INTERTEK PERFORMANCE EVALUATION OF AN EFFICIENT FAN CONTROLLER (EFC) INSTALLED ON HEAT PUMP AND HYDRONIC SPLIT-SYSTEMS

12/15/2016 Intertek Project No. G102791047
Revised 11-15-18

Report Scope:
This report summarizes the performance evaluation of an Efficient Fan Controller (EFC or smart EFC) energy efficiency measure for Heating, Ventilating, Air Conditioning (HVAC) systems. The EFC was installed on a new 14-SEER heat pump and a new 13-SEER split-system with hydronic heating coil. Testing was conducted at the Intertek® laboratory in Plano, Texas, under the direction of Ean Jones and Robert Mowris. 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 fan operation depending on the length of time the AC compressor or the furnace, heat pump, hydronic or electric heating system (referred to as "time delay" or fan-off delay"). The EFC automatically detects the type of HVAC system it is connected to and cooling or heating system operational mode. For heat pumps the EFC detects heat pump reversing valve operation and maintains the reversing valve position for cooling or heating throughout the fan-off time delay period. The EFC improves HVAC efficiency and saves energy by providing variable fan-off time delays based on HVAC system type, mode of operation, duration of cooling cycle or heating cycle (on and off cycle), 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, improve comfort, lengthen off-cycles, and reduce on-cycles. The smart EFC does not add fan-off delays to short cycles or to intermittent or hourly fan-on durations selected by users.

Description of Test Units
The heat pump test equipment schematic is shown in **Figure 1** and the hydronic test equipment schematic is shown in **Figure 2**. This report provides test results for heat pump heating and cooling tests and hydronic heating tests. The characteristics of the test units are described in **Table 1**.

Figure 1: Heat Pump Test Equipment Schematic

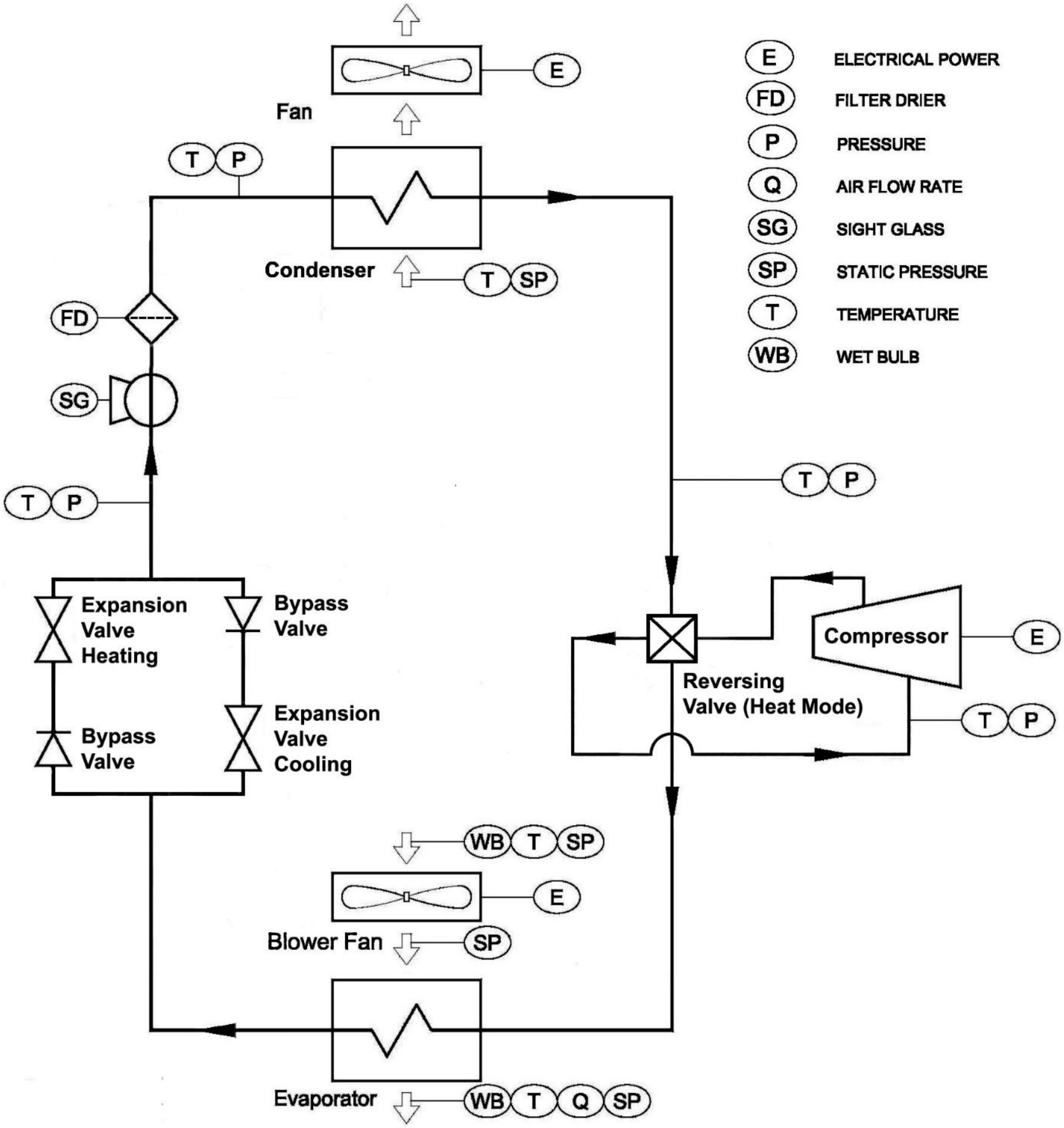
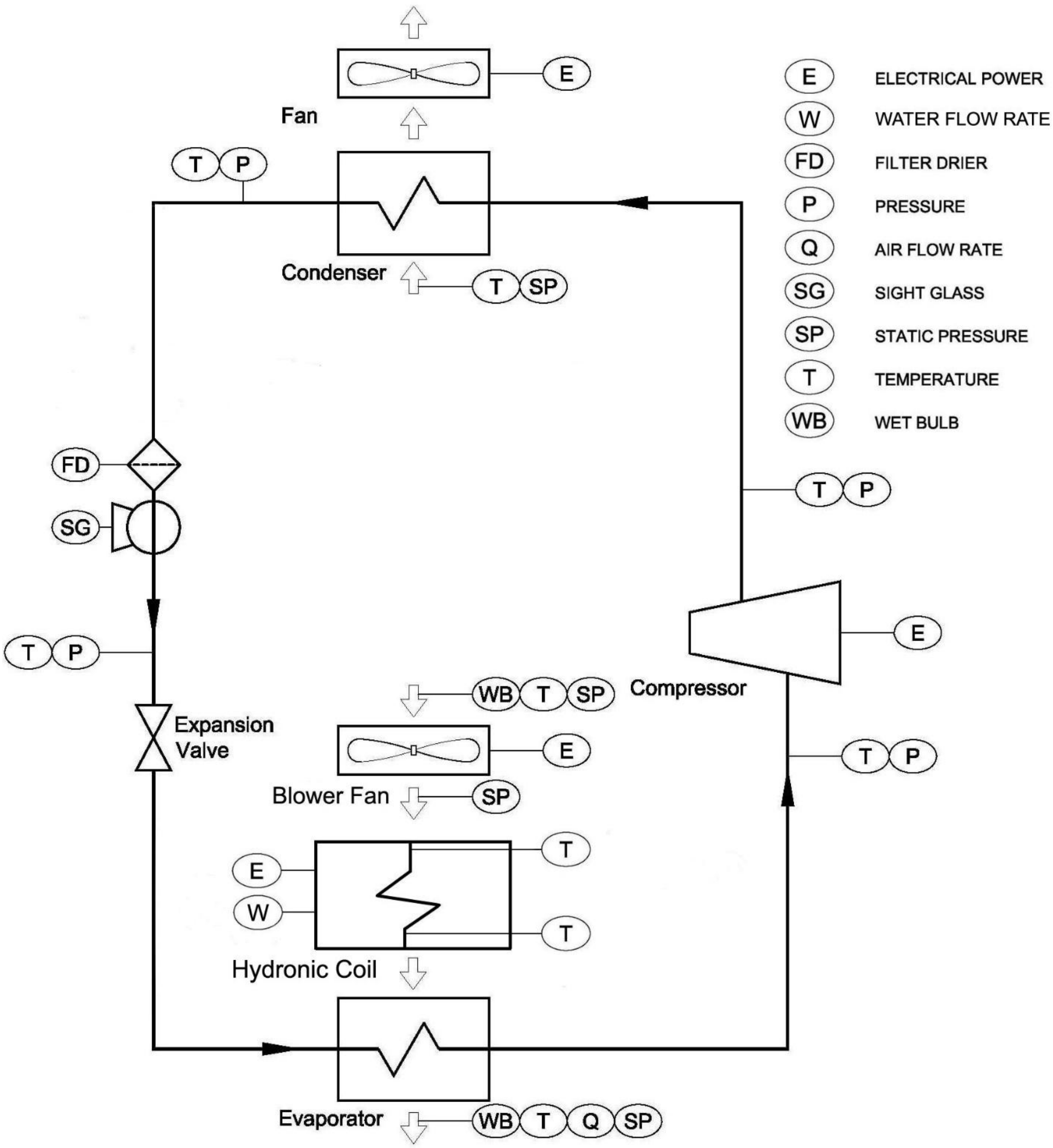


Figure 2: Hydronic Test Equipment Schematic



The 1.5-ton split-system Heat Pump (HP) rated total cooling capacity is 17,600 Btu per hour (Btuh) and the sensible cooling capacity is 13,900 Btuh at 95 degrees Fahrenheit (F) outdoor air temperature (OAT) and 525 cfm evaporator airflow with 80F indoor drybulb and 67F indoor wetbulb temperatures. The rated total cooling capacity is 17,000 Btuh and sensible cooling capacity is 13,600 Btuh at 95F OAT and 75F indoor drybulb and 62F indoor wetbulb temperatures. The rated heating capacity is 18,000 Btu per hour

at 47F OAT. The heat pump rated cooling efficiency is 14-SEER and the heating coefficient of performance (COP) is 3.76 at 47 degrees Fahrenheit (F) outdoor air temperature (OAT). The heat pump cooling or heating fan-off time delays are fixed during setup at either 0 seconds or 65 seconds after the cool or heat source turns off.

The 1.5-ton hydronic (HYD) split-system rated total cooling capacity is 17,500 Btu per hour at 95F OAT and 80F indoor drybulb and 67F indoor wetbulb temperature, The hydronic system rated cooling efficiency is 13-SEER with the model MHH-19-410 condensing coil and 95F OAT and 550 cfm evaporator airflow with 80F indoor drybulb and 67F indoor wetbulb temperatures. The rated heating capacity is 18,000 Btu per hour with 550 cfm airflow at 70F entering air drybulb temperature and 3 gallons per minute (gpm) at 140F hot water supply temperature. The rated hot water heating efficiency is 78%. The hydronic heating coil is designed to receive 1 to 3 gpm of 120 to 180 Fahrenheit (F) hot water circulated by a 1/25th hp (30W) pump where the water is heated by a storage water heater. The hydronic unit default cooling or heating time delay is fixed during setup at either 0 seconds or 60 seconds after the cool or heat source turns off.

Table 1: Description of Test Units – 1.5-ton Split-System Heat Pump and 1.5-ton Hydronic System

Unit Description	**1.5-ton Split-System Heat Pump**	**1.5-ton Split-System Hydronic**
ID Model Number	ARUF25B14AA	19CDX-HW
Input Voltage	208/230 VAC	208/230 VAC
Input Frequency	60 HZ	60 HZ
Phase	1 Phase	1 Phase
Type	Ducted Heat Pump Coil	Ducted Evaporator Coil/HW Coil
Rated Cooling Capacity	17,300 Btu/hr 525 scfm at 0.4 IWC 12,283 Btu/hr sensible	17,500 Btu/hr 550 scfm at 0.3 IWC 12,425 Btu/hr sensible
OD Model Number	GSZ140181KD	MHH-19-410
Fan Speed and RPM	1043 RPM	1550 RPM
Fan Time Delay Cooling	0 or 65 seconds Cooling	0 or 60 seconds Cooling
Fan Time Delay Heating	0 or 65 seconds Heating	0 or 60 seconds Heating
Frequency and Phase	60 HZ and Single Phase	60 HZ and Single Phase
Refrigerant Charge	R410A 92 Ounces	R410A 106 Ounces
Type	Air Cooled Condenser	Air Cooled Condenser
Heating Model Number	ARUF25B14AA	19CDX-HW
Rated Heat Capacity	18,000 Btu/hr 555 scfm at 0.47 IWC	18,000 Btu/hr 550 scfm at 0.4 IWC

Location and Dates of Tests:
Tests were performed at the Intertek Laboratory in Plano, Texas, from 11/07/2016 through 11/22/16.

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]

Each unit was tested in cooling and heating modes under non-steady state field conditions to measure sensible cooling or heating capacity and efficiency with no time delay or fixed time delay of 65 seconds for the split-system heat pump or 60 seconds for the split-system hydronic system after the cool or heat source turned off. Non-steady state cooling and heating tests were performed with the patented EFC product providing a variable time delay on the fan depending on length of time the cool or heat source operated.

Non-steady state testing of the 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.

[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.

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.

Baseline Tests:

AHRI 210/240 tests were performed to verify rated performance at nominal airflow and static pressure.

Test Equipment Calibration

The psychrometric room is designed to ASHRAE 37 specifications. 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.

EFC Performance Evaluation Results

The baseline and EFC non-steady state test parameters and test results for the 1.5-ton split- heat pump system and 1.5-ton split- hydronic system in cooling and heating mode are summarized in **Table 4** through **Table 19** and **Figure 3** through **Figure 18**. Detailed test data and results are on file at Intertek.

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 per hour (Btu/hr).[2] 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 by 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 accounted for as follows per ASHRAE 37 (section 7.3.3.3, p. 12).

[2] 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.

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

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/Wh), and

e_t = total cooling electric power consumption per time interval (Watts).

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

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 the 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 minus energy consumption 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 $$\Delta e_{CS} = \left[1 - \frac{\eta_{sc_o}}{\eta_{sc_g}}\right]100$$

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

An example calculation is provided for the 10-minute cooling test 103 (see **Table 4**) using **Equations 4** through **7**. With the no time delay baseline, the split-system air conditioner uses 0.24 kWh to supply 994 Btu of sensible cooling to the space with an efficiency of 4.08 Btu/Wh. With the EFC, the air conditioner uses 0.26 kWh to supply 1445 Btu of sensible cooling with an efficiency of 5.60 Btu/Wh. The cooling efficiency improvement of 37.3% with the EFC is calculated using **Equation 4**.

Example Eq. 4 $$\Delta\eta_{SC} = \left[\frac{\eta_{sc_e}}{\eta_{sc_o}} - 1\right]100 = \left[\frac{5.60}{4.08} - 1\right]100 = 37.3\%$$

Where, $\Delta\eta_{SC}$ = test 103 sensible cooling efficiency improvement with EFC = 37.3%

η_{sc_e} = test 103 sensible cooling efficiency with EFC = 5.60 Btu/Wh, and

η_{sc_o} = test 103 sensible cooling efficiency without EFC = 4.08 Btu/Wh.

The test 103 cooling energy of 0.354 kWh required to match the EFC sensible cooling capacity at the baseline efficiency is calculated using **Equation 5**.

Example Equation 5 $$E_{c_m} = \left[\frac{Q_{sc_e}}{\eta_o(1000)}\right] = \left[\frac{1445}{4.08\,(1000)}\right] = 0.354\ \text{kWh}$$

Where, E_{c_m} = baseline efficiency energy required to match EFC capacity = 0.354 kWh,

Q_{sc_e} = test 103 sensible cooling capacity with EFC = 1445 Btu, and

η_O = test 103 baseline sensible efficiency without EFC = 4.08 Btu/Wh.

The test 103 cooling energy savings of 0.096 kWh with EFC are calculated using **Equation 6**.

Example Eq. 6 $$\Delta E_C = \frac{Q_{c_e} - Q_{c_o}}{\eta_{sc_o}\,(1000\ \text{W/kWh})} + E_{c_o} - E_{c_e} = \frac{1445 - 994}{4.08\ (1000)} + 0.24 - 0.26 = 0.096\ \text{kWh}$$

Where, ΔE_c = test 103 cooling energy savings with EFC compared to baseline = 0.096 kWh,

Q_{c_o} = test 103 cooling capacity supplied by baseline system = 994 Btu,

Q_{ce} = test 103 cooling capacity supplied with EFC = 1445 Btu,

η_{sc_o} = test 103 baseline sensible cooling efficiency = 4.08 Btu/Wh,

E_{c_o} = test 103 baseline energy consumption = 0.24 kWh, and

E_{c_e} = test 103 energy consumption with EFC = 0.26 kWh.

The test 103 cooling percentage savings of 27.1% with EFC are calculated using **Equation 7**.

Example Equation 7 $$\Delta e_{cs} = 1 - \frac{\eta_{sc_o}}{\eta_{sc_e}} \times 100 = 1 - \frac{4.08}{5.6} \times 100 = 27.1\%$$

Where, Δe_{cs} = test 103 sensible cooling efficiency improvement with EFC = 27.1%,

η_{sc_o} = test 103 baseline sensible cooling efficiency = 4.08 Btu/Wh, and

η_{sc_e} = test 103 sensible cooling efficiency with EFC = 5.6 Btu/Wh.

The sensible heating capacity is based on the measured airflow rate, specific volume, and difference between the supply air specific heat times temperature and the return air specific heat times temperature per ASHRAE 37. **Equation 1** is used to calculate the non-steady state sensible heating capacity.[3]

Equation 1 $$Q_h = \sum_{t=0}^{n} q_{h_t} \left[\frac{t}{3600} \right]$$

Where, Q_h = heating capacity supplied by the heat pump or hydronic 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 heat pump or hydronic 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),

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

E_h = heat source energy consumption (Btu).

Heat pump heating energy consumption is equal to total kWh consumption times 3412 Btu per kWh as shown in **Equation 10**.

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

Equation 10 $$E_h = \sum_{t=0}^{n} e_t \left[\frac{t}{3600} \right] 3412$$

Where, E_h = heat pump heating energy consumption (Btu), and

e_t = electric power consumption per time interval for the heat pump (Watts).

Hydronic heating energy consumption is equal total energy delivered by the hot water heating system divided by the efficiency of the hot water heater as shown **Equation 11**.

Equation 11 $$E_h = \sum_{t=0}^{n} e_{h_t} \left[\frac{t}{3600} \right]$$

Where, E_h = hydronic heating energy consumption (Btu), and

$e_{h_t} = \frac{c_w (T_i - T_o)\dot{V}}{\eta_{wh}} \left[\frac{8.33 \text{ lbm}}{\text{gal}} \right] \left[\frac{60 \text{ min}}{\text{hr}} \right]$ = hydronic heating energy input (Btu/hr),

c_w = specific heat of water = 1 Btu/lbm-F,

T_i = inlet temperature of hydronic coil (F),

T_o = outlet temperature of hydronic coil (F),

$\dot{V}$ = volumetric water flow rate in gallons per minute (gpm),

η_{wh} = hydronic water heater efficiency = 0.78.

The heating efficiency improvement ($\Delta\eta_h$) for the EFC is calculated using **Equation 12**.

Equation 12 $$\Delta\eta_h = \left[\frac{\eta_{h_e}}{\eta_{h_o}} - 1 \right] 100$$

Where, $\Delta\eta_h$ = heating efficiency improvement with EFC (%),

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

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

The baseline heat pump heating energy to match the EFC heating capacity is calculated using **Equation 13**.

Equation 13 $$E_{h_m} = \left[\frac{Q_{h_e}}{\eta_{h_o} (3412 \text{ Btu/kWh})} \right]$$

Where, E_{h_m} = energy to match EFC heating capacity at baseline efficiency (kWh),

Q_{he} = heat pump heating capacity with EFC (Btu),

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

The baseline hydronic heating energy to match EFC heating capacity is calculated using **Equation 14**.

Equation 14 $$E_{h_m} = \left[\frac{Q_{h_e}}{\eta_{h_o}} \right]$$

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

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

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

For heat pump and hydronic heating systems, the EFC saves energy by providing longer variable fan-off time delays based on heat source operational time. The EFC recovers and supplies more heating capacity to the space to exceed thermostat setpoint temperatures, lengthen off-cycles, and reduce on-cycles. Energy savings are calculated using **Equation 15** for a heat pump in heating mode.

Equation 15 $$\Delta E_h = \frac{Q_{h_e} - Q_{h_o}}{\eta_{h_o}\ (3412\ \text{Btu/kWh})} + E_{h_o} - E_{h_e}$$

Where, ΔE_h = heat pump heating energy savings with EFC compared to baseline (kWh),

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

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

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

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

Energy savings are calculated using **Equation 16** for a hydronic heating system.

Equation 16 $$\Delta E_h = \frac{Q_{h_e} - Q_{h_o}}{\eta_{h_o}} + E_{h_o} - E_{h_e}$$

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

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

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

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

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

The heating energy savings percentage with the EFC is calculated using **Equation 17**.

Equation 17 $$\Delta\eta_h = \left[1 - \frac{\eta_{h_o}}{\eta_{h_e}} \right] 100$$

Where, $\Delta\eta_h$ = heating savings percentage with EFC compared to baseline (%),

η_{h_o} = baseline heat pump or hydronic heating efficiency (dimensionless), and

η_{h_e} = heat pump or hydronic heating efficiency with EFC (dimensionless).

An example calculation is provided for heat pump test 128 using **Equations 12** through **17** (**Table 8**). The baseline heat pump uses 0.466 kWh to supply 2,974 Btu with coefficient of performance (COP) efficiency of 1.87.[4] With the EFC, the heat pump uses 0.474 kWh to supply 3,464 Btu of heat to the space with a

[4] COP efficiency is defined as energy output divided by energy input (i.e., Btu out divided by kWh times 3412 Btu/kWh).

COP efficiency of 2.14.

The heating efficiency improvement with EFC is calculated using **Equation 12**.

Example Equation 12 $\Delta\eta_h = \left[\frac{\eta_{h_e}}{\eta_{h_o}} - 1\right] \times 100 = \left[\frac{2.14}{1.87} - 1\right] \times 100 = 14.3\%$

Where, $\Delta\eta_h$ = test 128 heating efficiency improvement with EFC = 14.3%,

η_{h_e} = test 128 heat pump heating efficiency with EFC = 2.14, and

η_{h_o} = test 128 baseline heat pump heating efficiency = 1.87.

The heat pump heating energy required to match the EFC heating capacity at the baseline efficiency is calculated using **Equation 13**.

Example Equation 13 $E_{h_m} = \left[\frac{Q_{h_e}}{\eta_{h_o}\,(3412\ \text{Btu/kWh})}\right] = \frac{3464}{1.87(3412)} = 0.543\ \text{kWh}$

Where, E_{h_m} = energy to match EFC heating capacity at baseline efficiency = 0.543 kWh,

Q_{h_e} = test 128 heat pump heating capacity with EFC = 3464 Btu,

η_{h_o} = test 128 heat pump heating efficiency = 1.87.

The heating energy savings with the EFC are calculated using **Equation 15**.

Example Eq. 15 $\Delta Q_h = \frac{Q_{h_e} - Q_{h_o}}{\eta_{h_o}\ (3412)} + E_{h_o} - E_{h_e} = \frac{3464 - 2974}{1.87\ (3412)} + 0.466 - 0.474 = 0.068\ \text{kWh}$

Where, ΔQ_h = test 128 heating energy savings with EFC = 0.068 kWh,

Q_{h_o} = test 128 baseline heat pump heating capacity = 3464 Btu,

Q_{he} = test 128 heat pump heating capacity with EFC = 2974 Btu,

η_{h_o} = baseline heat pump heating efficiency = 1.87,

E_{h_o} = baseline heat pump energy consumption = 0.466 kWh, and

E_{h_e} = heat pump energy consumption with EFC = 0.474 kWh.

The HP heating energy savings percentage with EFC is calculated using **Equation 17**.

Example Equation 17 $\Delta\eta_h = 1 - \frac{\eta_{h_o}}{\eta_{h_e}} = 1 - \frac{1.87}{2.14} \times 100 = 12.5\%$

Where, $\Delta\eta_h$ = test 128 heating efficiency improvement with EFC = 12.5%,

η_{h_o} = test 128 baseline heat pump heating efficiency = 1.87, and

η_{h_e} = test 128 heat pump heating efficiency with EFC = 2.14.

An example calculation is provided for hydronic test 175 using **Equations 12** through **17** (**Table 16**). The baseline hydronic system uses 4584 Btu to supply 1869 Btu with efficiency of 40.8%. With the EFC, the hydronic system uses 4548 Btu to supply 2379 Btu of heat with efficiency of 51.9%. The hydronic heating efficiency improvement with EFC is calculated using **Equation 12**.

Example Equation 12 $\Delta\eta_h = \left[\frac{\eta_{h_e}}{\eta_{h_o}} - 1\right] \times 100 = \left[\frac{0.519}{0.408} - 1\right] \times 100 = 27.3\%$

Where, $\Delta\eta_h$ = test 175 heating efficiency improvement with EFC = 27.3%,
η_{h_e} = test 175 hydronic heating efficiency with EFC = 0.519, and
η_{h_o} = test 175 baseline hydronic pump heating efficiency = 0.408.

The hydronic heating energy required to match the EFC heating capacity at the baseline efficiency is calculated using **Equation 13**.

Example Equation 13 $E_{h_m} = \left[\frac{Q_{h_e}}{\eta_{h_o}}\right] = \frac{2379}{0.408} = 5834 \text{ Btu}$

Where, E_{h_m} = energy to match EFC heating capacity at baseline efficiency = 5834 Btu,
Q_{he} = test 175 hydronic heating capacity with EFC = 2379 Btu,
η_{h_o} = test 175 hydronic heating efficiency without EFC = 40.8%.

The heating energy savings with the EFC are calculated using **Equation 16**.

Example Eq. 16 $\Delta Q_h = \frac{Q_{h_e} - Q_{h_o}}{\eta_{h_o}} + E_{h_o} - E_{h_e} = \frac{2379 - 1869}{0.408} + 4584 - 4584 = 1251 \text{ Btu}$

Where, ΔQ_h = test 175 heating energy savings with EFC = 1251 Btu,
Q_{h_o} = test 175 baseline hydronic heating capacity = 1869 Btu,
Q_{he} = test 175 hydronic heating capacity with EFC = 2379 Btu,
η_{h_o} = test 175 baseline hydronic heating efficiency = 0.408,
E_{h_o} = baseline hydronic energy consumption = 4584 Btu, and
E_{h_e} = hydronic energy consumption with EFC = 4584 Btu.

The hydronic heating efficiency improvement with EFC is calculated using **Equation 17**.

Example Equation 17 $\Delta\eta_h = 1 - \frac{\eta_{h_o}}{\eta_{h_e}} = 1 - \frac{0.408}{0.524} \times 100 = 21.4\%$

Where, $\Delta\eta_h$ = test 175 hydronic heating energy savings with EFC = 21.4%,
η_{h_o} = test 175 baseline hydronic heating efficiency = 0.408, and
η_{h_e} = test 175 hydronic heating efficiency with EFC = 0.524.

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

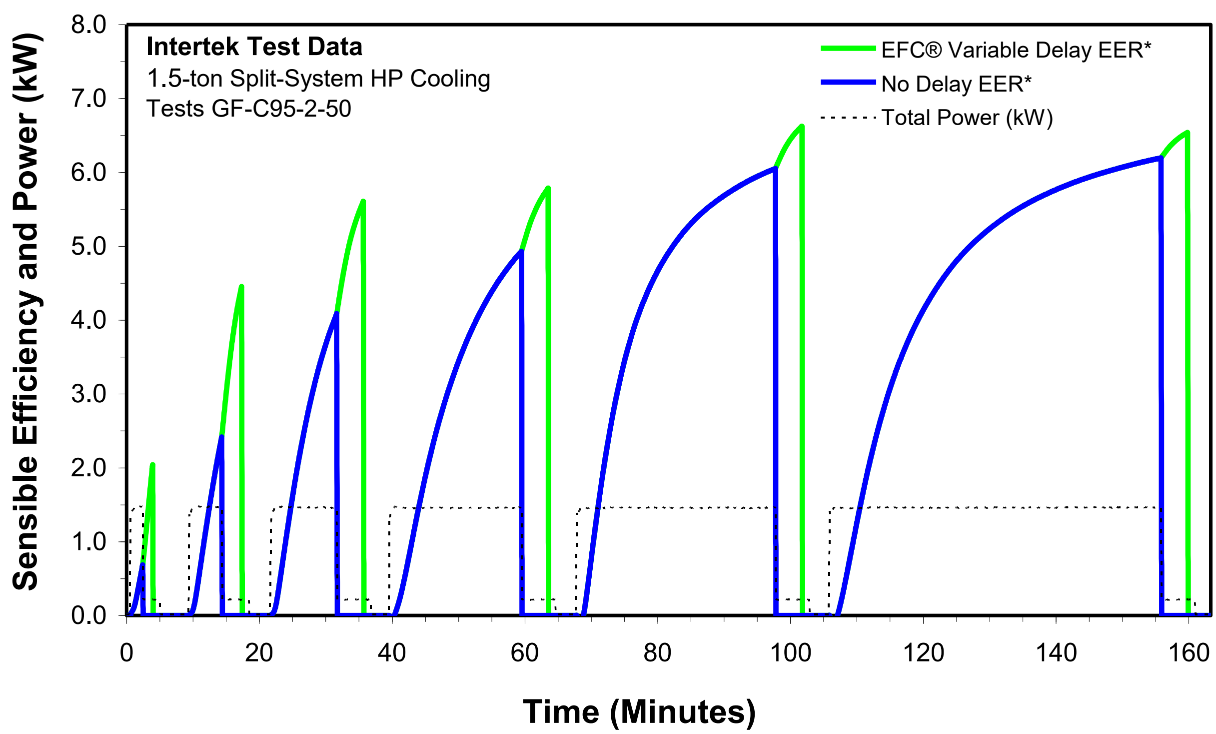
Heat Pump Cooling Tests at 95F OAT with No Delay and EFC Variable Time Delay

Cooling tests for the 1.5-ton split system heat pump 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 4** and **Figure 3** provide test results. Based on six tests, the EFC improved sensible efficiency by 5.6 to 198% and provides cooling energy savings of 5.3 to 66.5%.

Table 4: HP Cooling Tests at 95F OAT GF-C95-2-50 – No Delay and EFC Variable Delay

Description	**Test 101**	**Test 102**	**Test 103**	**Test 104**	**Test 105**	**Test 106**
Compressor On Time (minutes)	2	5	10	20	30	50
No Delay AC Energy (kWh) [a]	0.047	0.12	0.24	0.49	0.73	1.22
No Delay Sensible Cooling (Btu) [b]	32	294	994	2,395	4,414	7,543
No Delay Sensible Efficiency (Btu/Wh) [c=b/a/1000]	0.68	2.42	4.08	4.93	6.05	6.19
EFC AC Energy (kWh) [d]	0.052	0.13	0.26	0.50	0.74	1.23
EFC Sensible Cooling (Btu) [e]	106	589	1,445	2,891	4,928	8,058
EFC Sensible Efficiency (Btu/Wh) [f=e/d/1000]	2.03	4.45	5.60	5.78	6.62	6.54
EFC Sensible Efficiency Improvement [g=f/c-1]	**198.1%**	**84.4%**	**37.3%**	**17.3%**	**9.5%**	**5.6%**
EFC Extra Fan Energy (kWh)	0.005	0.011	0.014	0.014	0.014	0.014
No Delay AC Energy to Match EFC (kWh) [h=e/c/1000]	0.155	0.244	0.354	0.586	0.814	1.301
EFC Energy Savings (kWh) [i=h-d]	0.103	0.112	0.096	0.086	0.071	0.069
EFC Cooling Energy Savings [j=(1-c/f) or j=i/h]	**66.5%**	**45.8%**	**27.1%**	**14.7%**	**8.7%**	**5.3%**

Figure 3: HP Cooling Tests at 95F OAT GF-C95-2-50 – No Delay and EFC Variable Delay



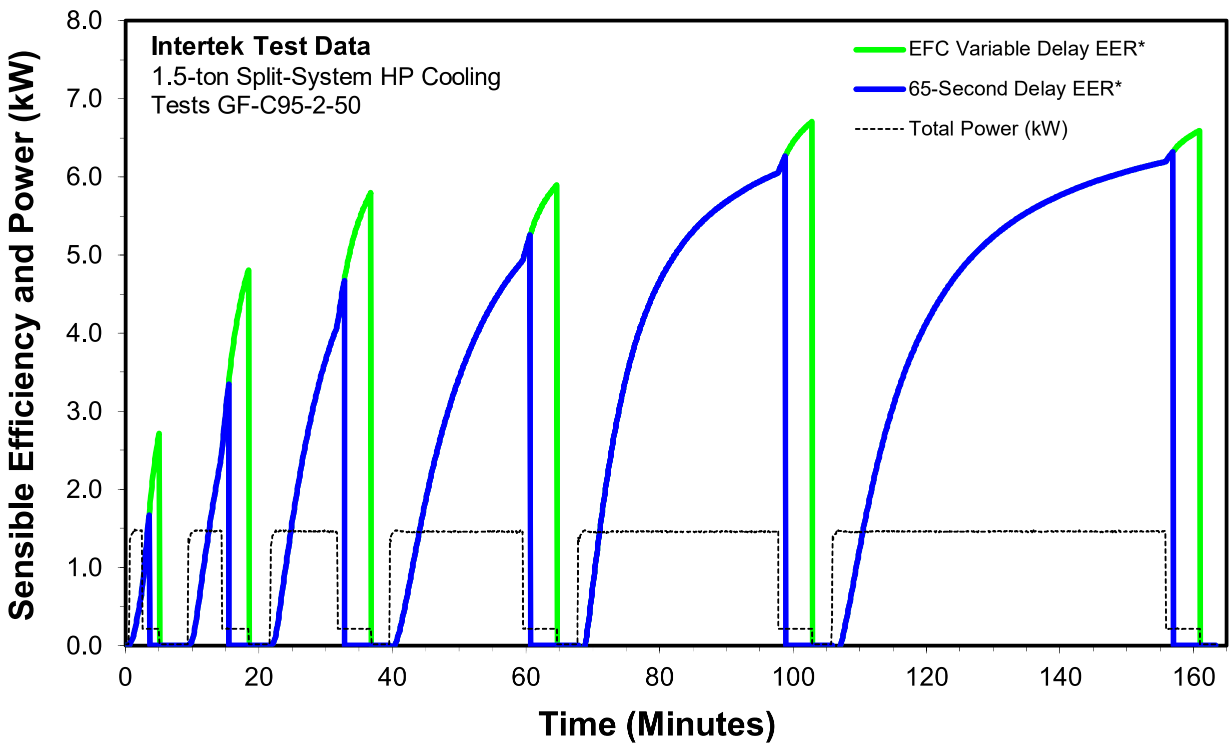
Heat Pump Cooling Tests at 95F OAT with 65-Second and EFC Variable Time Delay

Cooling tests for the 1.5-ton split system heat pump with 65-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 5** and **Figure 4** provide test results. Based on six tests, the EFC improved sensible efficiency by 4.2 to 62% and provides cooling energy savings of 4.1 to 38.3%.

Table 5: HP Cooling Tests at 95F OAT GF-C95-2-50 – 65-Second and EFC Variable Delay

Description	**Test 107**	**Test 108**	**Test 109**	**Test 110**	**Test 111**	**Test 112**
Compressor On Time (minutes)	2	5	10	20	30	50
65-Second Delay AC Energy (kWh) [a]	0.051	0.13	0.25	0.49	0.73	1.22
65-Second Delay Sensible Cooling (Btu) [b]	85	420	1,157	2,572	4,596	7,726
65-Sec. Delay Sensible Efficiency (Btu/Wh) [c=b/a/1000]	1.67	3.35	4.67	5.25	6.27	6.32
EFC AC Energy (kWh) [d]	0.056	0.14	0.26	0.50	0.75	1.24
EFC Sensible Cooling (Btu) [e]	152	655	1,518	2,970	5,015	8,147
EFC Sensible Efficiency (Btu/Wh) [f=e/d/1000]	2.71	4.81	5.80	5.89	6.71	6.59
EFC Sensible Efficiency Improvement [g=f/c-1]	**62.0%**	**43.6%**	**24.1%**	**12.2%**	**7.0%**	**4.2%**
EFC Extra Fan Energy (kWh)	0.005	0.011	0.014	0.014	0.014	0.014
65-Sec. Delay AC Energy to Match EFC (kWh) [h=e/c/1000]	0.091	0.196	0.325	0.565	0.800	1.288
EFC Energy Savings (kWh) [i=h-d]	0.035	0.059	0.063	0.061	0.052	0.052
EFC Cooling Energy Savings [j=(1-c/f) or j=i/h]	**38.3%**	**30.4%**	**19.4%**	**10.9%**	**6.6%**	**4.1%**

Figure 4: HP Cooling Tests at 95F OAT GF-C95-2-50 – 65-Second and EFC Variable Delay



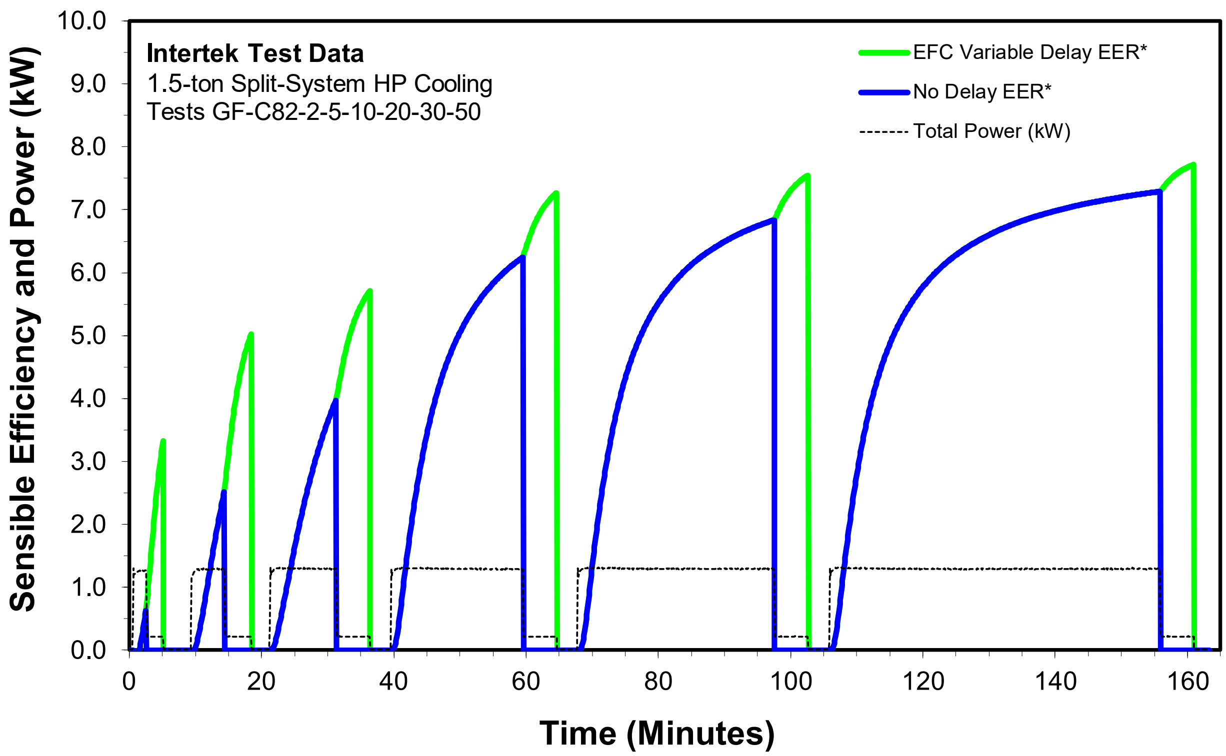
Heat Pump Cooling Tests at 82F OAT with No Delay and EFC Variable Time Delay

Cooling tests for the 1.5-ton split system heat pump with no time delay and EFC variable time delay were performed at typical field conditions of 75F DB and 62F WB indoor and 82F outdoor temperatures. **Table 6** and **Figure 5** provide test results. Based on six tests, the EFC improved sensible efficiency by 5.2 to 315% and provides cooling energy savings of 4.9 to 75.9%.

Table 6: HP Cooling Tests at 82F OAT GF-C82-2-50 – No Delay and EFC Variable Delay

Description	Test 113	Test 114	Test 115	Test 116	Test 117	Test 118
Compressor On Time (minutes)	2	5	10	20	30	50
No Delay AC Energy (kWh) [a]	0.040	0.107	0.216	0.431	0.642	1.077
No Delay Sensible Cooling (Btu) [b]	23	269	859	2,690	4,388	7,852
No Delay Sensible Efficiency (Btu/Wh) [c=b/a/1000]	0.57	2.51	3.97	6.25	6.84	7.29
EFC AC Energy (kWh) [d]	0.048	0.118	0.231	0.445	0.656	1.091
EFC Sensible Cooling (Btu) [e]	113	548	1,275	3,184	4,899	8,368
EFC Sensible Efficiency (Btu/Wh) [f=e/d/1000]	2.38	4.66	5.53	7.15	7.47	7.67
EFC Sensible Efficiency Improvement [g=f/c-1]	**315.7%**	**85.1%**	**39.1%**	**14.5%**	**9.2%**	**5.2%**
EFC Extra Fan Energy (kWh)	0.007	0.011	0.014	0.014	0.014	0.014
No Delay AC Energy to Match EFC (kWh) [h=e/c/1000]	0.198	0.218	0.321	0.510	0.716	1.148
EFC Energy Savings (kWh) [i=h-d]	0.150	0.100	0.090	0.065	0.060	0.056
EFC Cooling Energy Savings [j=(1-c/f) or j=i/h]	**75.9%**	**46.0%**	**28.1%**	**12.7%**	**8.4%**	**4.9%**

Figure 5: HP Cooling Tests at 82F OAT GF-C82-2-50 – No Delay and EFC Variable Delay



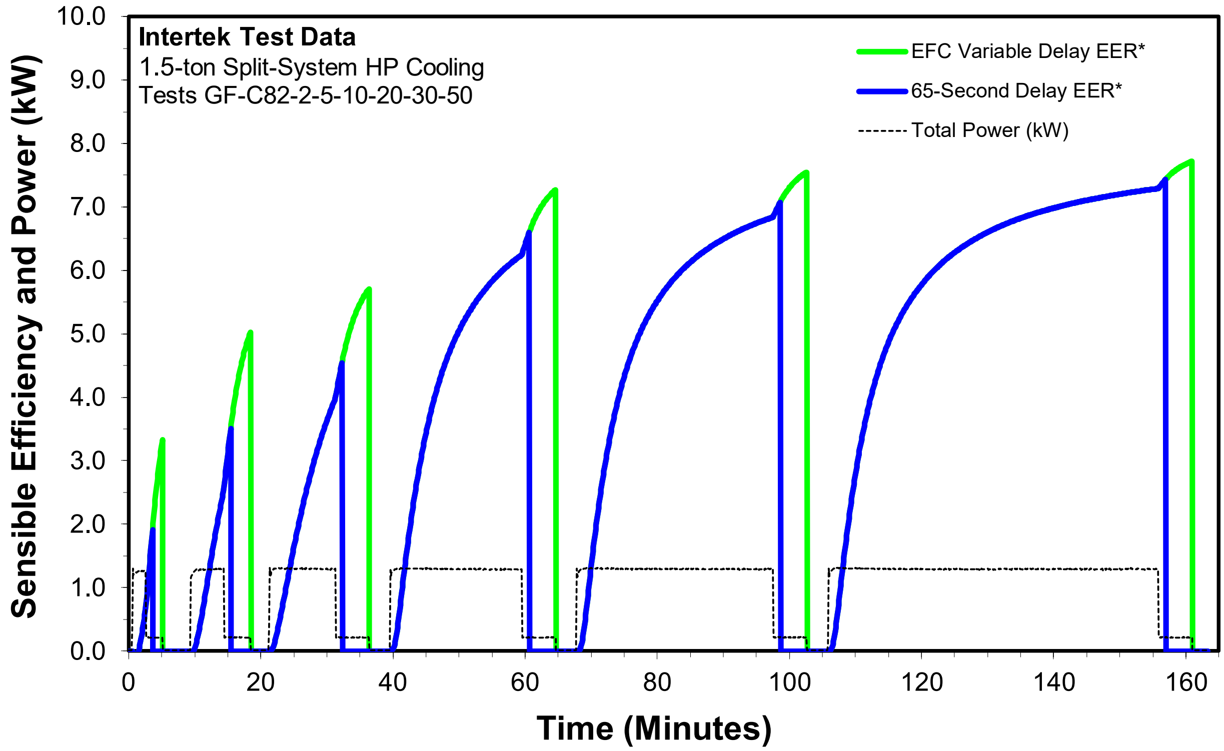
Heat Pump Cooling Tests at 82F OAT with 65-Second and EFC Variable Time Delay

Cooling tests for the 1.5-ton split system heat pump with 65-second delay and EFC variable time delay were performed at typical field conditions of 75F DB and 62F WB indoor and 82F outdoor temperatures. **Table 7** and **Figure 6** provide test results. Based on six tests, the EFC improved sensible efficiency by 3.8 to 71.9% and provides cooling energy savings of 3.7 to 41.8%.

Table 7: HP Cooling Tests at 82F OAT GF-C82-2-50 – 65-Second and EFC Variable Delay

Description	**Test 119**	**Test 120**	**Test 121**	**Test 122**	**Test 123**	**Test 124**
Compressor On Time (minutes)	2	5	10	20	30	50
65-Second Delay AC Energy (kWh) [a]	0.046	0.111	0.222	0.435	0.646	1.081
65-Second Delay Sensible Cooling (Btu) [b]	88	388	1,069	2,865	4,568	8,033
65-Sec. Delay Sensible Efficiency (Btu/Wh) [c=b/a/1000]	1.94	3.50	4.82	6.59	7.07	7.43
EFC AC Energy (kWh) [d]	0.051	0.122	0.234	0.449	0.660	1.095
EFC Sensible Cooling (Btu) [e]	171	611	1,339	3,263	4,982	8,453
EFC Sensible Efficiency (Btu/Wh) [f=e/d/1000]	3.33	5.02	5.71	7.27	7.55	7.72
EFC Sensible Efficiency Improvement [g=f/c-1]	**71.9%**	**43.5%**	**18.6%**	**10.2%**	**6.7%**	**3.8%**
EFC Extra Fan Energy (kWh)	0.006	0.011	0.013	0.014	0.014	0.014
65-Sec. Delay AC Energy to Match EFC (kWh) [h=e/c/1000]	0.088	0.175	0.278	0.495	0.704	1.137
EFC Energy Savings (kWh) [i=h-d]	0.037	0.053	0.043	0.046	0.044	0.042
EFC Cooling Energy Savings [j=(1-c/f) or j=i/h]	**41.8%**	**30.3%**	**15.6%**	**9.3%**	**6.3%**	**3.7%**

Figure 6: HP Cooling Tests at 82F OAT GF-C82-2-50 – 65-Second and EFC Variable Delay



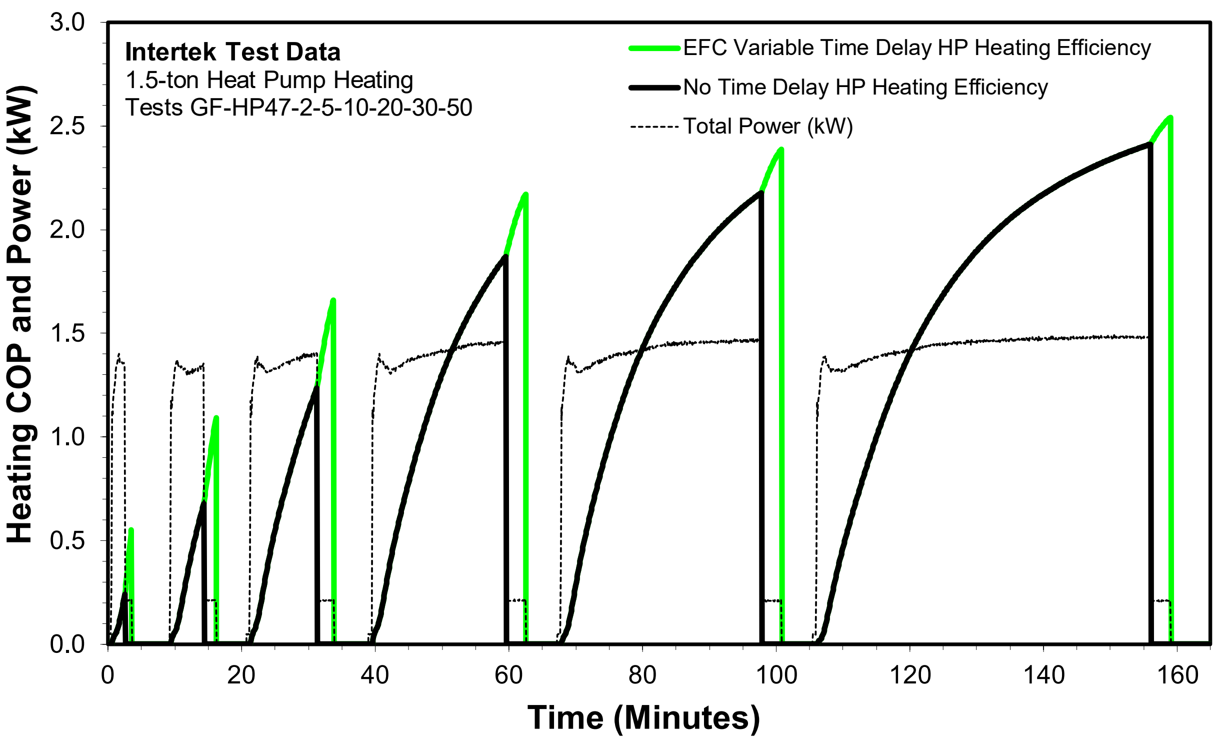
Heat Pump Heating Tests at 47F OAT with No Delay and Variable Delay

Heating tests for the 1.5-ton split-system heat pump were performed at typical field conditions of 70F DB and 55F WB indoor and 47F outdoor temperatures. **Table 8** and **Figure 7** provide test results. For the baseline tests the indoor fan operated with no time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 5.3 to 130.9% and provides heating energy savings of 5.1 to 56.7%.

Table 8: HP Heating Tests 47F OAT GF-HP47-2-50 – No Delay and EFC Variable Delay

Description	**Test 125**	**Test 126**	**Test 127**	**Test 128**	**Test 129**	**Test 130**
HP Compressor On Time (minutes)	2	5	10	20	30	50
No Delay HP Heating Energy Input (kWh) [a]	0.044	0.110	0.226	0.466	0.709	1.198
No Delay HP Heating Capacity (Btu) [b]	36	256	953	2,974	5,268	9,863
No Delay HP Heating Efficiency [c=b/a/3412]	0.24	0.68	1.24	1.87	2.18	2.41
EFC HP Energy Input (kWh [d]	0.047	0.116	0.232	0.474	0.719	1.208
EFC HP Heating Capacity (Btu) [e]	91	407	1,270	3,464	5,862	10,481
EFC HP Heating Efficiency [f=e/d/3412]	0.56	1.03	1.60	2.14	2.39	2.54
EFC HP Heating Efficiency Improvement [g=f/c-1]	130.9%	51.9%	29.2%	14.3%	9.7%	5.3%
EFC Extra Fan Energy (kWh)	0.004	0.005	0.007	0.009	0.010	0.010
No Delay HP Energy to Match EFC (kWh) [h=e/c/3412]	0.109	0.175	0.300	0.543	0.789	1.273
EFC Energy Savings (kWh) [i=h-d]	0.062	0.060	0.068	0.068	0.069	0.065
EFC Heating Savings [j=(1-c/f) or j=i/h]	**56.7%**	**34.2%**	**22.6%**	**12.5%**	**8.8%**	**5.1%**

Figure 7: HP Heating Tests 47F OAT GF-HP47-2-50 – No Delay and EFC Variable Delay



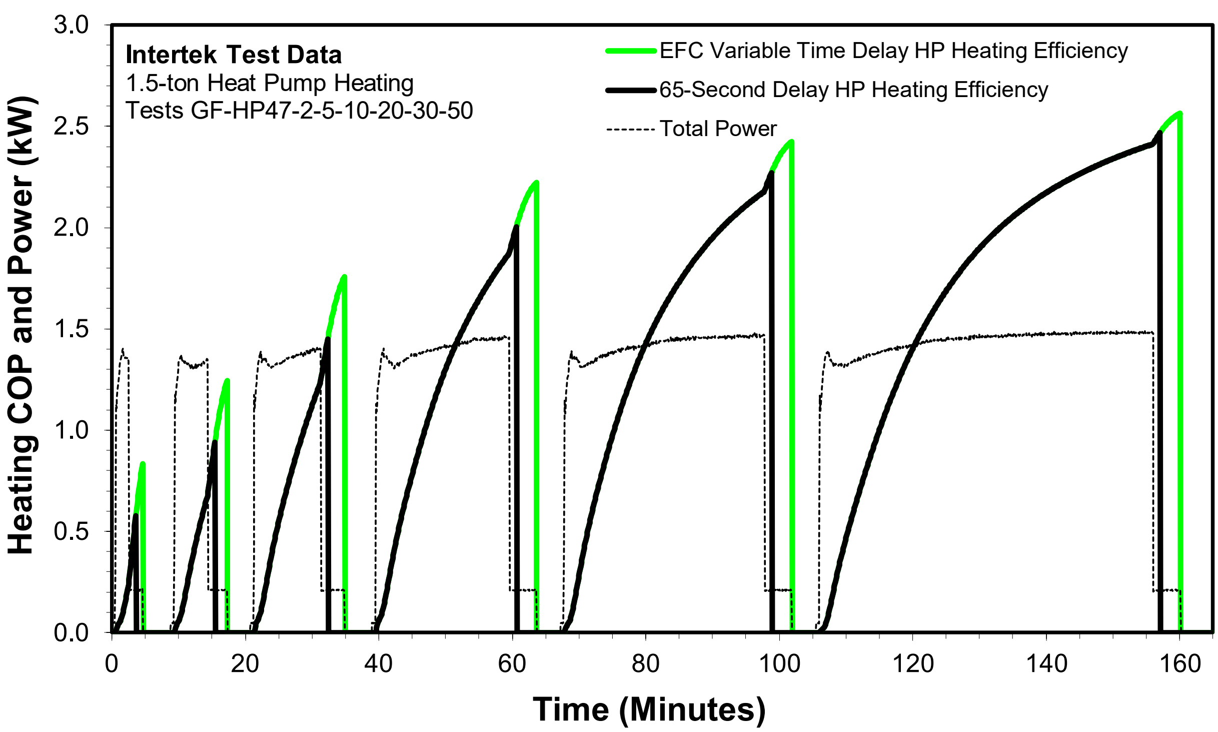
Heat Pump Heating Tests at 47F OAT with 65-Second Delay and Variable Delay

Heating tests for the 1.5-ton split-system heat pump were performed at typical field conditions of 70F DB and 55F WB indoor and 47F outdoor temperatures. **Table 9** and **Figure 8** provide test results. For the baseline tests the indoor fan operated with fixed 65-second time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 3.8 to 44.1% and provides heating energy savings of 3.7 to 30.6%.

Table 9: HP Heating Tests 47F OAT GF-HP47-2-50 – 65-Second Delay and EFC Variable Delay

Description	Test 131	Test 132	Test 133	Test 134	Test 135	Test 136
HP Compressor On Time (minutes)	2	5	10	20	30	50
65-Second Delay HP Heating Energy Input (kWh) [a]	0.048	0.114	0.229	0.469	0.712	1.202
65-Second Delay HP Heating Capacity (Btu) [b]	95	366	1,135	3,212	5,522	10,126
65-Second Delay HP Heating Efficiency [c=b/a/3412]	0.59	0.94	1.45	2.01	2.27	2.47
EFC HP Energy Input (kWh) [d]	0.051	0.119	0.236	0.478	0.723	1.212
EFC HP Heating Capacity (Btu) [e]	148	493	1,389	3,596	5,981	10,605
EFC HP Heating Efficiency [f=e/d/3412]	0.85	1.21	1.72	2.20	2.42	2.56
EFC HP Heating Efficiency Improvement [g=f/c-1]	44.1%	28.6%	18.7%	9.9%	6.7%	3.8%
EFC Extra Fan Energy (kWh)	0.004	0.005	0.007	0.009	0.010	0.010
65-Sec. Delay Energy to Match EFC (kWh) [h=e/c/3412]	0.074	0.153	0.281	0.526	0.772	1.258
EFC Energy Savings (kWh) [i=h-d]	0.023	0.034	0.044	0.047	0.049	0.046
EFC Heating Savings [j=(1-c/f) or j=i/h]	**30.6%**	**22.2%**	**15.8%**	**9.0%**	**6.3%**	**3.7%**

Figure 8: HP Heating Tests 47F OAT GF-HP47-2-50 – 65-Second Delay and EFC Variable Delay



Heat Pump Heating Tests at 17F OAT with No Delay and Variable Delay

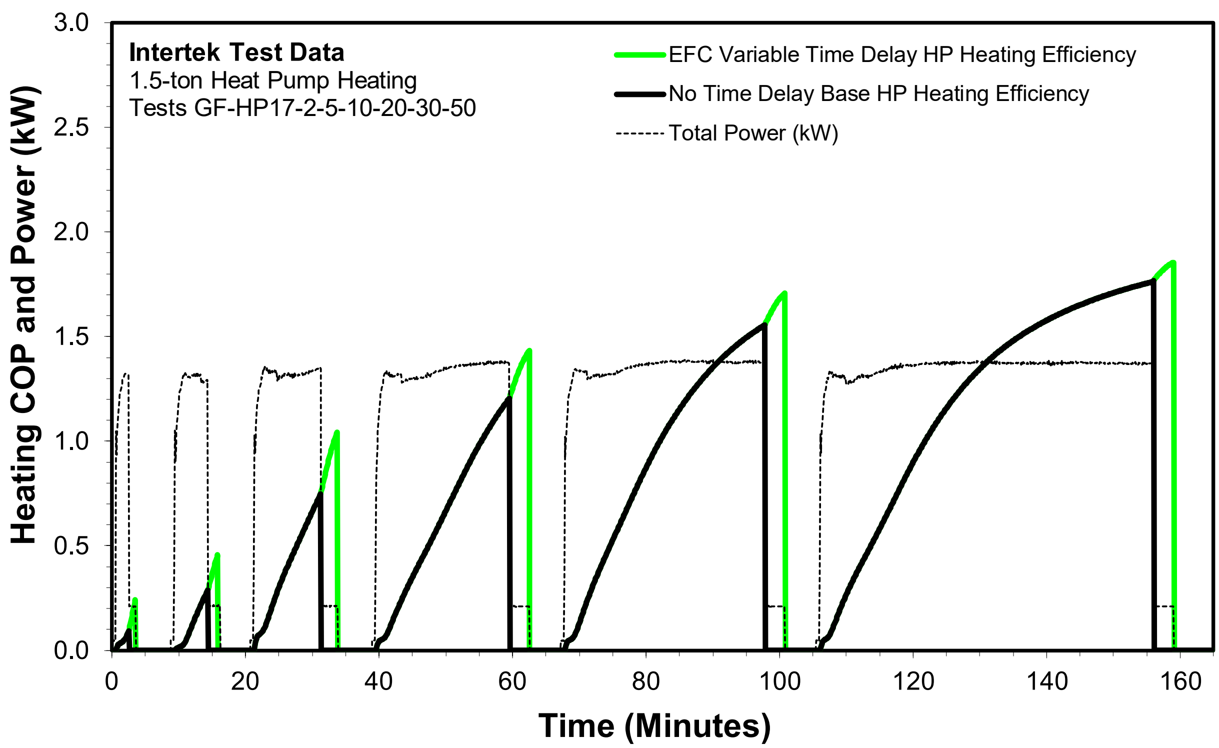
INTERTEK PERFORMANCE EVALUATION OF AN EFFICIENT FAN CONTROLLER (EFC) INSTALLED ON HEAT PUMP AND HYDRONIC SPLIT-SYSTEMS

Heating tests for the 1.5-ton split-system heat pump were performed at typical field conditions of 70F DB and 55F WB indoor and 17F outdoor temperatures. **Table 10** and **Figure 9** provide test results. For the baseline tests the indoor fan operated with no time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 4.9 to 154.5% and provides heating energy savings of 4.6 to 60.7%.

Table 10: HP Heating Tests 17F OAT GF-HP17-2-50 – No Delay and EFC Variable Delay

Description	Test 137	Test 138	Test 139	Test 140	Test 141	Test 142
HP Compressor On Time (minutes)	2	5	10	20	30	50
No Delay HP Heating Energy Input (kWh) [a]	0.041	0.106	0.218	0.444	0.677	1.127
No Delay HP Heating Capacity (Btu) [b]	13	104	559	1,824	3,595	6,804
No Delay HP Heating Efficiency [c=b/a/3412]	0.09	0.29	0.75	1.21	1.56	1.77
EFC HP Energy Input (kWh) [d]	0.045	0.112	0.226	0.452	0.688	1.138
EFC HP Heating Capacity (Btu) [e]	37	174	770	2,175	4,008	7,204
EFC HP Heating Efficiency [f=e/d/3412]	0.24	0.46	1.00	1.41	1.71	1.85
EFC HP Heating Efficiency Improvement [g=f/c-1]	154.5%	59.1%	33.4%	16.9%	9.7%	4.9%
EFC Extra Fan Energy (kWh)	0.004	0.005	0.007	0.009	0.011	0.011
No Delay HP Energy to Match EFC (kWh) [h=e/c/3412]	0.115	0.177	0.301	0.529	0.755	1.194
EFC Energy Savings (kWh) [i=h-d]	0.070	0.066	0.075	0.077	0.067	0.055
EFC Heating Savings [j=(1-c/f) or j=i/h]	**60.7%**	**37.1%**	**25.0%**	**14.5%**	**8.9%**	**4.6%**

Figure 9: HP Heating Tests 17F OAT GF-HP17-2-50 – No Delay and EFC Variable Delay



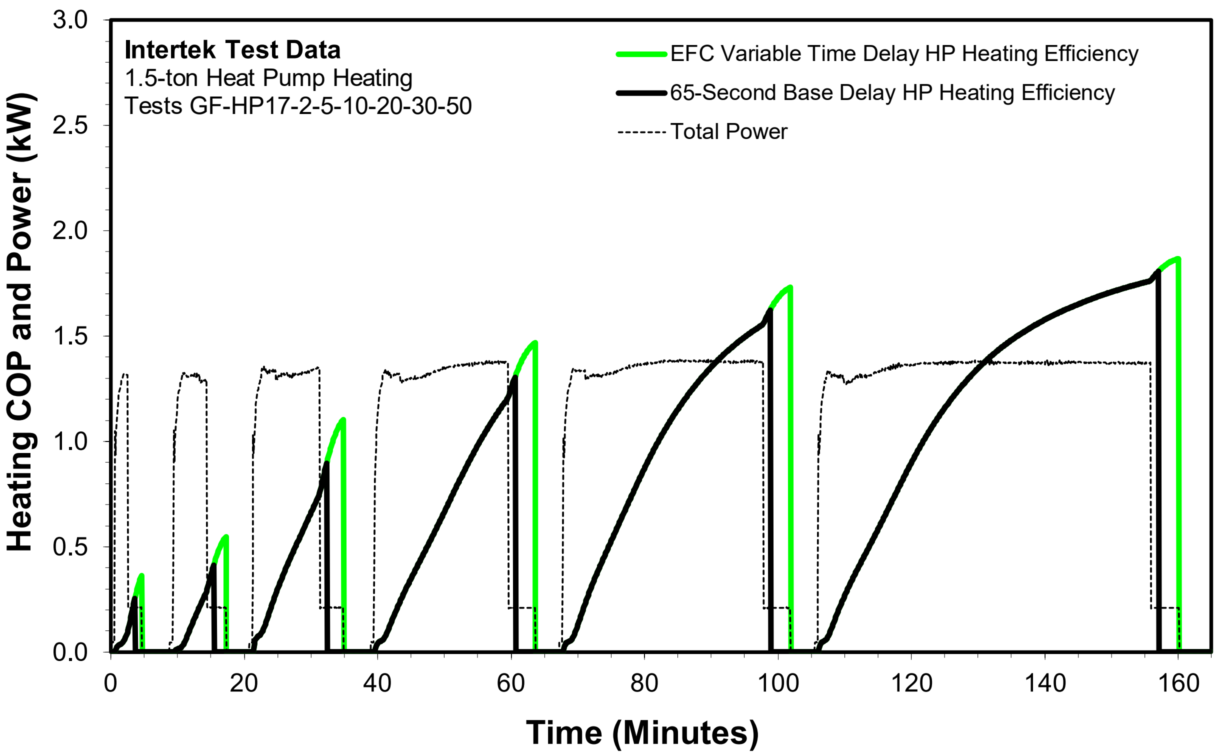
Heat Pump Heating Tests at 17F OAT with 65-Second Delay and Variable Delay

Heating tests for the 1.5-ton split-system heat pump were performed at typical field conditions of 70F DB and 55F WB indoor and 17F outdoor temperatures. **Table 11** and **Figure 10** provide test results. For the baseline tests the indoor fan operated with fixed 65-second time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 3.2 to 40.9% and provides heating energy savings of 3.1 to 29%.

Table 11: HP Heating Tests 17F OAT GF-HP17-2-50 – 65-Second Delay and EFC Variable Delay

Description	Test 143	Test 144	Test 145	Test 146	Test 147	Test 148
HP Compressor On Time (minutes)	2	5	10	20	30	50
65-Second Delay HP Heating Energy Input (kWh) [a]	0.046	0.110	0.222	0.447	0.681	1.131
65-Second Delay HP Heating Capacity (Btu) [b]	39	156	680	1,995	3,773	6,981
65-Second Delay HP Heating Efficiency [c=b/a/3412]	0.25	0.41	0.90	1.31	1.62	1.81
EFC HP Energy Input (kWh) [d]	0.050	0.116	0.229	0.457	0.693	1.143
EFC HP Heating Capacity (Btu) [e]	60	210	847	2,266	4,086	7,278
EFC HP Heating Efficiency [f=e/d/3412]	0.36	0.53	1.08	1.45	1.73	1.87
EFC HP Heating Efficiency Improvement [g=f/c-1]	40.9%	28.6%	20.6%	11.3%	6.5%	3.2%
EFC Extra Fan Energy (kWh)	0.004	0.006	0.007	0.009	0.012	0.012
65-Sec. Delay Energy to Match EFC (kWh) [h=e/c/3412]	0.070	0.149	0.277	0.508	0.737	1.179
EFC Energy Savings (kWh) [i=h-d]	0.020	0.033	0.047	0.051	0.045	0.037
EFC Heating Savings [j=(1-c/f) or j=i/h]	**29.0%**	**22.2%**	**17.1%**	**10.1%**	**6.1%**	**3.1%**

Figure 10: HP Heating Tests 17F OAT GF-HP17-2-50 – 65-Second Delay and EFC Variable Delay



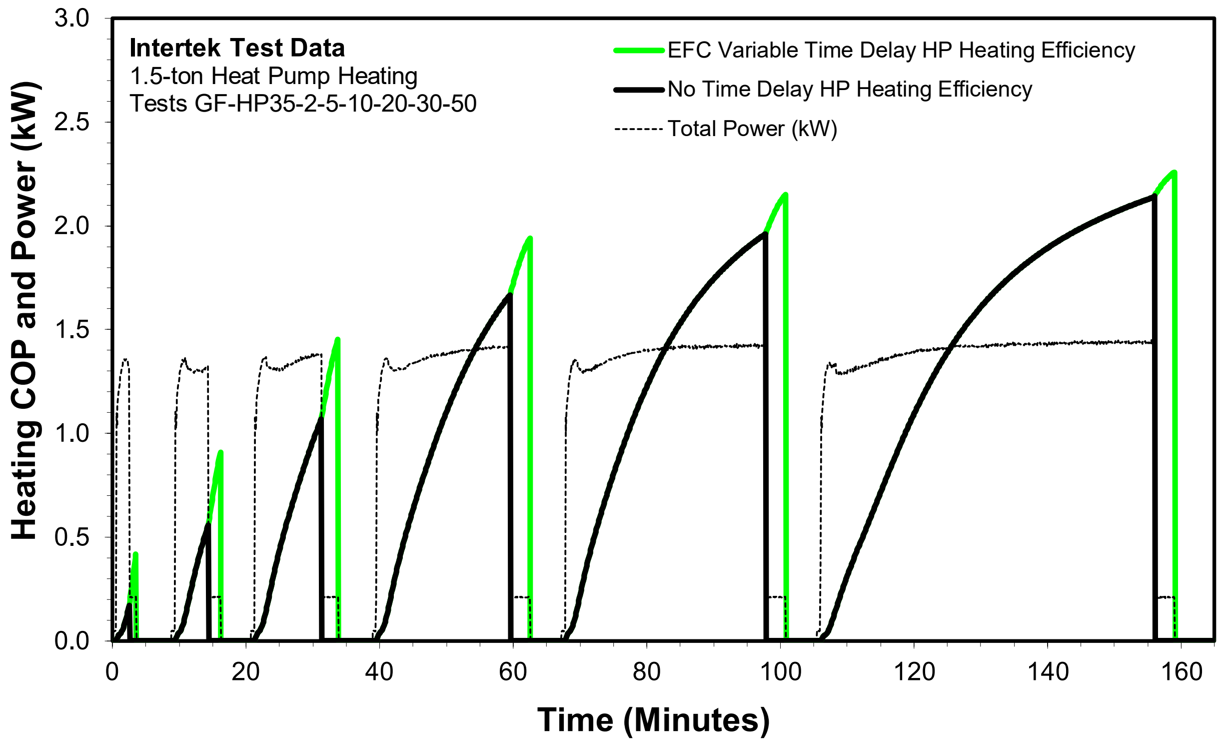
Heat Pump Heating Tests at 35F OAT with No Delay and Variable Delay

Heating tests for the 1.5-ton split-system heat pump were performed at typical field conditions of 70F DB and 55F WB indoor and 35F outdoor temperatures. **Table 12** and **Figure 11** provide test results. For the baseline tests the indoor fan operated with no time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 4.1 to 146.9% and provides heating energy savings of 4 to 59.5%.

Table 12: HP Heating Tests 35F OAT GF-HP35-2-50 – No Delay and EFC Variable Delay

Description	Test 149	Test 150	Test 151	Test 152	Test 153	Test 154
HP Compressor On Time (minutes)	2	5	10	20	30	50
No Delay HP Heating Energy Input (kWh) [a]	0.043	0.108	0.222	0.456	0.692	1.163
No Delay HP Heating Capacity (Btu) [b]	25	206	810	2,594	4,636	8,482
No Delay HP Heating Efficiency [c=b/a/3412]	0.17	0.56	1.07	1.67	1.96	2.14
EFC HP Energy Input (kWh) [d]	0.046	0.113	0.229	0.464	0.703	1.173
EFC HP Heating Capacity (Btu) [e]	66	332	1,091	3,031	5,159	9,029
EFC HP Heating Efficiency [f=e/d/3412]	0.42	0.86	1.40	1.91	2.15	2.26
EFC HP Heating Efficiency Improvement [g=f/c-1]	142.5%	53.3%	30.6%	14.6%	9.6%	5.5%
EFC Extra Fan Energy (kWh)	0.004	0.005	0.007	0.009	0.011	0.010
No Delay HP Energy to Match EFC (kWh) [h=e/c/3412]	0.112	0.174	0.298	0.532	0.771	1.238
EFC Energy Savings (kWh) [i=h-d]	0.066	0.060	0.070	0.068	0.068	0.064
EFC Heating Savings [j=(1-c/f) or j=i/h]	**58.8%**	**34.8%**	**23.4%**	**12.8%**	**8.8%**	**5.2%**

Figure 11: HP Heating Tests 35F OAT GF-HP35-2-50 – No Delay and EFC Variable Delay



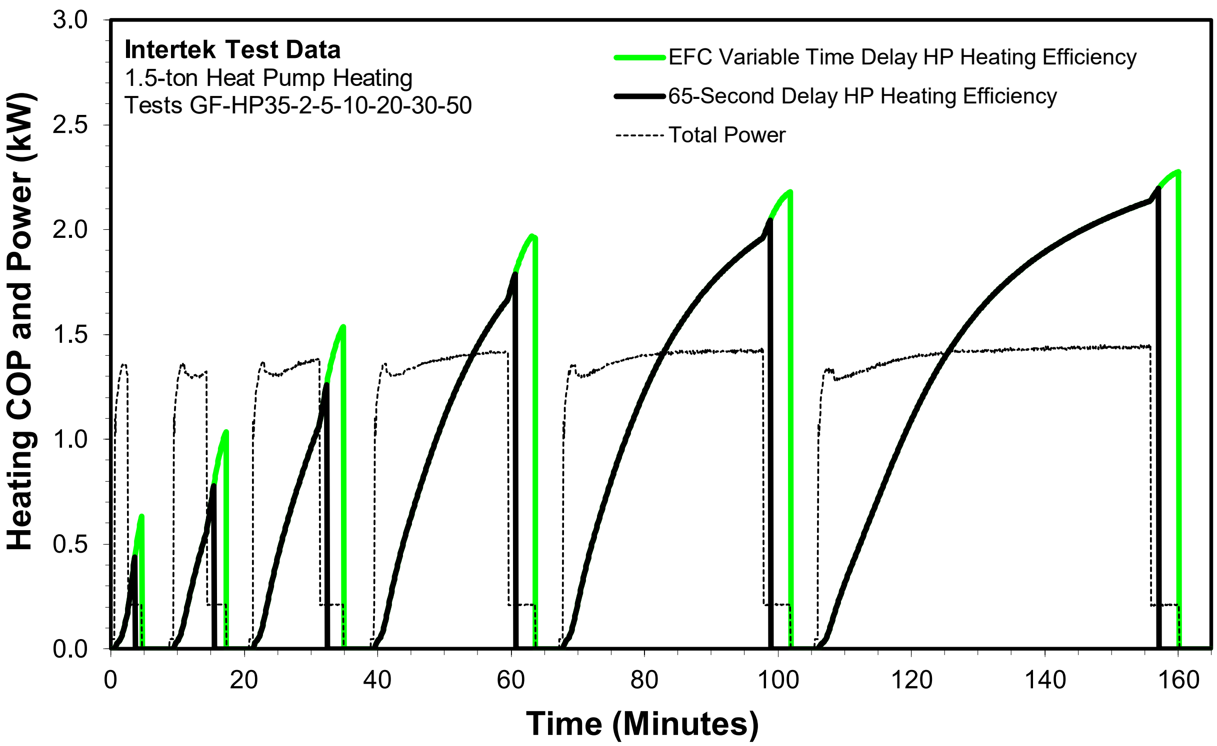
Heat Pump Heating Tests at 35F OAT with 65-Second Delay and Variable Delay

Heating tests for the 1.5-ton split-system heat pump were performed at typical field conditions of 70F DB and 55F WB indoor and 35F outdoor temperatures. **Table 13** and **Figure 12** provide test results. For the baseline tests the indoor fan operated with fixed 65-second time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 3.9 to 44.3% and provides heating energy savings of 3.7 to 30.7%.

Table 13: HP Heating Tests 35F OAT GF-HP35-2-50 – 65-Second Delay and EFC Variable Delay

Description	Test 155	Test 156	Test 157	Test 158	Test 159	Test 160
HP Compressor On Time (minutes)	2	5	10	20	30	50
65-Second Delay HP Heating Energy Input (kWh) [a]	0.046	0.112	0.225	0.459	0.696	1.167
65-Second Delay HP Heating Capacity (Btu) [b]	70	298	971	2,807	4,860	8,716
65-Second Delay HP Heating Efficiency [c=b/a/3412]	0.44	0.78	1.26	1.79	2.05	2.19
EFC HP Energy Input (kWh) [d]	0.050	0.117	0.232	0.468	0.707	1.177
EFC HP Heating Capacity (Btu) [e]	109	403	1,195	3,146	5,261	9,133
EFC HP Heating Efficiency [f=e/d/3412]	0.64	1.01	1.51	1.97	2.18	2.27
EFC HP Heating Efficiency Improvement [g=f/c-1]	44.3%	28.8%	19.3%	10.0%	6.6%	3.9%
EFC Extra Fan Energy (kWh)	0.004	0.005	0.007	0.009	0.011	0.011
65-Sec. Delay Energy to Match EFC (kWh) [h=e/c/3412]	0.072	0.151	0.277	0.515	0.754	1.222
EFC Energy Savings (kWh) [i=h-d]	0.022	0.034	0.045	0.047	0.047	0.045
EFC Heating Savings [j=(1-c/f) or j=i/h]	**30.7%**	**22.4%**	**16.1%**	**9.1%**	**6.2%**	**3.7%**

Figure 12: HP Heating Tests 35F OAT GF-HP35-2-50 – 65-Second Delay and EFC Variable Delay



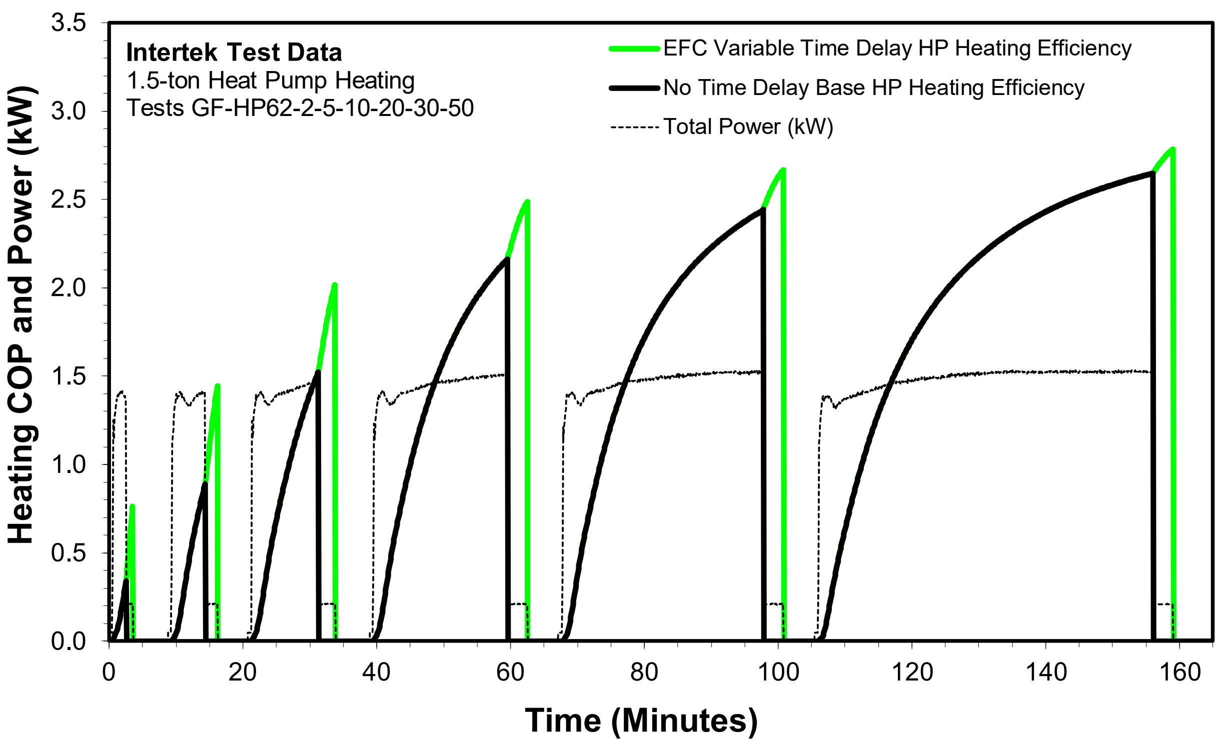
Heat Pump Heating Tests at 62F OAT with No Delay and Variable Delay

Heating tests for the 1.5-ton split-system heat pump were performed at typical field conditions of 70F DB and 55F WB indoor and 62F outdoor temperatures. **Table 14** and **Figure 13** provide test results. For the baseline tests the indoor fan operated with no time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 5.1 to 125.6% and provides heating energy savings of 4.9 to 55.7%.

Table 14: HP Heating Tests 62F OAT GF-HP62-2-50 – No Delay and EFC Variable Delay

Description	Test 161	Test 162	Test 163	Test 164	Test 165	Test 166
HP Compressor On Time (minutes)	2	5	10	20	30	50
No Delay HP Heating Energy Input (kWh) [a]	0.046	0.114	0.234	0.483	0.735	1.238
No Delay HP Heating Capacity (Btu) [b]	53	348	1,219	3,563	6,133	11,190
No Delay HP Heating Efficiency [c=b/a/3412]	0.34	0.89	1.53	2.16	2.45	2.65
EFC HP Energy Input (kWh) [d]	0.049	0.119	0.241	0.491	0.745	1.249
EFC HP Heating Capacity (Btu) [e]	129	555	1,601	4,115	6,782	11,865
EFC HP Heating Efficiency [f=e/d/3412]	0.77	1.36	1.95	2.45	2.67	2.78
EFC HP Heating Efficiency Improvement [g=f/c-1]	125.6%	52.7%	27.5%	13.5%	9.0%	5.1%
EFC Extra Fan Energy (kWh)	0.004	0.005	0.007	0.009	0.010	0.010
No Delay HP Energy to Match EFC (kWh) [h=e/c/3412]	0.111	0.182	0.307	0.558	0.812	1.313
EFC Energy Savings (kWh) [i=h-d]	0.062	0.063	0.066	0.066	0.067	0.064
EFC Heating Savings [j=(1-c/f) or j=i/h]	**55.7%**	**34.5%**	**21.6%**	**11.9%**	**8.3%**	**4.9%**

Figure 13: HP Heating Tests 62F OAT GF-HP62-2-50 – No Delay and EFC Variable Delay



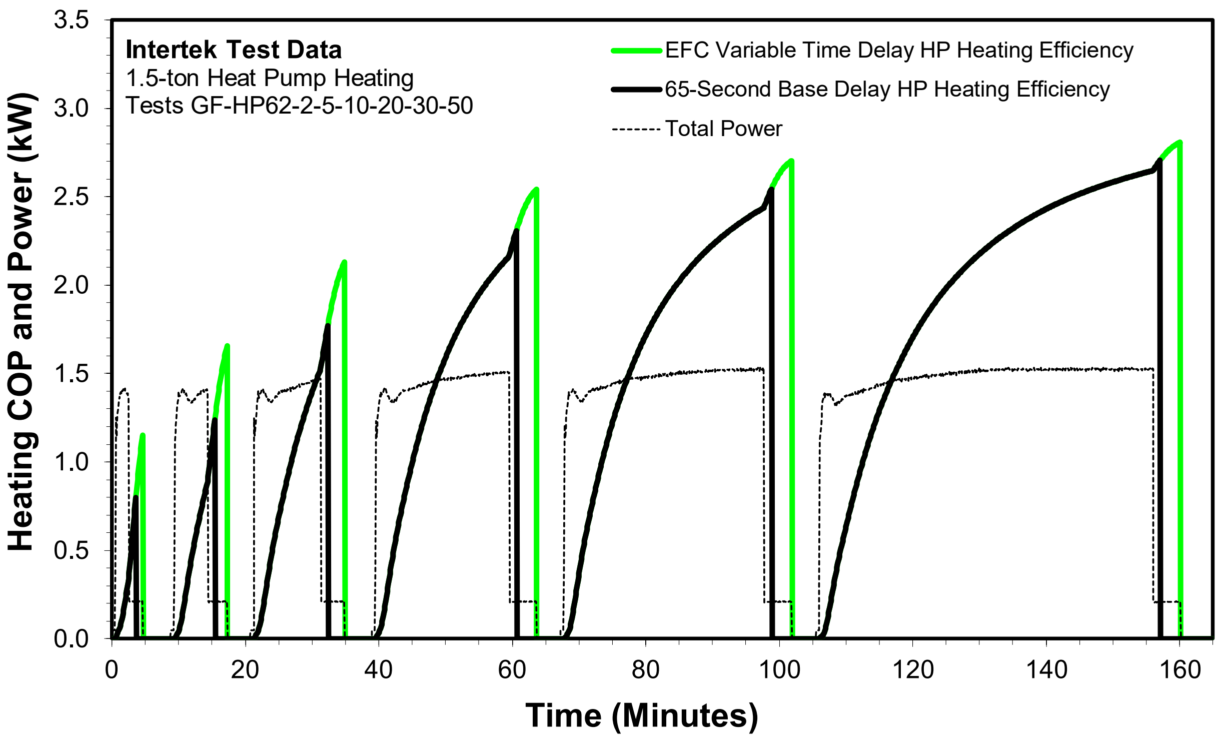
Heat Pump Heating Tests at 62F OAT with 65-Second Delay and Variable Delay

Heating tests for the 1.5-ton split-system heat pump were performed at typical field conditions of 70F DB and 55F WB indoor and 62F outdoor temperatures. **Table 15** and **Figure 14** provide test results. For the baseline tests the indoor fan operated with fixed 65-second time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 3.7 to 44% and provides heating energy savings of 3.6 to 30.6%.

Table 15: HP Heating Tests 62F OAT GF-HP62-2-50 – 65-Second Delay and EFC Variable Delay

Description	Test 167	Test 168	Test 169	Test 170	Test 171	Test 172
HP Compressor On Time (minutes)	2	5	10	20	30	50
65-Second Delay HP Heating Energy Input (kWh) [a]	0.050	0.118	0.238	0.486	0.738	1.242
65-Second Delay HP Heating Capacity (Btu) [b]	136	500	1,439	3,831	6,413	11,478
65-Second Delay HP Heating Efficiency [c=b/a/3412]	0.81	1.24	1.77	2.31	2.55	2.71
EFC HP Energy Input (kWh) [d]	0.053	0.123	0.245	0.495	0.749	1.253
EFC HP Heating Capacity (Btu) [e]	210	675	1,745	4,263	6,912	12,002
EFC HP Heating Efficiency [f=e/d/3412]	1.16	1.61	2.09	2.52	2.71	2.81
EFC HP Heating Efficiency Improvement [g=f/c-1]	44.0%	29.3%	17.8%	9.3%	6.3%	3.7%
EFC Extra Fan Energy (kWh)	0.004	0.005	0.007	0.009	0.011	0.010
65-Sec. Delay Energy to Match EFC (kWh) [h=e/c/3412]	0.076	0.159	0.288	0.541	0.796	1.299
EFC Energy Savings (kWh) [i=h-d]	0.023	0.036	0.044	0.046	0.047	0.046
EFC Heating Savings [j=(1-c/f) or j=i/h]	**30.6%**	**22.7%**	**15.1%**	**8.5%**	**5.9%**	**3.6%**

Figure 14: HP Heating Tests 62F OAT GF-HP62-2-50 – 65-Second Delay and EFC Variable Delay



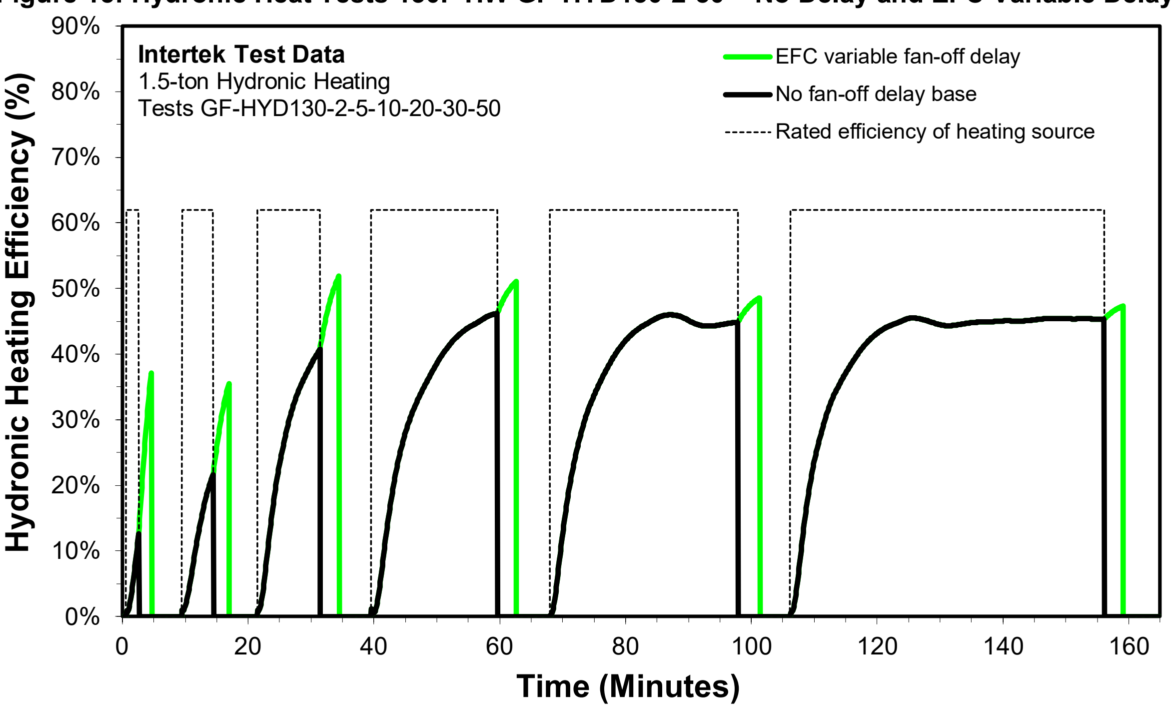
Hydronic Heating Tests with 130F Hot Water with No Delay and Variable Delay

Heating tests for the 1.5-ton split-system hydronic heating system were performed at typical field conditions of 70F DB and 55F WB indoor and 47F outdoor temperatures with average 130F hydronic temperature. **Table 16** and **Figure 15** provide test results. For the baseline tests the indoor fan operated with no time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 4.3 to 194.5% and provides heating savings of 4.2 to 66%. The maximum heating efficiency varies during heat source operation due hot water supply temperatures decreasing below the storage tank setpoint causing the water heater to cycle on and off.

Table 16: Hydronic Heat Tests 130F HW GF-HYD130-2-50 – No Delay and EFC Variable Delay

Description	**Test 173**	**Test 174**	**Test 175**	**Test 176**	**Test 177**	**Test 178**
Hydronic On Time (minutes)	2	5	10	20	30	50
No Delay Hydronic Energy Input (Btu) [a]	970	2,365	4,584	9,223	14,102	23,893
No Delay Heating Capacity (Btu) [b]	122	512	1,869	4,260	6,325	10,834
No Time Delay Heating Efficiency [c=b/a]	12.6%	21.6%	40.8%	46.2%	44.9%	45.3%
EFC Hydronic Energy Input (Btu) [d]	970	2,365	4,584	9,223	14,102	23,893
EFC Delivered Heating Capacity (Btu) [e]	360	839	2,379	4,709	6,854	11,303
EFC Hydronic Heating Efficiency [f=e/d]	37.1%	35.5%	51.9%	51.1%	48.6%	47.3%
EFC Heating Efficiency Improvement [g=f/c-1]	194.5%	64.0%	27.3%	10.5%	8.4%	4.3%
EFC Extra Fan Energy (kWh)	0.007	0.009	0.010	0.010	0.012	0.010
No Delay Energy to Match EFC [h=e/c]	2,855	3,878	5,834	10,195	15,282	24,928
EFC Energy Savings (Btu) [i=h-d]	1,886	1,513	1,251	972	1,180	1,035
EFC Heating Energy Savings [j=1-c/f]	**66.0%**	**39.0%**	**21.4%**	**9.5%**	**7.7%**	**4.2%**

Figure 15: Hydronic Heat Tests 130F HW GF-HYD130-2-50 – No Delay and EFC Variable Delay



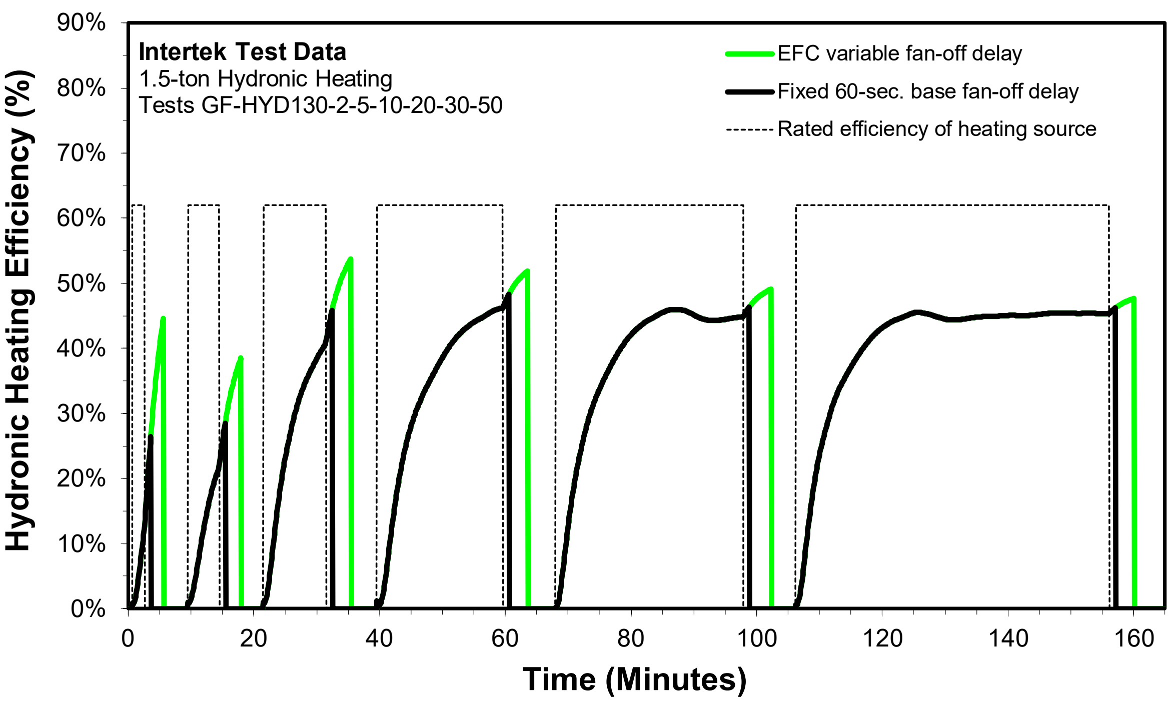
Hydronic Heating Tests with 130F Hot Water with 60-Second Delay and EFC Variable Delay

Heating tests for the 1.5-ton split-system hydronic heating system were performed at typical field conditions of 70F DB and 55F WB indoor and 47F outdoor temperatures with average 130F hydronic temperature. **Table 17** and **Figure 16** provide test results. For the baseline tests the indoor fan operated with 60-second time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 3.1 to 68.7% and provides heating savings of 3 to 40.7%. The maximum hydronic heating efficiency varies during heat source operation due hot water supply temperatures decreasing below the storage tank setpoint.

Table 17: Hydronic Heat Tests 130F HW GF-HYD130-2-50 – 60-Second and EFC Variable Delay

Description	Test 179	Test 180	Test 181	Test 182	Test 183	Test 184
Hydronic On Time (minutes)	2	5	10	20	30	50
60-Second Delay Hydronic Energy Input (Btu) [a]	970	2,365	4,584	9,185	14,102	23,893
60-Second Delay Heating Capacity (Btu) [b]	256	674	2,099	4,458	6,540	11,040
60-Second Time Delay Heating Efficiency [c=b/a]	26.4%	28.5%	45.8%	48.5%	46.4%	46.2%
EFC Hydronic Energy Input (Btu) [d]	970	2,365	4,584	9,185	14,102	23,893
EFC Delivered Heating Capacity (Btu) [e]	433	911	2,464	4,789	6,929	11,387
EFC Hydronic Heating Efficiency [f=e/d]	44.6%	38.5%	53.8%	52.1%	49.1%	47.7%
EFC Heating Efficiency Improvement [g=f/c-1]	68.7%	35.1%	17.4%	7.4%	6.0%	3.1%
EFC Extra Fan Energy (kWh)	0.007	0.009	0.010	0.009	0.012	0.010
60-Second Delay Energy to Match EFC [h=e/c]	1,636	3,194	5,382	9,868	14,942	24,643
EFC Energy Savings (Btu) [i=h-d]	666	830	799	683	840	750
EFC Heating Energy Savings [j=1-c/f]	**40.7%**	**26.0%**	**14.8%**	**6.9%**	**5.6%**	**3.0%**

Figure 16: Hydronic Heat Tests 130F HW GF-HYD130-2-50 – 60-Second and EFC Variable Delay



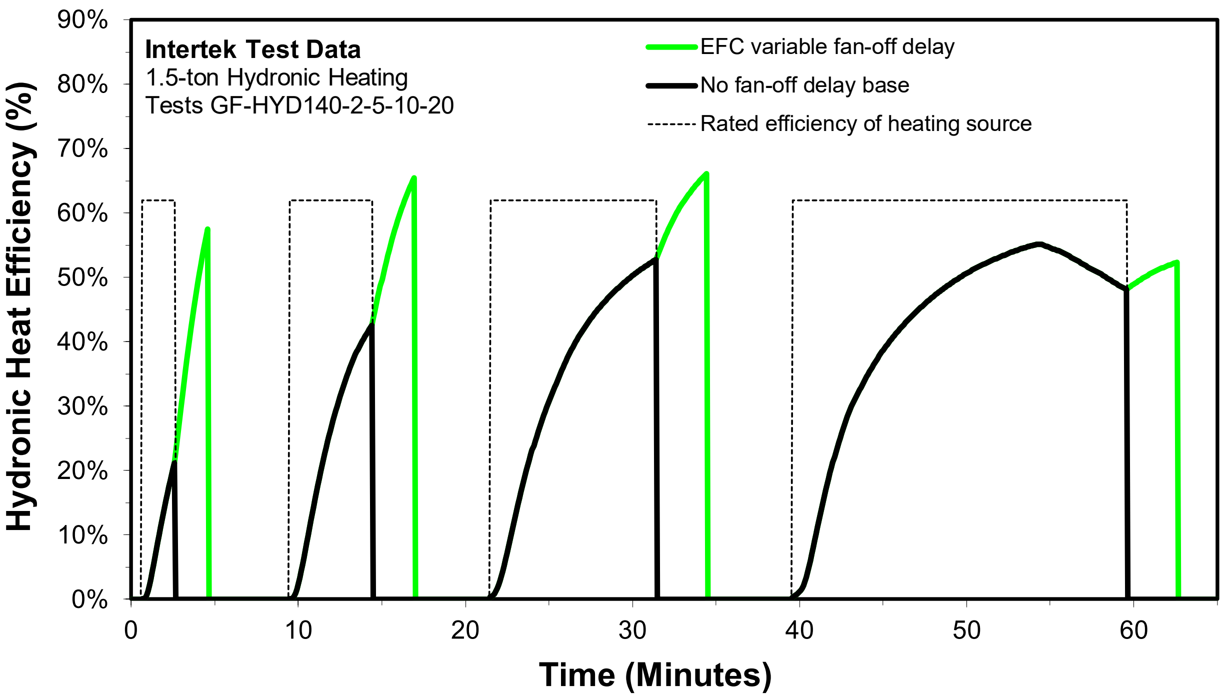
Hydronic Heating Tests with 140F Hot Water with No Delay and EFC Variable Delay

Heating tests for the 1.5-ton split-system hydronic heating system were performed at typical field conditions of 70F DB and 55F WB indoor and 47F outdoor temperatures with average 140F hydronic temperature. **Table 18** and **Figure 17** provide test results. For the baseline tests the indoor fan operated with no time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 10.5 to 171.9% and provides heating savings of 9.5 to 63.2%. The maximum hydronic heating efficiency varies during heat source operation due to hot water supply temperatures decreasing below the storage tank setpoint.

Table 18: Hydronic Heat Tests 140F HW GF-HYD140-2-50 – No Delay and EFC Variable Delay

Description	Test 185	Test 186	Test 187	Test 188
Hydronic On Time (minutes)	2	5	10	20
No Delay Hydronic Energy Input (Btu) [a]	874	2,365	4,467	9,650
No Delay Heating Capacity (Btu) [b]	185	1,006	2,358	4,643
No Time Delay Heating Efficiency [c=b/a]	21.1%	21.4%	52.8%	46.9%
EFC Hydronic Energy Input (Btu) [d]	874	2,365	4,467	9,650
EFC Delivered Heating Capacity (Btu) [e]	502	1,548	2,954	5,051
EFC Hydronic Heating Efficiency [f=e/d]	57.5%	35.2%	66.1%	51.8%
EFC Heating Efficiency Improvement [g=f/c-1]	171.9%	64.0%	25.3%	10.5%
EFC Extra Fan Energy (kWh)	0.007	0.008	0.010	0.010
No Delay Energy to Match EFC [h=e/c]	2,375	7,219	5,596	10,773
EFC Energy Savings (Btu) [i=h-d]	1,502	2,526	1,129	870
EFC Heating Energy Savings [j=(1-c/f) or j=i/h]	**63.2%**	**39.0%**	**20.2%**	**9.5%**

Figure 17: Hydronic Heat Tests 140F HW GF-HYD140-2-50 – No Delay and EFC Variable Delay



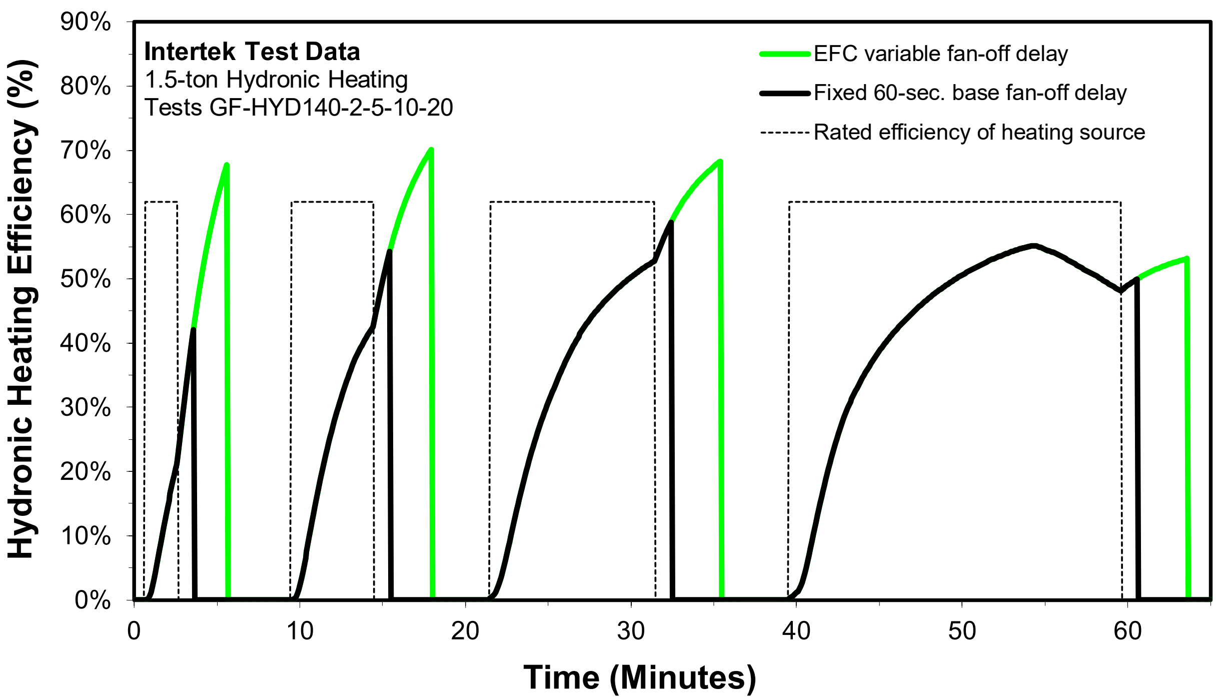
Hydronic Heating Tests with 140F Hot Water with 60-Second Delay and EFC Variable Delay

Heating tests for the 1.5-ton split-system hydronic heating system were performed at typical field conditions of 70F DB and 55F WB indoor and 47F outdoor temperatures with average 140F hydronic temperature. **Table 19** and **Figure 18** provide test results. For the baseline tests the indoor fan operated with 60-second time delay after the heat source turned off. With EFC the indoor fan operated with variable time delay after heat source turned off. Each pair of tests used the same energy for heating. The EFC improved heating efficiency by 6.4 to 60.8% and provides heating savings of 6 to 37.8%. The maximum hydronic heating efficiency varies due to hot water supply temperatures decreasing below the storage tank setpoint causing the water heater to turn on and off during hydronic heating.

Table 19: Hydronic Heat Tests 140F HW GF-HYD140-2-50 – 60-Second and EFC Variable Delay

Description	Test 191	Test 192	Test 193	Test 194
Hydronic On Time (minutes)	2	5	10	20
60-Second Delay Hydronic Energy Input (Btu) [a]	874	2,365	4,467	9,522
60-Second Delay Heating Capacity (Btu) [b]	368	1,282	2,627	4,820
60-Second Time Delay Heating Efficiency [c=b/a]	42.1%	54.2%	58.8%	50.6%
EFC Hydronic Energy Input (Btu) [d]	874	2,365	4,467	9,522
EFC Delivered Heating Capacity (Btu) [e]	592	1,658	3,052	5,127
EFC Hydronic Heating Efficiency [f=e/d]	67.8%	70.1%	68.3%	53.8%
EFC Heating Efficiency Improvement [g=f/c-1]	60.8%	29.3%	16.2%	6.4%
EFC Extra Fan Energy (kWh)	0.005	0.007	0.010	0.009
60-Second Delay Energy to Match EFC [h=e/c]	1,405	3,057	5,190	10,128
EFC Energy Savings (Btu) [i=h-d]	531	693	723	606
EFC Heating Energy Savings [j=(1-c/f) or j=i/h]	**37.8%**	**22.7%**	**13.9%**	**6.0%**

Figure 18 Hydronic Heat Tests 140F HW GF-HYD140-2-50 – 60-Second and EFC Variable Delay



Conclusion

The following conclusions are provided regarding the performance evaluation tests of the patented EFC installed on a 1.5-ton split-system heat pump HVAC unit. Based on 20 cooling tests, the EFC provides cooling energy savings of 4.9 to 75.9% compared to zero fan-off time delay and 3.7 to 41.8% compared to 65-second fan-off time delay. Based on 48 heat pump heating tests, the EFC provides heat pump energy savings of 4.6 to 60.7% compared to no time delay and 3.1 to 30.6% compared to 65-second time delay.

The following conclusions are provided regarding the performance evaluation tests of the EFC installed on a 1.5-ton split-system hydronic HVAC unit. Based on 20 hydronic heating tests with 130 to 140F hydronic supply temperature, the EFC provides heating energy savings of 4.2 to 66% compared to no time delay and 3 to 40.7% compared to fixed 60-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 fan energy increase per cycle with the EFC is 0.012 ± 0.001kWh or 17.9 ± 1.6% of cooling savings (i.e., 1 unit of extra fan energy provides 5.6 ± 0.5 units of cooling energy savings). For heat pump heating, the average fan energy increase per cycle with the EFC is 0.008 ± 0.001 kWh or 14.5 ± 1.2% of heating savings (i.e., 1 unit of extra fan energy provides 6.9 ± 0.57 units of heat pump heating energy savings). For hydronic heating, the average fan energy increase per cycle with the EFC is 0.009 ± 0.001 kWh or 8.9 ± 0.7% of heating savings (i.e., 1 unit of extra fan energy provides 11.2 ± 0.8 units of heating energy savings).[5]

Based on 24 cooling tests, the EFC improves cooling efficiency by 47 +/- 24% and provides cooling energy savings of 23.4 +/- 6.8%. Based on 48 heat pump heating tests, the EFC improves average heating efficiency by 30.3 +/- 8.7% and provides average heat pump heating energy savings of 19.2 +/- 3.7%. Based on 20 hydronic heating tests, the EFC improves average heating efficiency by 41 +/- 19.6% and provides average hydronic heating energy savings of 22.6 +/- 7%.

Report Number	Date	Description
102791047DAL-001A	12-15-16	Original version of report
102791047DAL-001B	11-15-18	Updated text and tables

[5] 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).

