{h_o} = heating capacity supplied by baseline furnace (Btu),

Q_{he} = heating capacity supplied by furnace with EFC (Btu),

E_{h_o} = baseline heating energy consumption (Btu), and

E_{h_e} = heating energy consumption with EFC (Btu).

The heating energy savings percentage for the EFC is calculated using **Equation 14**.

Equation 14 $\Delta e_h = \left[1 - \frac{\eta_{h_o}}{\eta_{h_e}} \right] 100$

Where, Δe_h = heating savings percentage with EFC compared to baseline (%),
η_{h_o} = baseline furnace heating efficiency (dimensionless), and
η_{h_g} = furnace heating efficiency with EFC (dimensionless).

An example calculation is provided for the 15-minute furnace test 15/16 (**Table 7**) using **Equations 11** through **14**. The baseline furnace uses 16,516 Btu to supply 10,041 Btu with efficiency of 60.8%.[6] With the EFC, the furnace uses 16,527 Btu to supply 11,810 Btu of heat to the space with a efficiency of 71.5%. The heating efficiency improvement with the EFC is calculated using **Equation 11**.

Example Equation 11 $\Delta \eta_h = \left[\frac{\eta_{hg}}{\eta_{h_o}} - 1 \right] \times 100 = \left[\frac{71.5}{60.8} - 1 \right] \times 100 = 17.5\%$

Where, $\Delta \eta_h$ = test 15/16 heating efficiency improvement with EFC = 17.5%,
η_{h_e} = test 15/16 furnace heating efficiency with EFC = 71.5%, and
η_{h_o} = test 15/16 baseline furnace heating efficiency = 60.8%.

The heating energy required to match the EFC heating capacity at the baseline efficiency is calculated using **Equation 12**.

Example Equation 12 $E_{h_m} = \left[\frac{Q_{h_e}}{\eta_{h_o}} \right] = \left[\frac{11810}{0.608} \right] = 19419 \text{ Btu}$

Where, E_{h_m} = energy required to match EFC heating capacity at baseline efficiency = 19419 Btu,
Q_{he} = heating capacity supplied by furnace with EFC = 11810 Btu,
η_{h_o} = heating efficiency without EFC = 0.608.

The heating energy savings with the EFC is calculated using **Equation 13**

Example Eq. 13 $\Delta Q_h = \frac{Q_{h_e} - Q_{h_o}}{\eta_{h_o}} + E_{h_o} - E_{h_e} = \frac{11810 - 10041}{0.608} + 16527 - 16511 = 2907 \text{ Btu}$

Where, ΔQ_h = test 15/16 heating energy savings with EFC = 2,907 Btu,
Q_{h_o} = test 15/16 baseline furnace heating capacity = 10,041 Btu,
Q_{he} = test 15/16 furnace heating capacity with EFC = 11,810 Btu,
η_{h_o} = baseline furnace heating efficiency = 60.8%,
E_{h_o} = baseline furnace energy consumption = 16,527 Btu, and
E_{h_g} = furnace energy consumption with EFC = 16,520 Btu.

[6] Furnace efficiency is defined as energy output divided by energy input (i.e., Btu out divided by Btu in).

The heating energy savings with the EFC is calculated using **Equation 14**.

Example Equation 14 $\Delta\eta_h = \left[1 - \frac{\eta_{h_o}}{\eta_{h_e}}\right] \times 100 = \left[1 - \frac{60.8}{71.5}\right] \times 100 = 14.9\%$

Where, $\Delta\eta_h$ = test 15/16 heating savings percentage with EFC = 14.9%,

η_{h_o} = test 15/16 baseline furnace heating efficiency = 60.8%, and

η_{h_e} = test 15/16 furnace heating efficiency with EFC = 71.5%.

Non-steady state tests for cooling and heating were performed with fixed time delay and EFC variable time delay to measure the sensible cooling or heating capacity and efficiency for the split-system or packaged natural gas furnace. Results for each test are provided in the following tables and figures.

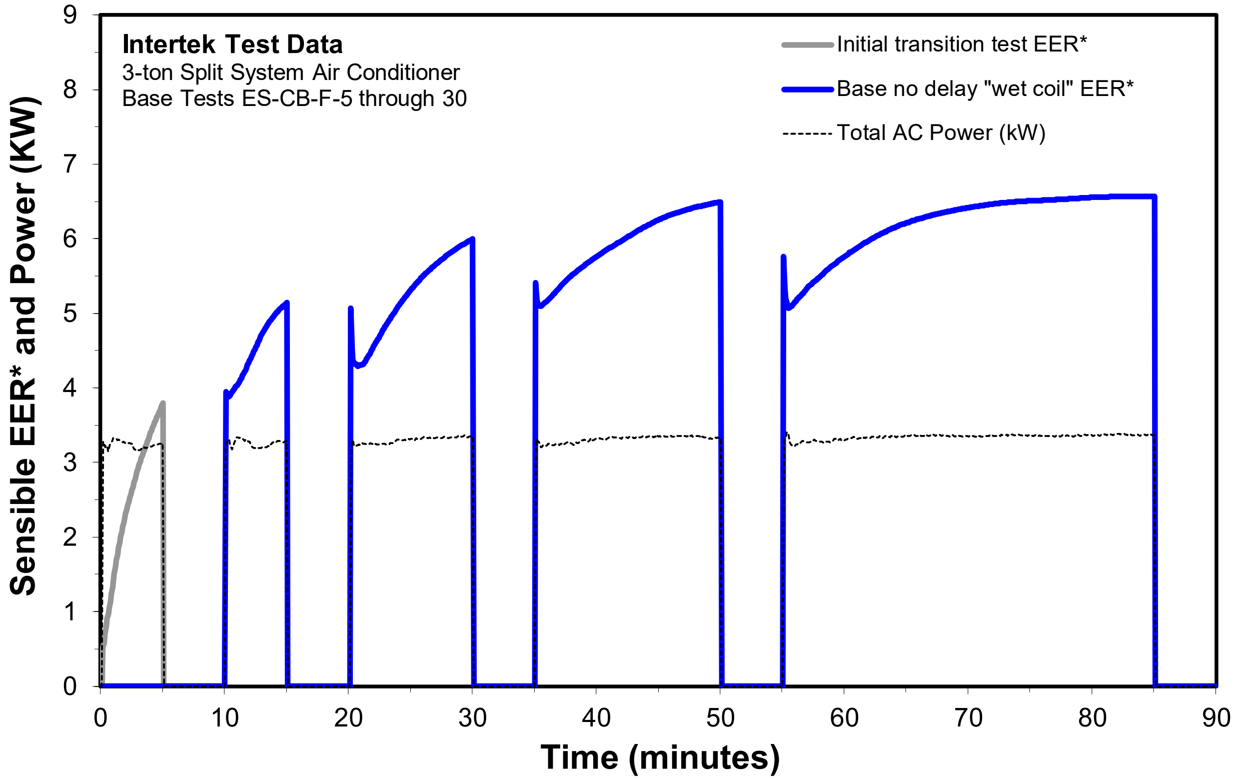
Cooling Tests for 3-ton Split-System with No Delay and EFC Variable Time Delay

Cooling tests were performed for the 3-ton split system with no fan-off delay at typical field conditions of 75F DB and 62F WB indoor and 95F outdoor temperatures. **Table 4** and **Figure 6** provide test results. For the no fan-off delay tests the sensible EER* ranges from 3.79 for 5 minutes AC on time to 6.57 for 30 minutes AC on time.

Table 4: 3-ton Split-System Cooling Tests ES-CB-F-5-30 – No Fan-off Delay

Description	Test 200	Test 201	Test 202	Test 203	Test 204
Compressor On Time (minutes)	5	5	10	15	30
Base AC energy use (kWh) [a]	0.265	0.271	0.544	0.828	1.673
Base sensible cooling (Btu) [b]	1,006	1,396	3,264	5,381	10,995
Base sensible efficiency (EER*) [c=b/a/1000]	3.79	5.14	6.00	6.49	6.57

Figure 6: 3-ton Split-System Base Cooling Tests ES-CB-F-5-30 – No Fan-off Delay

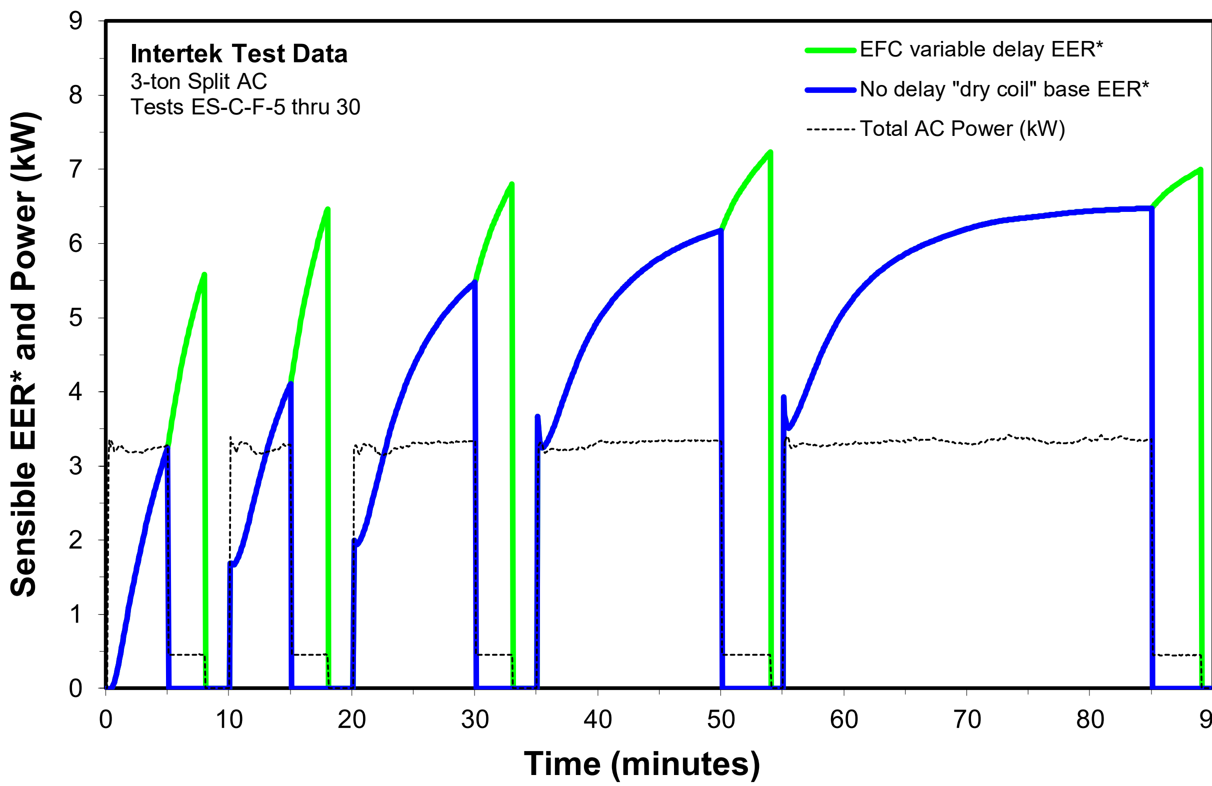


For EFC tests in **Figure 7**, water is evaporated from the evaporator coil at the end of each fan-off delay producing an initial dry coil ("dry coil"), and sensible EER* ranges from 5.58 for 5 minutes to 7.0 for 30 minutes AC on time. The EFC improves sensible EER* by 8 to 72.1% and provides cooling energy savings of 7.4 to 41.9% compared to the no delay initial dry coil conditions in **Table 5**. Compared to the no delay initial wet coil conditions in **Table 4**, the EFC improves sensible efficiency by 6.5 to 47.1% and provides energy savings of 6.1 to 32%. For non-successive base case tests (with 15 to 30 minutes between tests) or fixed fan-off delay tests, the initial evaporator coil condition is closer to a dry coil.

Table 5: 3-ton Split-System Cooling Tests ES-C-F-5 through 30 – No Delay and Variable Delay

Description	Test 1	Test 2	Test 3	Test 4	Test 5
Compressor On Time (minutes)	5	5	10	15	30
No-Time Delay AC Energy (kWh) [a]	0.264	0.270	0.541	0.825	1.666
No-Time Delay Sensible Cooling (Btu) [b]	857	1,109	2,965	5,094	10,791
No-Time Delay Sensible Efficiency (Btu/W) [c=b/a/1000]	3.24	4.11	5.48	6.17	6.48
EFC AC Energy (kWh) [d]	0.287	0.293	0.564	0.855	1.696
EFC Sensible Cooling (Btu) [e]	1,602	1,893	3,837	6,186	11,864
EFC Sensible Efficiency (Btu/W) [f=e/d/1000]	5.58	6.47	6.805	7.23	7.00
EFC Sensible Efficiency Improvement [g=f/c-1]	72.1%	57.4%	24.2%	17.2%	8.0%
EFC Extra Fan Energy (kWh)	0.023	0.023	0.023	0.030	0.030
No Delay Cooling Energy to Match EFC (kWh) [h=e/c/1000]	0.494	0.461	0.700	1.002	1.831
EFC Energy Savings (kWh) [i=h-d or i=(e-b)/c/1000+a-d]	0.207	0.168	0.137	0.147	0.136
EFC Cooling Energy Savings [j=(1-c/f) or j=i/h]	**41.9%**	**36.5%**	**19.5%**	**14.7%**	**7.4%**
Wet coil base sensible efficiency (EER*) [Table 4] [k]	3.79	5.14	6.00	6.49	6.57
EFC Sensible Efficiency Improvement [l=f/-1]	47.1%	25.7%	13.5%	11.4%	6.5%
EFC Cooling Savings vs. Wet Coil Tests [Table 4] [l=1-k/g]	**32.0%**	**20.5%**	**11.9%**	**10.2%**	**6.1%**

Figure 7: 3-ton Split-System Cooling Tests ES-C-F-5 through 30 – No Delay and Variable Delay



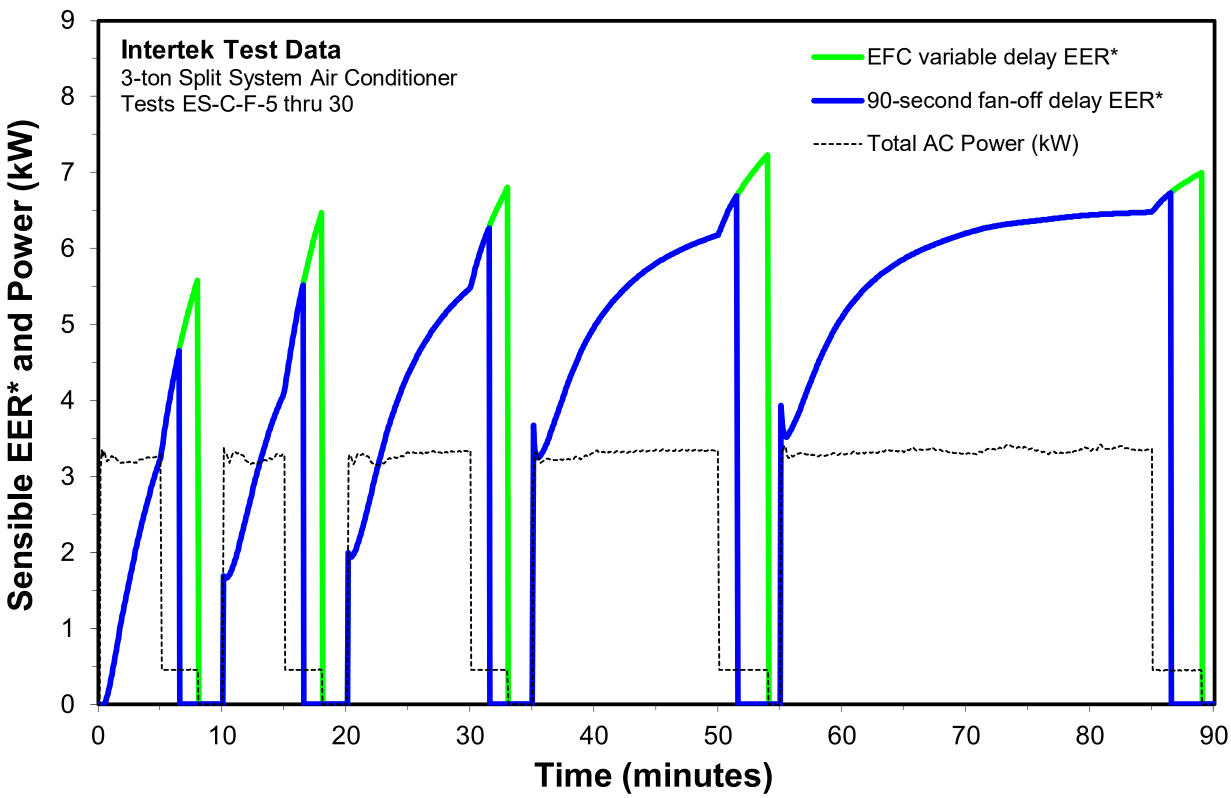
Cooling Tests for 3-ton Split-System with 90-Second and EFC Variable Time Delay

Cooling tests for the 3-ton split system with 90-second delay and EFC variable time delay were performed at typical field conditions of 75F DB and 62F WB indoor and 95F outdoor temperatures. **Table 6** and **Figure 8** provide test results. Based on five tests, the EFC improved sensible cooling efficiency by 4 to 19.9% and provides cooling energy savings of 3.8 to 16.6%.

Table 6: 3-ton Split-System Cooling Tests ES-C-F-5 through 30 – 90-Second and Variable Delay

Description	**Test 6**	**Test 7**	**Test 8**	**Test 9**	**Test 10**
Compressor On Time (minutes)	5	5	10	15	30
90-Second Delay AC Energy (kWh) [a]	0.276	0.281	0.553	0.836	1.677
90-Second Delay Sensible Cooling (Btu) [b]	1,283	1,553	3,465	5,598	11,285
90-Second Delay Sensible Efficiency (Btu/W) [c=b/a/1000]	4.65	5.52	6.27	6.69	6.73
EFC AC Energy (kWh) [d]	0.287	0.293	0.564	0.855	1.696
EFC Sensible Cooling (Btu) [e]	1,602	1,893	3,837	6,186	11,864
EFC Sensible Efficiency (Btu/W) [f=e/d/1000]	5.58	6.47	6.80	7.23	7.00
EFC Sensible Efficiency Improvement [g=f/c-1]	19.9%	17.2%	8.5%	8.1%	4.0%
EFC Extra Fan Energy (kWh)	0.011	0.011	0.011	0.019	0.019
90-Sec. Delay Cooling Energy to Match EFC (kWh) [h=e/c/1000]	0.344	0.343	0.612	0.924	1.763
EFC Energy Savings (kWh) [i=h-d or i=(e-b)/c/1000+a-d]	0.057	0.050	0.048	0.069	0.067
EFC Cooling Energy Savings [j=(1-c/f) or j=i/h]	**16.6%**	**14.7%**	**7.8%**	**7.5%**	**3.8%**

Figure 8: 3-ton Split-System Cooling Tests ES-C-F-5 through 30 – 90-Second and Variable Delay



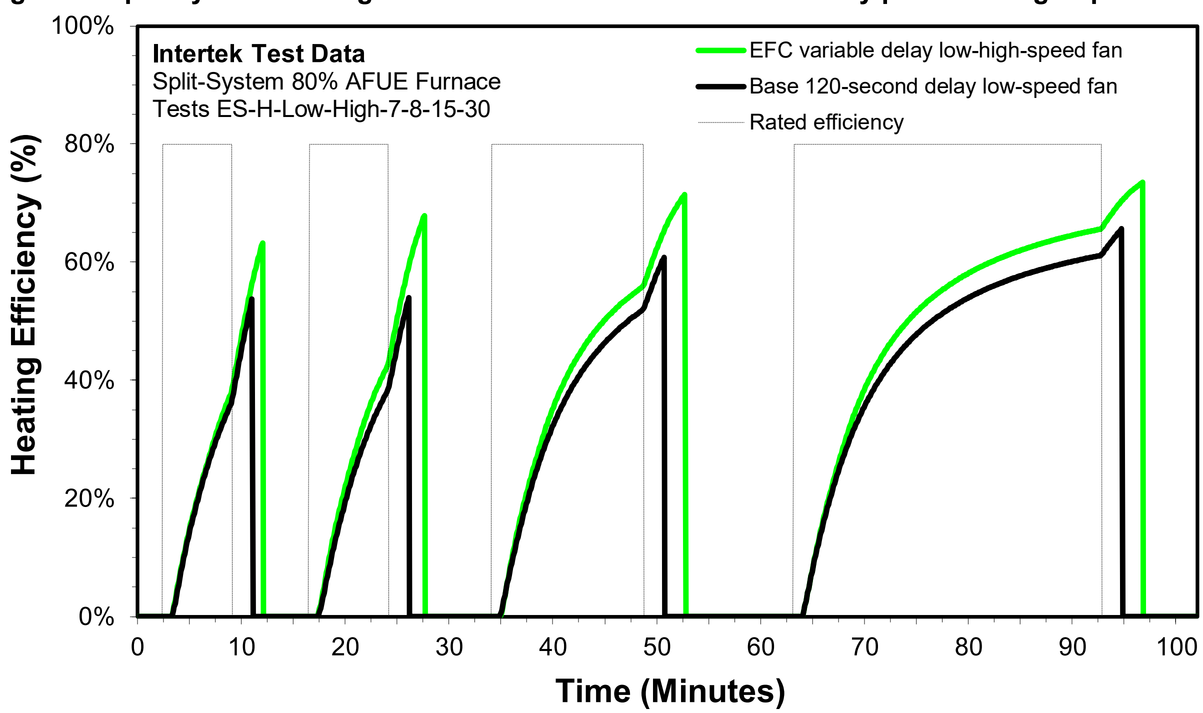
Heating Tests for Split-System with 120-Second and Variable Delay plus Low-High Speed Fan

Heating tests for the 3-ton split-system were performed at typical field conditions of 72F DB and 53F WB indoor and 42F outdoor temperatures. **Table 7** and **Figure 9** provide test results. For the baseline tests the indoor fan operated at low speed with fixed 120-second time delay after furnace turned off. With EFC the indoor fan operated at low speed for first 4-minutes and high speed after with variable time delay after furnace turned off. Each pair of tests used approximately the same gas energy (within 0.08%). High speed provided 11.3% more airflow than low speed. The EFC improved heating efficiency by 11.8 to 25.8% and provides heating energy savings of 10.5 to 20.5%.

Table 7: Split-System Heating Tests – 120-Second and Variable Delay plus Low-High Speed Fan

Description	Test 11/12	Test 13/14	Test 15/16	Test 17/18
Furnace On Time (minutes)	7	8	15	30
120-Second Delay Heating Capacity (Btu) [a]	3,962	4,617	10,041	21,926
120-Second Delay Furnace Energy Input (Btu) [b]	7,375	8,559	16,511	33,407
120-Second Time Delay Heating Efficiency [c=a/b]	53.7%	53.9%	60.8%	65.6%
EFC Delivered Heating Capacity (Btu) [d]	4,668	5,763	11,810	24,555
EFC Furnace Energy Input (Btu) [e]	7,378	8,494	16,527	33,474
EFC Heating Efficiency [f=d/e]	63.3%	67.8%	71.5%	73.4%
EFC Heating Efficiency Improvement [g=f/c-1]	17.8%	25.8%	17.5%	11.8%
EFC Extra Fan Energy (kWh) [h]	0.008	0.003	0.015	0.015
120-Sec. Delay Furnace Energy to Match EFC (Btu) [i=e/c]	8,690	10,684	19,419	37,412
EFC Energy Savings (Btu) [k=i-e or k=(d-a)/c+b-e]	1,312	2,190	2,891	3,939
EFC Heating Energy Savings [l=(1-c/f) or l=i/k]	**15.1%**	**20.5%**	**14.9%**	**10.5%**

Figure 9: Split-System Heating Tests – 120-Second and Variable Delay plus Low-High Speed Fan



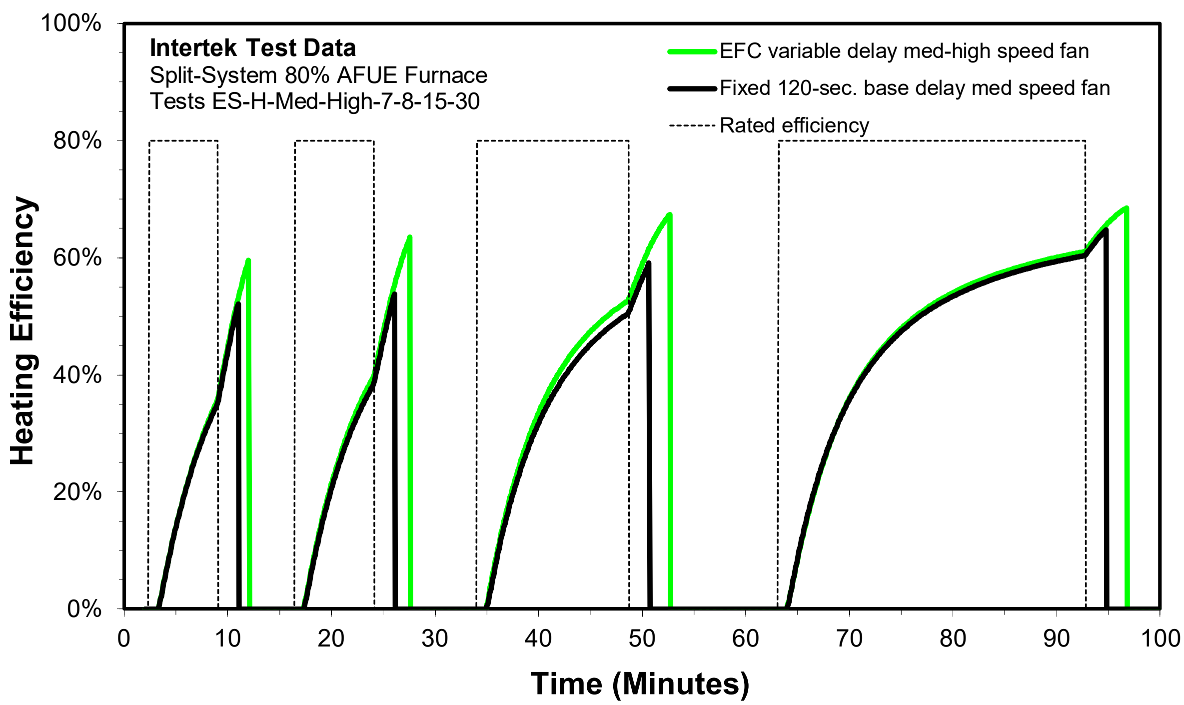
Heating Tests for Split-System with 120-Second and Variable Delay plus Med-High Speed Fan

Heating tests for the 3-ton split-system were performed at typical field conditions of 72F DB and 53F WB indoor and 42F outdoor temperatures. **Table 8** and **Figure 10** provide test results. For baseline heating tests the furnace fan operated at medium speed with fixed 120-second time delay after furnace turned off. With EFC the indoor fan operated at medium speed for the first 4-minutes and high speed afterwards with variable time delay after the furnace turned off. Each pair of tests used approximately the same gas energy (within 0.07%). High speed provided 4.8% more airflow than medium. Based on four tests, the EFC improved heating efficiency by 5.5 to 17.9% and provides heating energy savings of 5.3 to 15.2%.

Table 8: Split-System Heating Tests – 120-Second and Variable Delay plus Med-High Speed Fan

Description	**Test 19/20**	**Test 21/22**	**Test 23/24**	**Test 25/26**
Furnace On Time (minutes)	7	8	15	30
120-Second Delay Furnace Energy Input (Btu) [a]	7,406	8,515	16,476	33,387
120-Second Delay Heating Capacity (Btu) [b]	3,886	4,613	9,813	21,793
120-Second Time Delay Heating Efficiency [c=b/a]	52.5%	54.2%	59.6%	65.3%
EFC Furnace Energy Input (Btu) [d]	7,385	8,546	16,396	33,409
EFC Delivered Heating Capacity (Btu) [e]	4,434	5,458	11,118	23,036
EFC Heating Efficiency [f=e/d]	60.0%	63.9%	67.8%	68.9%
EFC Heating Efficiency Improvement [g=f/c-1]	14.4%	17.9%	13.8%	5.5%
EFC Extra Fan Energy (kWh)	0.011	0.015	0.024	0.034
120-Sec. Delay Furnace Energy to Match EFC (Btu) [h=e/c]	8,450	10,070	18,654	35,277
EFC Energy Savings (Btu) [i=h-d or i=(e-b)/c+a-d]	1,065	1,528	2,270	1,882
EFC Heating Energy Savings [j=(1-c/f) or j=i/h]	**12.6%**	**15.2%**	**12.2%**	**5.3%**

Figure 10: Split-System Heating Tests – 120-Second and Variable Delay plus Med-High Speed Fan



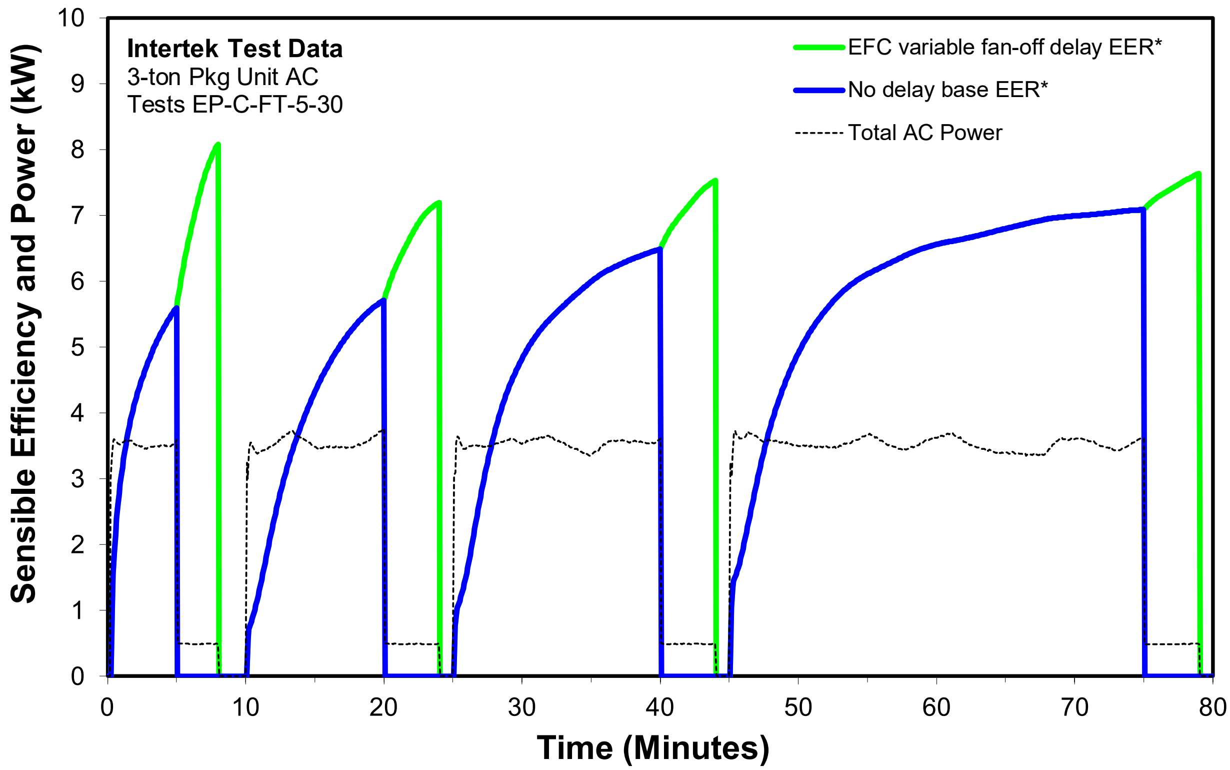
Cooling Tests for 3-ton Packaged Unit with No Delay and EFC Variable Time Delay

Cooling tests for the 3-ton packaged unit with no time delay and EFC variable time delay were performed at typical field conditions of 75F DB and 62F WB indoor and 95F outdoor temperatures. **Table 9** and **Figure 11** provide test results. Based on four tests, the EFC improved sensible efficiency by 7.8 to 44.4% and provides cooling energy savings of 7.2 to 30.7%.

Table 9: 3-ton Packaged Cooling Tests EP-C-FT-5 through 30 – No Delay and Variable Delay

Description	Test 27	Test 28	Test 29	Test 30
Compressor On Time (minutes)	5	10	15	30
No-Time Delay AC Energy (kWh) [a]	0.283	0.590	0.883	1.764
No-Time Delay Sensible Cooling (Btu) [b]	1,585	3,368	5,733	12,509
No-Time Delay Sensible Efficiency [c=b/a/1000]	5.60	5.71	6.49	7.09
EFC AC Energy (kWh) [d]	0.308	0.622	0.916	1.797
EFC Sensible Cooling (Btu) [e]	2,487	4,482	6,903	13,732
EFC Sensible Efficiency [f=e/d/1000]	8.09	7.20	7.54	7.64
EFC Sensible Efficiency Improvement [h=f/c-1]	44.4%	26.0%	16.1%	7.8%
EFC Extra Fan Energy (kWh)	0.025	0.033	0.033	0.033
No Delay input to match EFC (kWh) [h=e/c/1000]	0.444	0.785	1.063	1.936
EFC Energy Savings (kWh) [i=h-d or i=(e-b)/c/1000+a-d]	0.136	0.162	0.147	0.140
EFC Cooling Energy Savings [g=(1-c/f) or g=i/h]	**30.7%**	**20.7%**	**13.9%**	**7.2%**

Figure 11: 3-ton Packaged Cooling Tests EP-C-FT-5 through 30 – No Delay and Variable Delay



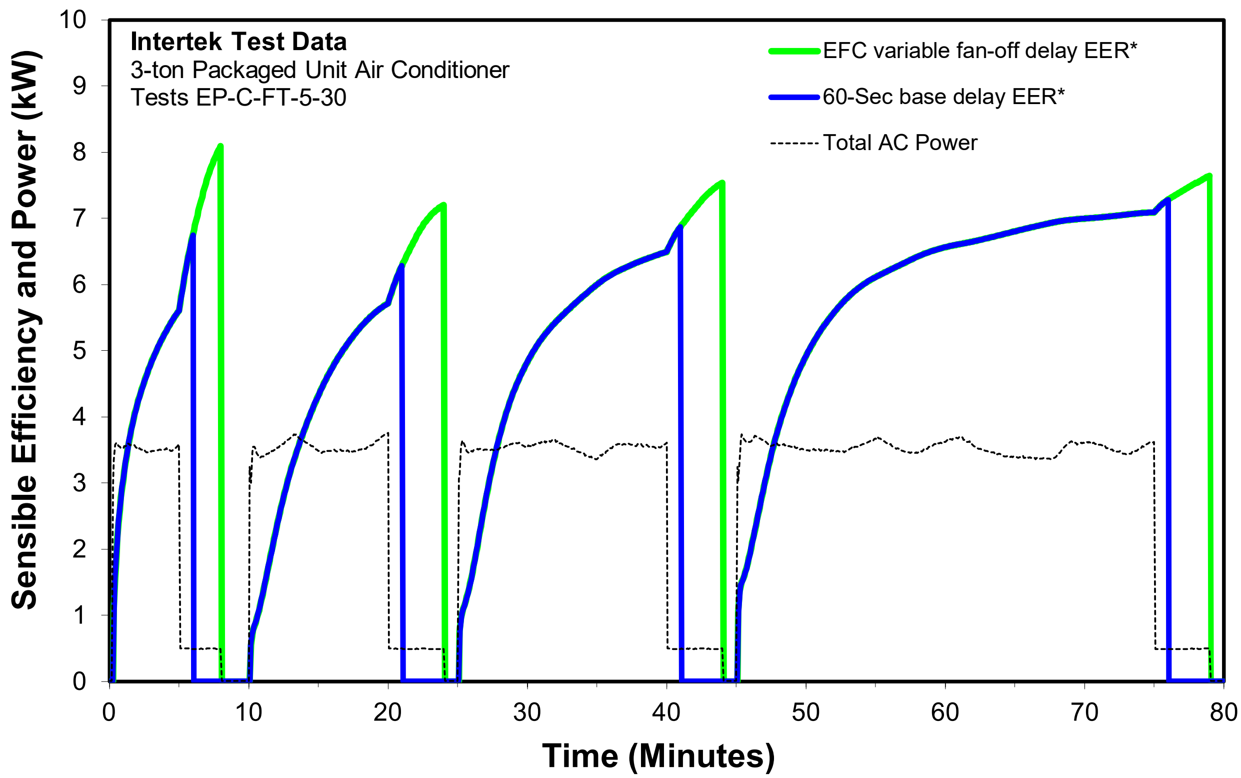
Cooling Tests for 3-ton Packaged Unit with 60-Second and EFC Variable Time Delay

Cooling tests for the 3-ton packaged unit with 60-second time delay and EFC variable time delay were performed at typical field conditions of 75F DB and 62F WB indoor and 95F outdoor temperatures. **Table 10** and **Figure 12** provide test results. Based on four tests, the EFC improved sensible efficiency by 5 to 19.8% and provides cooling energy savings of 4.7 to 16.6%.

Table 10: 3-ton Packaged Cooling Tests EP-C-FT-5 through 30 – 60-Second and Variable Delay

Description	Test 31	Test 32	Test 33	Test 34
Compressor On Time (minutes)	5	10	15	30
60-Second Delay AC Energy (kWh) [a]	0.291	0.598	0.891	1.772
60-Second Delay Sensible Cooling (Btu) [b]	1,963	3,756	6,125	12,903
60-Second Delay Sensible Efficiency [c=b/a/1000]	6.74	6.28	6.87	7.28
EFC AC Energy (kWh) [d]	0.308	0.622	0.916	1.797
EFC Sensible Cooling (Btu) [e]	2,487	4,482	6,903	13,732
EFC Sensible Efficiency [f=e/d/1000]	8.09	7.20	7.54	7.64
EFC Sensible Efficiency Improvement [h=f/c-1]	19.9%	14.6%	9.7%	5.0%
EFC Extra Fan Energy (kWh)	0.016	0.025	0.025	0.025
60-Sec delay input to match EFC (kWh) [h=e/c/1000]	0.369	0.713	1.005	1.886
EFC Energy Savings (kWh) [i=h-d or i=(e-b)/c/1000+a-d]	0.061	0.091	0.089	0.089
EFC Cooling Energy Savings [g=(1-c/f) or g=i/h]	**16.6%**	**12.7%**	**8.8%**	**4.7%**

Figure 12: 3-ton Packaged Cooling Tests EP-C-FT-5 through 30 – 60-Second and Variable Delay



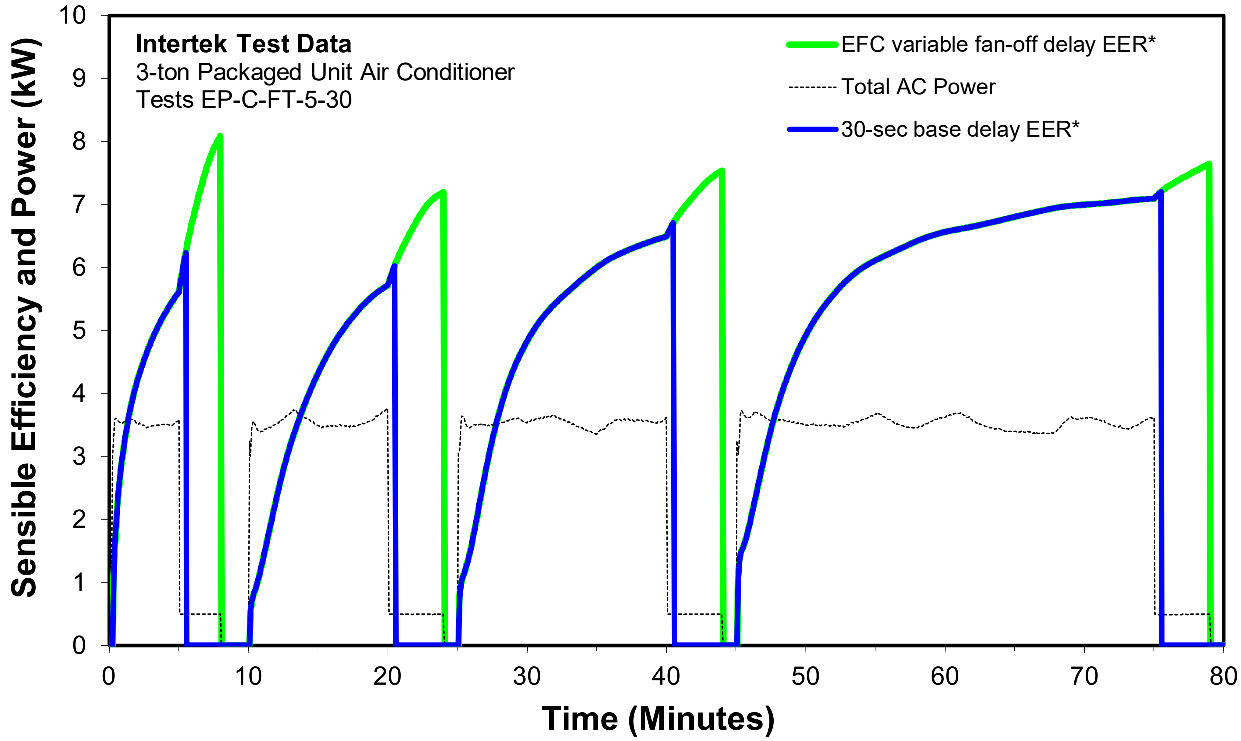
Cooling Tests for 3-ton Packaged Unit with 30-Second and EFC Variable Time Delay

Cooling tests for the 3-ton packaged unit with 30-second time delay and EFC variable time delay were performed at typical field conditions of 75F DB and 62F WB indoor and 95F outdoor temperatures. **Table 11** and **Figure 13** provide test results. Based on four tests, the EFC improved sensible efficiency by 6.2 to 29.5% and sensible cooling efficiency by 5.8 to 22.8%.

Table 11: 3-ton Packaged Cooling Tests EP-C-FT-5 through 30 – 30-Second and Variable Delay

Description	Test 59	Test 60	Test 61	Test 62
Compressor On Time (minutes)	5	10	15	25
30-Second Delay AC Energy (kWh) [a]	0.287	0.594	0.887	1.768
30-Second Delay Sensible Cooling (Btu) [b]	1,818	3,615	6,008	12,879
30-Second Delay Sensible Efficiency (Btu/W) [c=b/a/1000]	6.33	6.09	6.77	7.28
EFC AC Energy (kWh) [d]	0.307	0.622	0.916	1.797
EFC Sensible Cooling (Btu) [e]	2,522	4,514	6,971	13,896
EFC Sensible Efficiency (Btu/W) [f=e/d/1000]	8.20	7.26	7.61	7.73
EFC Sensible Efficiency Improvement [g=f/c-1]	29.5%	19.3%	12.4%	6.2%
EFC Extra Fan Energy (kWh)	0.021	0.028	0.029	0.029
30-Sec. Delay Cooling Energy to Match EFC (kWh) [h=e/c/1000]	0.398	0.742	1.030	1.908
EFC Energy Savings (kWh) [i=h-d or i=(e-b)/c/1000+a-d]	0.091	0.120	0.114	0.111
EFC Cooling Energy Savings [j=(1-c/f) or j=i/h]	**22.8%**	**16.2%**	**11.0%**	**5.8%**

Figure 13: 3-ton Packaged Cooling Tests EP-C-FT-5 through 30 – 30-Second and Variable Delay



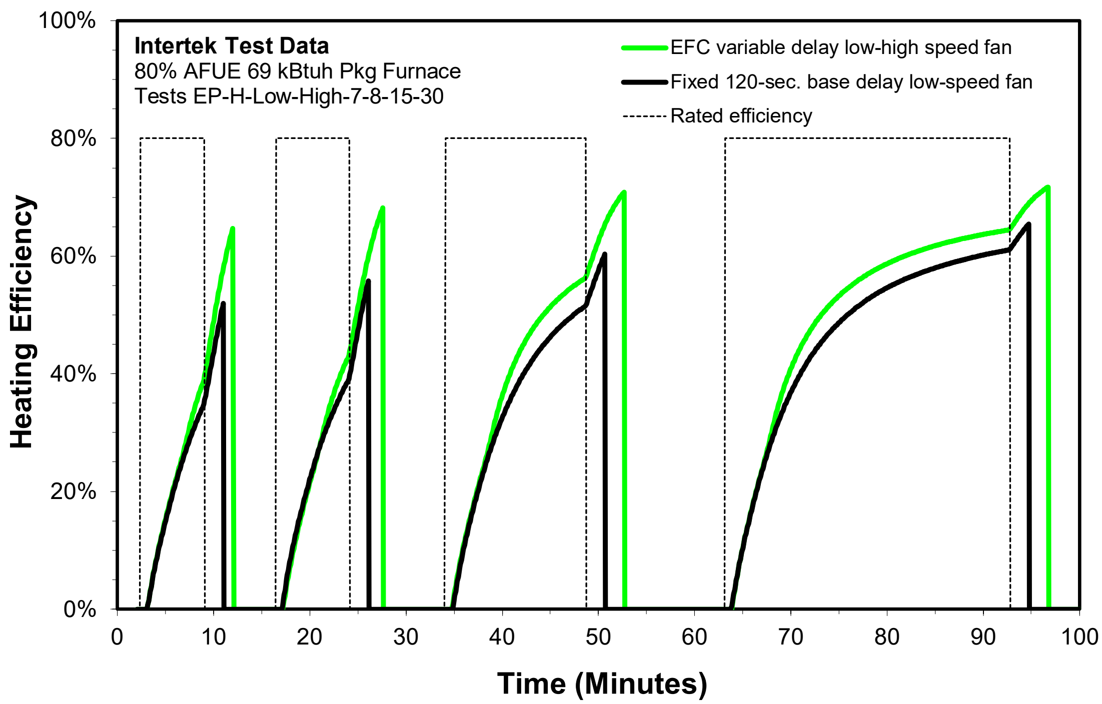
Heating Tests for Packaged Unit with 120-Second and Variable Delay plus Low-High Speed Fan

Heating tests for the 3-ton packaged unit with 120-second time delay and EFC variable time delay were performed at typical field conditions of 72F DB and 54F WB indoor and 42F outdoor temperatures. **Table 12** and **Figure 14** provide test results. For baseline heating tests the indoor fan was operated at low speed with fixed 120-second time delay after furnace turned off. With EFC the indoor fan operated at low speed for first 4-minutes and high speed after with variable time delay after furnace turned off. High speed provided 24.4% more airflow than low speed. The EFC improves heating efficiency by 9.5 to 24.7% and provides heating energy savings of 8.7 to 19.8%.

Table 12: Packaged Unit Heating Tests – 120-Second and Variable Delay plus Low-High Speed Fan

Description	Test 35/36	Test 37/38	Test 39/40	Test 41/42
Furnace On Time (minutes)	7	8	15	30
120-Second Delay Heating Capacity (Btu) [a]	4,095	5,037	10,320	22,395
120-Second Delay Furnace Energy Input (Btu) [b]	7,888	9,027	17,101	34,189
120-Second Time Delay Heating Efficiency [c=b/a]	51.9%	55.8%	60.3%	65.5%
EFC Delivered Heating Capacity (Btu) [e]	5,072	6,097	12,018	24,455
EFC Furnace Energy Input (Btu) [d]	7,837	8,963	16,954	34,085
EFC Heating Efficiency [f=e/d]	64.7%	68.0%	70.9%	71.7%
EFC Heating Efficiency Improvement [g=f/c-1]	24.7%	21.9%	17.5%	9.5%
EFC Extra Fan Energy (kWh)	0.021	0.028	0.052	0.092
120-Sec. Delay Furnace Energy to Match EFC (Btu) [h=e/c]	9,770	10,927	19,914	37,334
EFC Energy Savings (Btu) [i=h-d or i=(e-b)/c+a-d]	1,934	1,964	2,960	3,249
EFC Heating Energy Savings [j=(1-c/f) or j=i/h]	**19.8%**	**18.0%**	**14.9%**	**8.7%**

Figure 14: Packaged Heating Tests – 120-Second and Variable Delay plus Low-High Speed



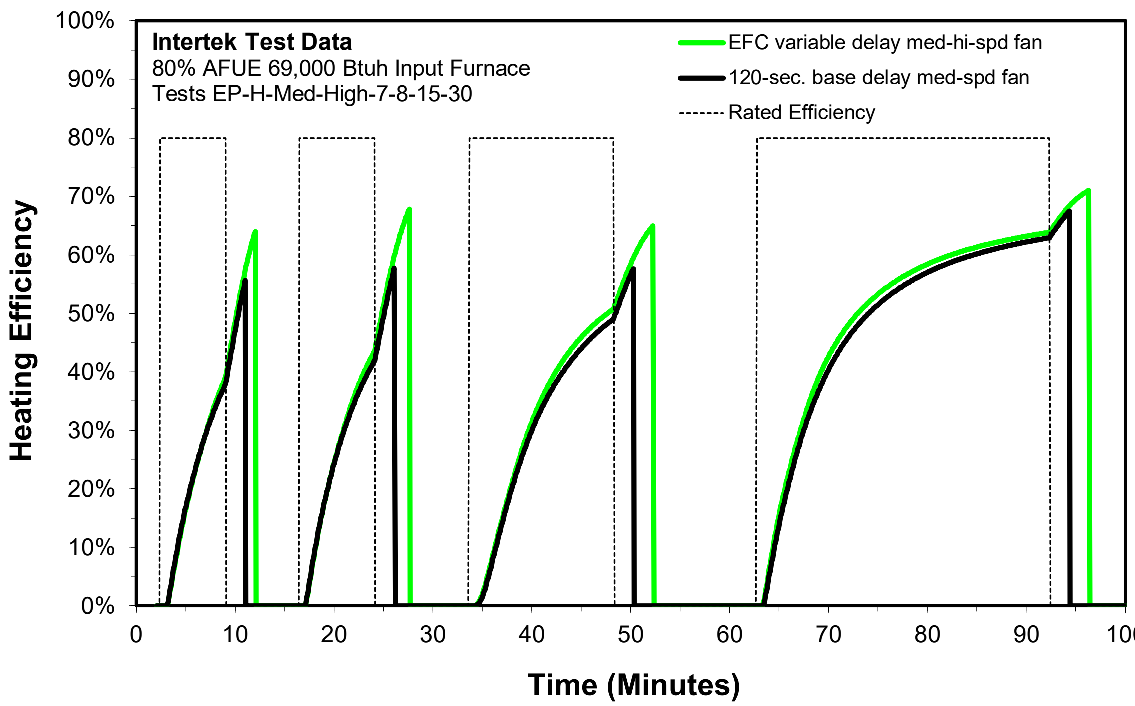
Heating Tests for Packaged Unit with 120-second and Variable Delay plus Med-High Speed Fan

Heating tests for the 3-ton packaged unit with 120-second time delay and EFC variable time delay were performed at typical field conditions of 72F DB and 54F WB indoor and 42F outdoor temperatures. **Table 13** and **Figure 15** provide results. For the baseline heating tests the indoor fan operated at medium speed with fixed 120-second time delay after furnace turned off. With EFC the indoor fan operated at medium speed for first 4-minutes and high speed after with variable time delay after furnace turned off. High speed provided 6.8% more airflow than medium speed. The EFC improves heating efficiency by 5.3 to 17.5% and provides heating energy savings of 5 to 14.9%.

Table 13: Packaged Gas Heating Tests – 120-Second and Variable Delay plus Med-High Speed Fan

Description	Test 43/44	Test 45/46	Test 47/48	Test 49/50
Furnace On Time (minutes)	7	8	15	30
120-Second Delay Heating Capacity (Btu) [a]	4,382	5,201	9,781	23,111
120-Second Delay Furnace Energy Input (Btu) [b]	7,878	9,012	16,974	34,254
120-Second Time Delay Heating Efficiency [c=b/a]	55.6%	57.7%	57.6%	67.5%
EFC Delivered Heating Capacity (Btu) [e]	4,990	6,066	10,945	24,461
EFC Furnace Energy Input (Btu) [d]	7,801	8,948	16,841	34,427
EFC Heating Efficiency [f=e/d]	64.0%	67.8%	65.0%	71.1%
EFC Heating Efficiency Improvement [g=f/c-1]	15.0%	17.5%	12.8%	5.3%
EFC Extra Fan Energy (kWh)	0.014	0.022	0.031	0.050
120-Sec. Delay Furnace Energy to Match EFC (Btu) [h=e/c]	8,971	10,510	18,993	36,255
EFC Energy Savings (Btu) [i=h-d or i=(e-b)/c+a-d]	1,170	1,562	2,152	1,828
EFC Heating Energy Savings [j=(1-c/f) or j=i/h]	**13.0%**	**14.9%**	**11.3%**	**5.0%**

Figure 15: Packaged Unit Heating Tests – 120-Second and Variable Delay + Med-High Speed Fan



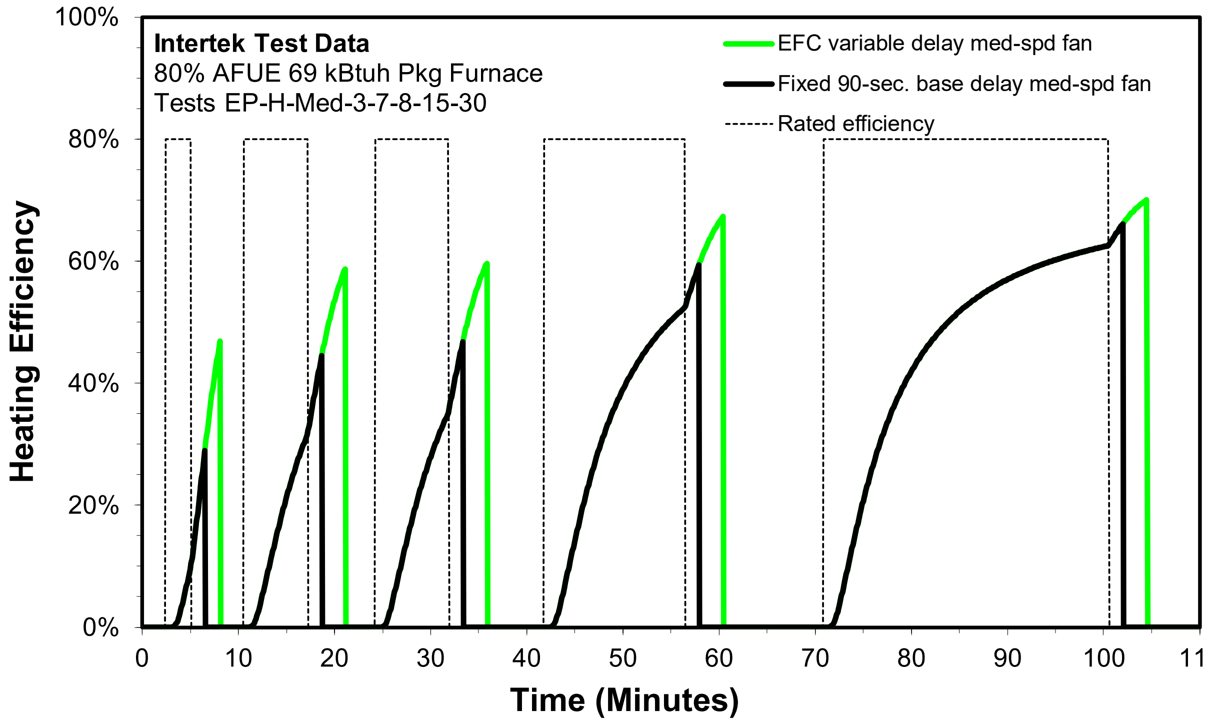
Heating Tests for Packaged Unit with 120-Second and Variable Delay and Medium Speed Fan

Heating tests for the 3-ton packaged unit with 120-second time delay and EFC variable time delay were performed at typical field conditions of 72F DB and 54F WB indoor and 42F outdoor temperatures. **Table 14** and **Figure 16** provide test results. For baseline heating tests the indoor fan operated at medium speed with fixed 120-second time delay after furnace turned off. With EFC the fan operated at medium speed with variable time delay after furnace turned off. Each pair of tests used the same gas energy. The EFC improves heating efficiency by 4.4 to 21.5% and provides heating energy savings of 4.2 to 17.8%.

Table 14: Packaged Unit Heating Tests – 120-Second and Variable Delay and Medium Speed Fan

Description	Test 51/52	Test 53/54	Test 55/56	Test 57/58
Furnace On Time (minutes)	7	8	15	30
120-Second Delay Heating Capacity (Btu) [a]	3,755	4,485	9,887	21,952
120-Second Delay Furnace Energy Input (Btu) [b]	7,774	8,952	16,081	32,695
120-Second Time Delay Heating Efficiency [c=b/a]	48.3%	50.1%	61.5%	67.1%
EFC Delivered Heating Capacity (Btu) [e]	4,566	5,173	10,826	22,907
EFC Furnace Energy Input (Btu) [d]	7,774	8,952	16,081	32,695
EFC Heating Efficiency [f=e/d]	58.7%	57.8%	67.3%	70.1%
EFC Heating Efficiency Improvement [g=f/c-1]	21.5%	15.3%	9.5%	4.4%
EFC Extra Fan Energy (kWh)	0.014	0.011	0.014	0.014
120-Sec. Delay Furnace Energy to Match EFC (Btu) [h=e/c]	9,453	10,325	17,609	34,118
EFC Energy Savings (Btu) [i=h-d or i=(e-b)/c+a-d]	1,681	1,373	1,528	1,423
EFC Heating Energy Savings [j=(1-c/f) or j=i/h]	**17.8%**	**13.3%**	**8.7%**	**4.2%**

Figure 16: Packaged Unit Heating Tests – 120-Second and Variable Delay and Medium Speed Fan



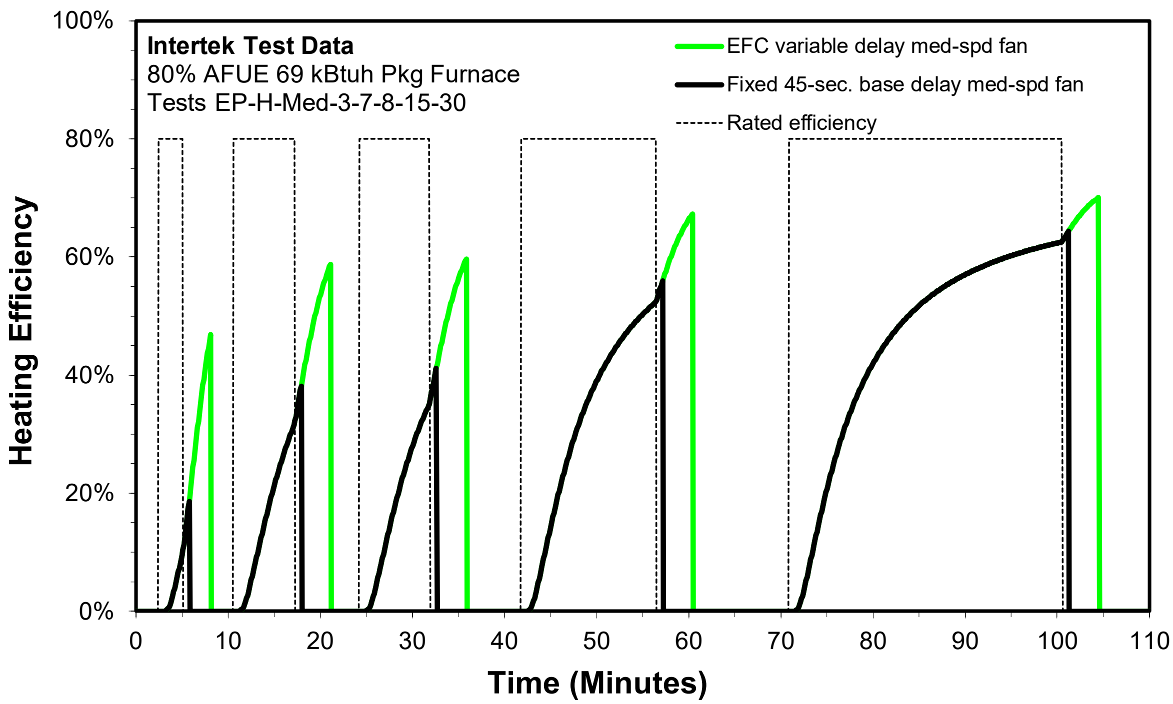
Heating Tests for Packaged Unit with 45-Second and Variable Delay and Medium Fan Speed

Heating tests for the 3-ton packaged unit with 45-second time delay and EFC variable time delay were performed at typical field conditions of 72F DB and 54F WB indoor and 42F outdoor temperatures. **Table 15** and **Figure 17** provide test results. For the baseline heating tests the indoor fan operated at medium speed with fixed 45-second time delay after furnace turned off. The EFC heating tests were performed with the variable time delay after the furnace turned off. Each pair of tests used the same amount of gas input energy. The EFC improves heating efficiency by 8.8 to 42.8% and provides heating energy savings of 8.1 to 30%.

Table 15: Packaged Unit Heating Tests – 45-Second and Variable Delay and Medium Speed Fan

Description	Test 63/52	Test 65/54	Test 67/56	Test 69/58
Furnace On Time (minutes)	7	8	15	30
45-Second Delay Heating Capacity (Btu) [a]	2,966	3,680	9,004	21,054
45-Second Delay Furnace Energy Input (Btu) [b]	7,774	8,952	16,081	32,695
45-Second Time Delay Heating Efficiency [c=b/a]	38.2%	41.1%	56.0%	64.4%
EFC Delivered Heating Capacity (Btu) [e]	4,566	5,173	10,826	22,907
EFC Furnace Energy Input (Btu) [d]	7,774	8,952	16,081	32,695
EFC Heating Efficiency [f=e/d]	58.7%	57.8%	67.3%	70.1%
EFC Heating Efficiency Improvement [g=f/c-1]	53.9%	40.6%	20.2%	8.8%
EFC Extra Fan Energy vs. 45-sec delay (kWh)	0.023	0.020	0.023	0.023
45-Sec. Delay Furnace Energy to Match EFC (Btu) [h=e/c]	11,967	12,585	19,336	35,574
EFC Energy Savings (Btu) [i=h-d or i=(e-b)/c+a-d]	4,193	3,633	3,255	2,878
EFC Heating Energy Savings [j=(1-c/f) or j=i/h]	**35.0%**	**28.9%**	**16.8%**	**8.1%**

Figure 17: Packaged Unit Tests – 45-Second and Variable Delay and Medium Speed Fan



Conclusion

The following conclusions are provided regarding the performance evaluation tests of the EFC installed on a 3-ton split-system HVAC unit. Based on 10 cooling tests, the EFC provides cooling energy savings of 7.4 to 41.9% compared to zero fan-off time delay and 3.8 to 16.6% compared to 90-second fan-off time delay. Based on 16 gas furnace heating tests, the EFC provides heating energy savings of 5.3 to 20.5% compared to low- or medium-speed heater fan operation and fixed 120-second time delay.

The following conclusions are provided regarding the performance evaluation tests of the EFC installed on a 3-ton packaged HVAC unit. Based on 12 cooling tests, the EFC provides cooling energy savings of by 7.2 to 30.7% compared to zero fan-off time delay, 5.8 to 22.8% compared to 30-second fan-off time delay, and 4.7 to 16.6% compared to 60-second fan-off time delay. Based on 32 gas furnace heating tests, the EFC provides heating energy savings of 5 to 19.8% compared to low- or medium-speed heater fan operation and fixed 120-second time delay and 4.2 to 30% compared to medium-speed heater fan operation with a 45- or 120-second fan-off time delay.

The EFC requires extra fan energy to recover and deliver additional sensible cooling or heating capacity from the HVAC system evaporator or heat exchanger to improve cooling or heating efficiency, lengthen off-cycles, and save cooling or heating energy. For cooling, the average extra fan energy per cycle with the EFC is 0.024 ± 0.002 kWh or 21 ± 2.2% of cooling savings (i.e., 1 unit of extra fan energy provides 4.7 ± 0.5 units of cooling energy savings). For heating, the average extra fan energy per cycle with the EFC is 0.029 ± 0.004 kWh or 14 ± 2% of heating savings (i.e., 1 unit of extra fan energy provides 7.1 ± 1 units of heating energy savings).[7] For heating, the average low-to-high airflow increase was 18% and the average medium-to-high airflow increase was 6.2%. Increasing airflow to high speed during furnace operation supplies more heating capacity to satisfy the space heating thermostat sooner, reduce furnace operation, and save gas energy.

Based on 22 cooling tests, the EFC improves sensible cooling efficiency by 4 to 72.1% and provides cooling energy savings of 3.8 to 41.9%. Based on 48 gas furnace heating tests, the EFC improves heating efficiency by 4.4 to 42.8% and provides heating energy savings of 4.2 to 30%.

Report Number	Date	Description
101756555DAL-001A	08-04-15	Original version of report
101756555DAL-001B	11-15-18	Updated text and tables

[7] The EFC extra fan energy for heating is valued at 10,354 Btu/kWh based on natural gas electricity generation. US Energy Information Agency (EIA) 2013. Average Tested Heat Rates by Prime Mover and Energy Source, 2007-2013. https://www.eia.gov/electricity/annual/html/epa_08_02.html).