U.S. DEPARTMENT OF ENERGY

Residential Cold-Climate Heat Pump Technology Challenge Specification and Supporting Documents

Version 1.2

September 24, 2021

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I. Objective and Scope

A. Objective

As part of the Initiative for Better Energy, Emissions, and Equity ("E3 Initiative"), the US Department of Energy ("DOE") is launching a technology challenge ("the Challenge") to accelerate performance of cold climate heat pump ("CCHP") technologies. In partnership with US Environmental Protection Agency ("EPA"), Natural Resources Canada ("NRCan"), heat pump ("HP") manufacturers and other stakeholders, DOE aims to: 1) develop a new technology specification for a high-performance CCHP that meets consumer needs, 2) demonstrate CCHP performance in the lab and in the field, and 3) launch pilot programs with partners, such as utilities, to identify and alleviate installation challenges. The expected timeline for this challenge would develop, test, and commercialize the CCHP products by 2024.

B. Scope

The CCHP Technology Challenge ("the Challenge") is focused on residential, centrally ducted, electric-only HPs.[1] The Challenge has two segments: one for a CCHP optimized for 5°F (-15°C) operation ("5°F challenge") and the other for a CCHP optimized for -15°F (-26°C) operation ("-15°F challenge") Manufacturers can choose to participate in either one or both segments of the Challenge, although both the 5ºF (-15 ºC) and -15°F (-26°C) requirements must be met for a heat pump participating in the -15°F (-26°C) Challenge. The scope of the Challenge is limited to CCHP model submissions ("Unit(s)") that:

[1] Other equipment and market segments may be considered for inclusion in the future.

(1) Have a nominal cooling capacity (or nominal heating capacity for a heating-only HP) greater than or equal to 24,000 Btu/h and less than or equal to 65,000 Btu/h. [2]

(2) Meet all of the minimum specification requirements detailed in Section II.

(3) Comply with all applicable federal and state standards, regulations and laws governing these types of HPs. This includes compliance with all applicable safety and environmental standards.

II. Technology Specifications

The Challenge specifications consist of performance specifications (seasonal heating performance, heating performance at 5°F [-15°C], heating performance at -15°F), a low global warming potential ("GWP") requirement, and connected product criteria requirements.

A. Performance Specifications

The goal for the Challenge specification is to advance the performance of CCHP technologies above the performance of best-in-class products today, while also meeting consumer and stakeholder expectations. The performance specifications were developed based on a review of current CCHP performance data from the Northeast Energy Efficiency Partnerships ("NEEP") database and discussions with several manufacturers on technology opportunities and limitations. This section outlines the performance specifications that would exceed current products on the market today and meet the 2024 commercialization timeline. Manufacturers must meet the seasonal heating performance requirements and can choose to participate in either one or both segments of the Challenge (heating performance at 5°F, heating performance at -15°F).

1. Seasonal Heating Performance

(1) If the Unit(s) is a northern triple capacity HP, the Unit(s) shall have a minimum HP heating season performance factor ("HSPF2") as measured per Appendix M1 of Subpart B1 of 10 CFR 430 ("Appendix M1") of 8.5 (Region V). If the manufacturer chooses to conduct the non-regulatory verification tests using a defrost setting for Region V, the HSPF2 requirement shall be met by Appendix M1 tests conducted both with the standard regulatory test requirement for the defrost controls setting and with the setting set for Region V.

[2] "Btu/h" refers to British thermal units per hour.

(2) If the Unit(s) is a Variable-speed HP, the Unit(s) shall include:

a. Minimum capacity at 47°F (8°C), validated using the Min/Mild verification procedure described in Appendix A of this document, shall be at least 30% less than the nominal capacity at 47°F (8°C), the capacity for test $H1_N$ of Appendix M1 (i.e. turndown of 30% to a 70% capacity ratio).

b. Minimum HP HSPF2 of 8.5 (Region V) determined using Appendix M1, subject to adjustment, as described below. If the manufacturer chooses to conduct the non-regulatory verification tests using a defrost setting for Region V, the HSPF2 requirement shall be met by Appendix M1 tests conducted both with the standard regulatory test requirement for the defrost controls setting and with the setting set for Region V.

c. Capacity factor: HSPF2 requirement shall be increased 1% for each 10% difference in turndown of the 47°F (8°C) minimum capacity, as measured using the Min/Mild verification procedure described in Appendix A of this document, compared to the turndown represented by the 47°F (8°C) minimum $H1_1$ capacity measured using Appendix M1. This would be subject to a tolerance of 3% of $H1_1$ capacity (i.e. if the verification test capacity is with 3% of the Appendix M1 $H1_1$ capacity, the capacity factor is zero). See Appendix B: *HSPF2 Adjustment* of this document for an explanation and example of this adjustment.

d. COP factor: HSPF2 requirement shall be increased 2% for each 10% difference between the COP measured for the $H1_1$ test using the Min/Mild verification procedure described in Appendix A of this document, compared to the COP measured for the $H1_1$ test using Appendix M1 and adjusted for capacity in case there is a turndown gap involving the capacity factor above. See Appendix B: *HSPF2 Adjustment* of this document for an explanation of this adjustment to account for potential compressor speed fluctuations during verification testing.

(3) The Unit(s) shall provide a minimum number of electric heat stages[3] corresponding to the electric heat requirement in kilowatts (kW[4]) as set out in Table II-1. Continuous control of electric heating staging would comply with these requirements. Electric heat staging requirements should be verifiable in manufacturer product literature (e.g., installation

[3] Control in which a control signal external to the electric heat kit including its relays calls separately for each sequential heating stage.
[4] a measure of 1,000 watts of electrical power.

manual, user manual, spec sheets).[5] In addition, during verification testing with electric heating elements engaged (H2_RH and H4_Max/Cold_RH), no more than one stage shall be energized by the controls.

Table II-1: Electric Heat Staging Requirement

Electric Heat (kW)	Minimum Number of Electric Heat Stages
>0 and ≤5	1
>5 and ≤10	2
>10 and ≤15	3
>15	3

2. Heating Performance at 5°F (-15°C), based on the H4_Max/Cold verification test and the Test to Validate Maximum Cut-In and Cut-Out Temperatures.

(1) Unit(s) shall have a minimum ratio of maximum heating capacity[6] at 5°F (-15°C) to nominal heating capacity at 47°F (8°C), the capacity for test $H1_N$ of Appendix M1, equal to 1.0.[7]

(2) Unit(s) shall have a minimum HP coefficient of performance ("COP") corresponding to the COP requirements set out in Table II-2.

(3) Unit(s) shall have a low-temperature compressor cut-out no higher than -10°F (-23°C) and cut-in no higher than -5°F (-21°C).

Table II-2 summarizes the requirements for heating performance at 5°F (-15°C) for the Unit .

[5] Draft manufacturer product literature would be acceptable prior to product commercialization.
[6] Capacity corresponding to the highest compressor speed allowed for extended periods of operation (i.e. not including temporary "boost" or "turbo" modes) at the specified ambient temperature.
[7] Manufacturers had concerns with the current requirements for a capacity ratio at 5°F relative to 47°F, indicating that someone could bend the rules by reducing the H1N 47°F capacity to achieve the target. The current test procedure limits the reduction of H1N by requiring that the compressor speed for the H1N test can only be lower than the compressor speed for the A2 cooling capacity test if the H1N capacity is no lower.

Table II-2: Performance Requirements at 5°F (-15°C)[2]

HP nominal capacity[1] (Btu/h)	COP at 5°F (-15°C)	Capacity Ratio	Low-temperature compressor cut-out	Low-temperature compressor cut-in
≥24,000 and ≤ 36,000	2.4	100%	≤ -10°F (-23°C)	≤ -5°F (-21°C)
>36,000 and ≤ 48,000	2.4	100%		
>48,000	2.1	100%		

[1] Capacity for the A2 test of Appendix M1 for a heating/cooling heat pump. Capacity of the $H1_N$ test of Appendix M1 for a heating-only heat pump.

[2] All of the requirements in the second through fifth columns are mandatory as indicated for the specified ranges of HP nominal capacity.

3. Heating Performance at -15°F (-26°C), based on the Max/Extreme verification test or Extrapolation Approach verification tests (H3_Max/Cold, H4_Max/Cold, Max/Extreme Power Input Only) and the Test to Validate Maximum Cut-In and Cut-Out Temperatures, *optional.*

(1) Heating Performance (Capacity and COP) at -15°F (-26°C) shall be measured and reported.

(2) Unit(s) shall have a low-temperature compressor cut-out no higher than -20°F (-29°C) and cut-in no higher than -15°F (-26°C).

B. Low-GWP Requirements

(1) Unit(s) shall employ a refrigerant that has a GWP of no more than 750 as measured per the American Society of Heating, Refrigerating, and Air-Conditioning Engineers ("ASHRAE") book of Fundamentals 2017, which refers to 100 year GWP values from the Intergovernmental Panel on Climate Change ("IPCC") Fourth Assessment Report ("AR4").

C. Connected Product Criteria

(1) Unit(s) shall comply with Sections 3C (Installation Capabilities), 4B (Communications), 4C (Consumer Feedback) and 4D (Demand Response) of the ENERGY STAR Product

Specification for Central Air Conditioner and Heat Pump Version 6.0 ("ENERGY STAR CACHP Specification v6.0").[8]

(2) Verification of connected product criteria shall comply with Section 5 and Table 5 of the ENERGY STAR CACHP Specification v6.0 relating to "Installation Capabilities" and "Connected Products: Demand Response". The verification procedure for the Challenge would also incorporate any future updates to the ENERGY STAR CACHP specification for applicable connected product capabilities.

D. Technology Specifications Summary

Table II-3 summarizes the technology specifications that the Unit(s) must meet per the Challenge.

[8] Note that general compliance with ENERGY STAR requirements other than those explicitly cited in this document is not necessary.

Table II-3: Summary of the Challenge specifications

HP nominal capacity (Btu/h)[1]	**Seasonal Heating Performance**		**Heating at 5°F (-15°C)**				**Heating at -15°F (-26°C) *(optional)***	
	Minimum HSPF2	Min. Turndown ratio	COP at 5°F (-15°C)	Capacity Ratio	Low-temperature compressor cut-out at 5°F (-15°C)	Low-temperature compressor cut-in at 5°F (-15°C)	Low-temperature compressor cut-out at -15°F (-26°C)	Low-temperature compressor cut-in at -15°F (-26°C)
≥24,000 and ≤36,000	8.5 * (1 + Capacity factor[2]) * (1 + COP factor[3])	30%	2.4	100%	≤ -10°F (-23°C)	≤ -5°F (-21°C)	≤ -20 °F (-29°C)	≤ -15 °F (-26°C)
>36,000 and ≤48,000			2.4	100%				
>48,000			2.1	100%				

[1] Capacity for the A2 test of Appendix M1 for a heating/cooling heat pump. Capacity of the $H1_N$ test of Appendix M1 for a heating-only heat pump.

[2] Capacity factor: 1 percent for every 10% $H1_1/H1_N$ gap. The capacity factor for northern triple capacity HPs is 0.

[3] COP factor: 2 percent for every 10% excess COP gap between the expected COP reduction and the measured COP reduction from the $H1_1$ verification test and the $H1_1$ regulatory test

Additional Requirements:	
(1)	Unit(s) shall comply with electric heat staging requirements as set out in Table II-1
(2)	Unit(s) refrigerant shall have a GWP no greater than 750 (AR4 100-year).
(3)	Unit shall comply with Sections 3C, 4B, 4C, and 4D of the ENERGY STAR CACHP specification.

III. Reporting Requirements

When certifying a Unit(s) for the Challenge, manufacturers shall meet the certification requirements in 10 CFR 429.16(e) applicable for products sold on and after January 1, 2023 (i.e. using Appendix M1) and report the following additional information:

- HSPF2 (Region V)
- Capacity and Power Input for each Appendix M1 test point
- Capacity, Power Input, and COP for each Validation test procedure test point
- Whether the Model has demand defrost
- Whether all of the Model's manufacturer-authorized auxiliary electric resistance heat options comply with the auxiliary electric resistance heat requirements of the specification.
- Result of the validation testing

In addition, the following non-public information shall be reported.

- Whether verification testing is to be conducted using defrost settings compatible with Climate Region V instead of the climate region specified in Appendix M1.
- The thermostat setting (no lower than 73 °F) to achieve maximum-capacity heating operation, if it is not the highest control setting.
- Specification of control device if not shipped with the unit (see Appendix A Section D.1)

IV. Public Participation

Manufacturer participation requirements and procedures will be detailed in a separate commitment letter, which will be provided to interested parties.

Appendix A: Test Procedure

A. Purpose:

The purpose of this test procedure is to validate performance attributes of central HPs that are critical for their successful deployment for heating operation in cold-climate regions. The test procedure includes test elements incorporating actions of system controls that affect system performance.

This test procedure complements and augments regulatory test procedures such as the federal test procedure established by the Department of Energy (Appendix M1 to Subpart B of Part 430 " Uniform Test Method for Measuring the Energy Consumption of Central Air Conditioners and Heat Pumps") for the purpose of evaluating aspects important for cold climate operation that are not fully evaluated by regulatory procedures.

This procedure is to characterize the following performance attributes:

- HP unloading capability (i.e. capacity turn-down) at 47ºF (8.3ºC) outdoor conditions
- HP capacity level and efficiency at 5ºF (-15ºC) and -15ºF (-26ºC) outdoor conditions
- Validation of Demand Defrost operation, and
- Control strategies of unit equipped with electric resistance heating elements

B. Scope:

This procedure applies to central ducted HPs with a variable-speed compressor or northern HPs, as defined in Appendix M1 and which are also CCHPs. The test procedure addresses both 5 ºF (-15 ºC) and -15 ºF (-26 ºC) CCHPs.

C. Definitions:

Refer to Appendix M1 and ENERGY STAR definitions.

Cold Climate Heat Pump (CCHP) means a central HP that can provide mechanical air heating utilizing refrigerant vapor compression cycle or a combination of mechanical air heating and electric resistance heating at low outdoor temperature, at least as low as 5 ºF.

> *5 ºF (-15 ºC) Cold Climate Heat Pump* means a Cold Climate Heat Pump capable of heat pump operation down to 5 ºF (-15 ºC) ambient temperature.
>
> *-15 ºF (-26 ºC) Cold Climate Heat Pump* means a Cold Climate Heat Pump capable of heat pump operation down to -15 ºF (-26 ºC) ambient temperature.

Native Control means configuring the unit under test with settings specified for field use and removing the unit from "test mode" used for steady-state tests.

D. Testing Apparatus and Setup:

Refer to Appendix M1 (incorporated by reference) for setup unless otherwise modified by this document.

1. Control Device:

For units shipped with a control device (i.e. thermostat or remote-controller), the control device is considered an integral component of Native Control and should be used for testing. For units that are intended to be used with a communicating control but the control device is not shipped with the unit, the manufacturer must specify the communicating control device that is most commonly installed with the unit to be used during testing. The manufacturer has the option of specifying one or more proprietary thermostats (communicating and/or 24-volt) and/or to specify that any generic thermostat can be used to test the unit.

Install the control device on a flat surface (i.e. wood or insulation) extending 12" from the nearest edge on all sides. The control device must be located outside of the return air duct opening and within 12" of the mid-point of the nearest edge of the return air duct opening. A thermocouple located at control device return air sensor location (i.e. within 2" of the inlet opening for the remote or wall-mounted thermostat) shall be installed. An additional thermocouple shall be located at the return air thermistor (i.e. within 2" of the return air thermistor provided by the test unit), if present. If both thermocouples are installed, they shall agree within 1°F of each other. Each thermocouple shall also agree with the air entering dry-bulb sensor within 1°F. Mixing fans may be used to ensure temperature uniformity. If used, the mixing fans shall not be directed at the control device. Air velocity at the control device shall not exceed 50 fpm. Baffles or a perforated-plate box may be used to reduce control device air velocity to this limit.

2. Required Accessories

If specific accessories are necessary to achieve the intended performance, the manufacturer shall specify these accessories. They shall be installed as indicated in the manufacturer Installation and Operations ("I&O") manual prior to all testing.

3. Control Settings:

Native Control settings shall be determined from the manufacturer I&O manual shipped with the unit. The settings designated for CCHP operation shall be used, unless otherwise specified in this document. Where multiple control settings can be selected for CCHP operation, any of the specified options may be used. In the event that control settings required to operate the unit are not present in the manufacturer I&O manual, the hierarchy shall be product label instructions, then use the as-shipped settings. For airflow control settings, see Table A-2.

4. Electric Resistance Heating:

Electric resistance heating elements shall be installed and configured for operation after completion of the regulatory testing (e.g. Appendix M1). Additionally, a power meter shall be

installed to independently measure the electrical energy of the heating elements separately from the system power measurement.

Install at least the first two stages of electric resistance heat. The manufacturer shall specify the staging controls of the installed electric resistance heat as appropriate. However, the staging control selection shall be based on the fewest discrete control steps allowed, using the full heating input configuration closest to the value shown in Table A-1 below for the given Heat Pump Class and Capacity. A heat pump being tested for designation for both 5 °F and -15 °F operation would use the -15 °F configuration.

Table A-1: Electric Heating Element(s) Input Configuration

Heat Pump Class	Nominal Heating Capacity ($H1_N$) (Btu/h)	Full Heating Input Configuration (kW)
5 °F	≤ 36,000 Btu/h	10
	> 36,000 Btu/h and ≤ 50,000	15
	> 50,000 Btu/h	20
-15 °F	≤ 36,000 Btu/h	15
	> 36,000 Btu/h and ≤ 50,000	20
	> 50,000 Btu/h	25

5. Thermocouple Grid at the Indoor Outlet Duct
For units that control to the supply air temperature (for cross checking in the transient operation during the short defrost period)

6. Defrost Mode and Settings
Use the same settings specified for regulatory testing (e.g. Appendix M1). The manufacturer has the option of using a defrost setting aligned with Climate Region V for the verification testing rather than the setting specified for regulatory testing if the installation instructions provide clear guidance regarding set-up with this option for Region V locations. However, in this case, Appendix M1 heating mode testing with this changed setting would be required in addition to standard regulatory testing. In this case, both measured HSPF2 (Region V) values must meet the HSPF2 (Region V) requirement. The decision to adopt this approach shall be noted in non-public reporting regarding testing of the model.

E. Test Conditions and Tolerances:
Test conditions, test condition tolerances and test operating tolerances for the required regulatory tests are as specified in Appendix M1.

Test conditions for additional CCHP-Focused tests are specified in Table A-2 and Table A-3 of this procedure. Follow the test procedure specified in the "CCHP-Focused Tests" (section F of

this Appendix) to determine the total heating capacity $\dot{Q}_h^k(T)$ and total electrical power, $\dot{E}_h^k(T)$ for each verification test.

Table A-2: Additional CCHP-Focused Test Conditions for Variable-Speed CCHP						
Test Description		**Air Entering Indoor**		**Air Entering Outdoor**		**Air Volume Rate[1]**
		DB (°F)	WB (°F)	DB (°F)	WB (°F)	
Required for 5°F and -15°F heat pumps	Min/Mild	70	60(max)	47	43	Heating Min
	H2_RH[6]			35	33	Heating Int
	H4_Max/Cold[2]			5	4 (max)	Heating Full
	H4_Max/Cold_RH[6]			5	4 (max)	Heating Full
Required for -15°F heat pumps if using the full-measurement approach	Max/Extreme[3]			-15	-15 (max)	[5]
Required for -15°F heat pumps if using the extrapolation approach	H3_Max/Cold[4]			17	15	Heating Full
	Max/Extreme Power Input Only			-15	-15 (max)	Heating Full

[1] Set to the airflow as specified in section 3.1.4 of Appendix M1.

[2] Adjustment from the maximum operation is allowed by adjusting the thermostat and applied load if needed to meet both capacity and COP targets. If the extrapolation approach is used to determine -15 ºF (-26 ºC) performance, the 5 ºF (-15 ºC) test used for extrapolation must be run at maximum operation, and a second 5 ºF (-15 ºC) test may be run with the load and thermostat adjusted to meet both targets.

[3] Adjustment from the maximum operation is allowed by adjusting the thermostat and applied load if needed to meet both capacity and COP targets.

[4] Use the same compressor speed achieved in the H4_Max/Cold test.

[5] Air Volume Rate for the Max/Extreme full-measurement approach shall be determined by the native controls using the airflow control settings corresponding to the $H4_2$ test.

[6] "RH" designates tests with electric resistance heat elements engaged.

Table A-3: Additional CCHP-Focused Test Conditions for Northern CCHP						
Test Description		**Air Entering Indoor**		**Air Entering Outdoor**		**Air Volume Rate[1]**
		DB (°F)	WB (°F)	DB (°F)	WB (°F)	
Required for 5°F and -15°F heat pumps	H2_RH[5]	70	60 (max)	35	33	Heating Full
	H4_Max/Cold[2,4]			5	4 (max)	Heating Full
	H4_Max/Cold_RH[5]			5	4 (max)	Heating Full
Required for -15°F heat pumps if using the full-measurement approach	Max/Extreme[4]			-15	-15 (max)	Heating Full
Required for -15°F heat pumps if using the extrapolation approach	H3_Max/Cold[3,4]			17	15	Heating Full
	Max/Extreme Power Input Only			-15	-15 (max)	Heating Full

[1] Set to the airflow setting(s) as specified in section 3.1.4 of Appendix M1.

[2] This is an additional CCHP-focused test for two-capacity northern heat pumps. For triple-capacity northern heat pumps it is a required regulatory test.

[3] Use the same compressor staging used in the H4_Max/Cold test.

[4] Expected to be steady state tests.

[5] "RH" designates tests with electric resistance heat elements engaged.

Test operating and condition tolerances for additional CCHP-focused tests shall be as specified in Table A-4 or otherwise specified in the Cold Climate Heat Pump Challenge Test Procedures section.

Table A-4: Test Tolerance for Native Control Test		
	Test operating tolerance[1]	**Test condition tolerance**
Indoor dry-bulb, °F:		
Entering temperature	1.0*	2.0*
Leaving temperature	4.0*	-
Indoor wet-bulb, °F:		
Entering temperature	Note 2	-
Outdoor dry-bulb, °F:		
Entering temperature	1.0*	2.0*
Leaving temperature	-	-
Outdoor wet-bulb, °F:		
Entering temperature	1.0	1.0*
Leaving temperature	-	-
External resistance to airflow, inches of water	0.05	
Electrical voltage, % of rdg	2.0	1.5
Nozzle pressure drop, % of rdg	8.0*	

[1] Values with an asterisk differ from the Appendix M1 requirement

[2] There is no indoor wet-bulb tolerance, but indoor wet-bulb shall be measured.

F. Cold Climate Heat Pump Verification Test Procedures:

Regulatory Tests:

Conduct all Tests Required for Certification of Compliance with the applicable regulatory requirements (i.e. Appendix M1 tests).[9] For HPs with variable-speed compressors or for two-capacity northern HPs, also conduct the optional $H4_2$ test as specified in Table 13 or Table 14 of Appendix M1. Determine the total heating capacity $\dot{Q}_h^k(T)$ and total electrical power, $\dot{E}_h^k(T)$ for each test.

[9] This includes the $H4_3$ test for triple-capacity northern heat pumps.

For the H1_1 and H2_v tests, note the settings of the indoor room conditioning system controls to allow matching the same load levels (i.e. sensible cooling delivered by the conditioning system to the indoor room) during the corresponding CCHP-focused tests.

Additional Data Collection for CCHP Verification to Confirm Demand Defrost Control:

Collect data throughout the testing, including transitions between test conditions. Data collection frequency during periods that are not official test periods may be once per minute. Monitor during this time all additional temperature parameters specified by the manufacturer to be inputs for determination of defrost initiation, e.g., coil temperature, refrigerant temperature(s), etc. Also monitor pressures if accessible. Monitor the system for defrosts and parameters that are inputs for determination of defrost initiation throughout the period that the system is operating in heating mode during the regulatory testing, including the transition periods and stabilization periods. If the HP is turned off at any time during transition between test conditions, record the times of shutoff and restarting. Record for each defrost the time of its occurrence, whether it is manually initiated or automatically initiated by the controls, and its duration (time between defrost initiation and resumption of heating operation).

CCHP-Focused Tests

After completing regulatory tests and before commencing with additional testing, install electric heating elements as described in "Testing Apparatus and Setup" (Section D of this Appendix). If using the extrapolation approach for the Max/Extreme (-15°F test), separately measure the power consumption of the indoor fan, outdoor fan, compressor and electric resistance heat.

Conduct the tests described as follows. Determine the total heating capacity $\dot{Q}_h^k(T)$ and total electrical power, $\dot{E}_h^k(T)$ for each test.

1. Min/Mild (47 ºF Outdoor):
   Variable-Speed CCHP

   1. *Setup.* Configure the unit under test to operate under Native Controls (i.e., removed from "test mode" used for steady state tests). Set the airflow as specified in section 3.1.4 of Appendix M1. Ensure the electric resistance heat is not enabled. Allow the system to operate at the H1 conditions to achieve the target capacity as determined from the $H1_1$ test. Initially set up operation at the target capacity by setting the chamber conditioning equipment to operate at the conditioning levels used for the $H1_1$ test. Adjustments may be required to achieve the capacity target. The control device set point of the system under test shall be set at the air entering dry-bulb temperature specified in Table A-2. Then, identify and correct for the appropriate control device set point adjustment by adjusting the control device set point by the difference between the displayed return/ambient air temperature on the control device and the thermocouple(s) specified in the testing apparatus and setup section.

2. *Pretest Interval for Steady-state Determination.* Allow the system to operate at the H1 conditions to achieve the target capacity as determined from the $H1_1$ test with no On/Off compressor cycling until steady-state requirements are achieved. Steady-state shall be considered to have been met when the test operating and test condition tolerances listed in Table A-4 are met for at least 30 minutes and the average capacity shall be achieved within +/-3% of the $H1_1$ capacity.

    a. If the system is unable to operate within +/-3% of the $H1_1$ capacity with no on/off cycling, increase incrementally the total sensible cooling addition to the indoor room until there is no On/Off compressor cycling and steady-state requirements are achieved. Steady-state shall be considered to have been met when the test operating and test condition tolerances listed in Table A-4 are met for at least 30 minutes. There is no tolerance applied to the resultant average capacity.

    b. If the system is unable to achieve steady-state requirements within four (4) hours after the last incremental adjustment of the total sensible cooling addition to the indoor room, the pretest interval is complete and dynamic equilibrium criteria (described in section 3 below) shall apply during the official test period.

3. *Official Test Period.* Once the official test period begins, continuously monitor all instrumentation as required by Appendix M1 (equal intervals that span 5 minutes or less), except for power which shall be recorded each second unless using an integrating power meter. The official test period shall be one hour. For systems that attain the steady-state determination during the pretest interval, test condition and operating tolerances from Table A-4 shall apply during the official test period. For systems that were unable to meet the steady-state determination, dynamic equilibrium criteria shall apply during the official test period. Dynamic equilibrium is attained when both average capacity and average system power input measured in successive test period intervals are within 2 percent of each other—these test periods intervals shall be at least 30 minutes in duration and comprise a whole number of system cycles if regular fluctuations occur—if regular fluctuations do not occur, the intervals shall be 30 minutes in duration. The official test measurements for dynamic equilibrium conditions shall be the average values measured during these two successive intervals.

Northern CCHP

The regulatory $H1_1$ test represents the Min/Mild test for Northern CCHPs.

2. H2_RH (35 ºF Outdoor):

Variable-Speed CCHP

1. *Setup.* Configure the unit under test to operate under Native Controls (i.e., removed from

"test mode" used for steady state tests). Set the airflow as specified in section 3.1.4 of Appendix M1. Confirm that the defrost controls of the HP are set as specified in section testing apparatus and setup of this procedure. Ensure the electric resistance heat is enabled. Allow the system to operate at the H2 conditions to achieve the target capacity as determined from the $H2_v$ test for at least 30 minutes at the specified Table A-2 test conditions and Table A-4 tolerances before starting the "preliminary" test period. The preliminary test period must immediately precede the "official" test period, which is the heating and defrost interval over which data are collected for evaluating average space heating capacity and average electrical power consumption. The control device set point shall be set at the air entering dry-bulb temperature specified in Table A-2. Identify and correct for the appropriate control device set point adjustment by adjusting the control device set point by the difference between the displayed return/ambient air temperature on the control device and the thermocouple(s) specified in the testing apparatus and setup section.

2. *Preliminary and Official Test*. Conduct the preliminary and official test as specified in section c. through e. in section 3.9 of Appendix M1 with the following exceptions: a.) Indoor entering dry-bulb temperature test operating tolerance for sub-interval H2 and sub-interval D3 are omitted. b.) indoor entering wet-bulb temperature operating tolerance is omitted. During the preliminary and official test periods, the total sensible cooling addition to the indoor room shall not be changed. Confirm that the resistance heating element operates as set up in the section testing apparatus and setup for units that enable resistance heating during the defrost period.

3. *Data to be Recorded during the Official Test Period.* For the official test period, collect and use the following data to calculate average space heating capacity and electrical power. During heating and defrosting intervals when the controls of the HP have the indoor blower on, continuously record the dry-bulb temperature of the air entering and leaving the indoor coil. Record the total electrical energy consumed and that is consumed by the resistance heating element(s), expressed in watt-hours, from defrost termination to defrost termination, $e_{DEF}^{total}(35)$, $e_{DEF}^{RH}(35)$, respectively, as well as the corresponding elapsed time in hours, $\Delta\tau_{FR}$. Evaluate average space heating capacity as specified in section 3.9.1 of Appendix M1 except replace reference to $Q_h^k(35)$ with $Q_h^{RH}(35)$.

<u>*Northern CCHP*</u>

Conduct the H2_RH test as described for Variable-speed CCHPs, except that the airflow-control settings shall be the same as those used for the Appendix M1 $H2_2$ test and the target capacity shall be as determined from the $H2_2$ test.

3. H4_Max/Cold (5 ºF Outdoor):
Conduct a Max/Cold test with the electric resistance heaters not energized to determine maximum HP capacity and COP for this operation. Then conduct a Max/Cold test with the electric resistance heaters energized to confirm heating element staging. Conduct the tests as described below.

Max/Cold test with electric heating element(s) not engaged:

Variable-Speed CCHP

1. *Setup*. Configure the unit under test to operate under Native Controls (i.e., removed from "test mode" used for steady state tests). Ensure the electric resistance heat is not enabled. Set the airflow as specified in section 3.1.4 of Appendix M1. The control device set point of the system under test shall be set at its highest setpoint unless the manufacturer provides instructions in non-public reporting that the control device should be set at an intermediate value. In the latter case, the manufacturer shall indicate in non-public reporting the appropriate setpoint, which must be at least 73 ºF. Set the indoor room conditioning system to control the room conditions such that the test unit return air conditions are as specified in Table A-2 with tolerances as indicated in Table A-4.

2. *Pretest Interval for Steady-state Determination*. Allow the system to operate at the $H4_2$ conditions to achieve the target capacity as determined from the $H4_2$ test until either steady-state requirements are achieved or until four (4) hours have elapsed. Steady-state shall be considered to have been met when the test operating and test condition tolerances listed in Table A-4 are met for at least 30 minutes and the average capacity shall be achieved within +/-3% of the $H4_2$ capacity. If the system is unable to attain steady-state operation within the four-hour pretest interval, then dynamic equilibrium criteria shall apply during the official test period.

3. *Defrost Period.* At conclusion of pre-test interval, conduct a defrost cycle following the provisions of Appendix M1 section 3.10. This defrost cycle may be manually or automatically initiated. Terminate the defrost sequence using the HP's defrost controls.

4. *Official Test Period.* Consistent with ASHRAE 37 requirements, the official test period shall not begin until 10 minutes after the conclusion of the defrost period, and test tolerances shall not apply during that time. Once the official test period begins, continuously monitor all instrumentation as required by Appendix M1 (equal intervals that span 5 minutes or less), except for power which shall be recorded each second unless using an integrating power meter. The official test period shall be one hour. For systems that attain the steady-state determination during the pretest interval, test condition and operating tolerances from Table A-4 shall apply during the official test period. For

systems that were unable to meet the steady-state determination, dynamic equilibrium criteria shall apply during the official test period. Dynamic equilibrium is attained when both average capacity and average system power input measured in successive test period intervals are within 2 percent of each other—these test periods intervals shall be at least 30 minutes in duration and comprise a whole number of system cycles if regular cycling occurs—if regular cycling does not occur, the intervals shall be 30 minutes in duration. The official test measurements for dynamic equilibrium conditions shall be the average values measured during these two successive intervals.

5. *Optional Adjustments for Variable-Speed Heat Pumps.* If the heating capacity exceeds its target and the COP is less than its target as determined from the $H4_2$ test, the following adjustments are allowed. Control the total sensible cooling provided by the conditioning system to the indoor room such that the heating load approaches and eventually equals the target heating capacity. (Note: Heating tests are sensible only. Therefore, no latent addition to the indoor room shall be made.). In tandem, incrementally reduce the indoor unit thermostat set point as needed such that the air entering the indoor unit approaches the target indoor room dry bulb temperature until either the heating capacity and COP targets are both met, or the heating capacity drops to 100% of its H1N heating capacity. At these settings, conduct an official test as described in section 4 above.

   Note that while these optional adjustments may be made for a -15 ºF HP tested using the extrapolation approach to demonstrate that heating capacity and COP can both meet their targets, a highest-thermostat-setting test is still required for use as the basis for the extrapolation.

Northern CCHP

The regulatory $H4_3$ test represents the Max/Cold test for Triple-Capacity Northern CCHPs.

Conduct the optional $H4_2$ test of Appendix M1 to represent the Max/Cold test for Two-Capacity Northern CCHPs.

Max/Cold Test with electric heating element(s) engaged:

Variable-Speed CCHP

1. *Setup.* Configure the unit under test to operate under Native Controls (i.e., removed from "test mode" used for steady state tests). Enable at least the first two stages of electric resistance heat. Set the airflow as specified in section 3.1.4 of Appendix M1. The control device set point shall be set at the air entering dry-bulb temperature specified in Table A-2. Identify and correct for the appropriate control device set point adjustment by adjusting the control device set point by the difference between the displayed return/ambient air

temperature on the control device and the thermocouple(s) specified in the testing apparatus and setup section.

2. *Pretest Interval for Steady-state Determination*. Allow the system to operate at the $H4_2$ conditions. to achieve a capacity equal to 1.3 times the H1_N capacity until either steady-state requirements are achieved or until four (4) hours have elapsed. Steady-state shall be considered to have been met when the test operating and test condition tolerances listed in Table A-4 are met for at least 30 minutes. If the system is unable to attain steady-state operation within the four-hour pretest interval, then dynamic equilibrium criteria shall apply during the official test period.

3. *Defrost Period.* At conclusion of pre-test interval, conduct a defrost cycle following the provisions of Appendix M1 section 3.10. This defrost cycle may be manually or automatically initiated. Terminate the defrost sequence using the HP's defrost controls.

4. *Official Test Period.* Consistent with ASHRAE 37 requirements, the official test period shall not begin until 10 minutes after the conclusion of the defrost period, and test tolerances shall not apply during that time. Once the official test period begins, continuously monitor all instrumentation as required by Appendix M1 (equal intervals that span 5 minutes or less), except for power which shall be recorded each second unless using an integrating power meter. Record the electrical energy consumed by the resistance heating element(s), expressed in watt-hours, $e_h^{RH}(5)$ and the corresponding elapsed time of the official test period in hours, $\Delta\tau_h$. The official test period shall be one hour. For systems that attain the steady-state determination during the pretest interval, test condition and operating tolerances from Table A-4 shall apply during the official test period. For systems that were unable to meet the steady-state determination, dynamic equilibrium criteria shall apply during the official test period. Dynamic equilibrium is attained when both the 30-min average capacity and system power input measured in successive 30-minute intervals are within 2 percent of each other—these test periods intervals shall be at least 30 minutes in duration and comprise a whole number of system cycles if regular cycling occurs—if regular cycling does not occur, the intervals shall be 30 minutes in duration. The official test measurements for dynamic equilibrium conditions shall be the average values measured during these two successive intervals. The official test period average capacity shall be within 5% of the 130% capacity in step 2.

Northern CCHP

Conduct the Max/Cold test with electric heat engaged as described for Variable-speed CCHPs, except that the airflow-control settings shall be as used for Maximum Heating Full-Load.

4. Max/Extreme (-15 ºF Outdoor):

If using the full-measurement approach:

For units that are capable of HP operation down to -15°F outdoor condition, conduct the Max/Extreme test following the procedure as specified in the Max/Cold test with electric heating element(s) not engaged except that the outdoor room conditions shall be as specified in Table A-2 (or Table A-3 for Northern CCHPs) and the air volume rate shall be determined by the native controls using the airflow control settings corresponding to the $H4_2$ test for the Max/Extreme test condition.

If using the extrapolation approach:

For Variable-speed CCHPs, conduct the CCHP-Focused test H3_Max/Cold at conditions specified in Table A-2 subsequent to the high-thermostat-setting H4_Max/Cold test with electric heating element(s) not engaged. Set the compressor at the speed achieved in the high-thermostat-setting H4_Max/Cold test. Manufacturer must provide data I/O means for monitoring the compressor speed (i.e. driver frequency or RPS). All other settings should remain the same as those used in H4_Max/Cold test.

If the compressor speed recorded during the high-thermostat-setting H4_Max/Cold test matches the compressor speed of the regulatory H3_2 test to the nearest 1 Hz power input frequency or 1 rps rotational speed, the manufacturer has the option of using the H3_2 test results in lieu of conducting the H3_Max/Cold test.

For Triple-capacity Northern CCHPs, the extrapolation is based on the $H3_3$ and $H4_3$ tests described in Appendix M1. For Two-capacity Northern CCHPs, the extrapolation is based on the $H3_2$ and $H4_2$ tests described in Appendix M1

Conduct the Max/Extreme Power Input Only test at the operating condition specified in Table A-2 or Table A-3 with the electric resistance heating elements not engaged. Set the thermostat to its highest setting unless the manufacturer provides instructions in non-public reporting that the control device should be set at an intermediate value. In the latter case, the manufacturer shall indicate in non-public reporting the appropriate setpoint, which must be at least 73 ºF and the same setpoint as initially set in the H4_Max/Cold test. Capacity measurement is not required for this test. Maintaining indoor unit external static pressure also is not required. Measure total power input, and also separately measure power input for the indoor unit, the outdoor fan, and the compressor.

Test to Validate Maximum Cut-In and/or Cut-Out Temperatures

Conduct this test after the performance test with the coldest outdoor temperature. Capacity does not need to be measured. Measure a parameter that provides positive indication that the HP is operating in HP mode (e.g. power or discharge pressure). Also monitor the temperature of air

entering the outdoor coil using one or more air samplers or parallel thermocouple grid(s) on each side of the HP that has air inlets. Record measurements at a time interval of one-minute or shorter.

Ensure that the HP is operating. Compensation load on indoor room may be reduced during test if desired to avoid compressor temporary boost mode or excessive room temperature reduction. Reduce outdoor chamber temperature to a level that is 3 ºF warmer than the maximum allowable cut-out temperature for the intended HP specification. Pause outdoor chamber temperature reduction for 3 minutes to allow conditions to stabilize.

Continue reducing outdoor chamber temperature in steps or continuously at an average rate of 1 ºF every 5 minutes. If the test purpose is only to validate that the cut-out temperature is no higher than a maximum value, the test ends 5 minutes after the average outdoor coil air inlet temperature crosses the specified maximum, or 5 minutes after the HP stops operating, whichever comes first. Note either that the HP was still operating when the target maximum cut-out temperature occurred, or that average outdoor coil air inlet temperature when the HP operation stopped.

If the test purpose is to also validate the cut-in temperature, continue reducing outdoor chamber temperature. When the HP stops operating, continue recording data for 5 minutes. At this point, reverse the temperature ramp and increase outdoor chamber temperature 1 ºF every 5 minutes. Continue the test until 5 minutes after the HP operation restarts. Note the average outdoor coil air inlet temperature when the HP stops operation as the cut-out temperature and the temperature 30 seconds after it restarts as the cut-in temperature.

G. Data to be Recorded:

For all standard heating mode tests specified in Appendix M1, continuously record all required parameters to calculate the average space heating capacity $Q_h^k(T)$ and average electrical power $E_h^k(T)$ as specified in Appendix M1.

For a -15 ºF HP tested using the extrapolation approach, when conducting the high-thermostat-setting H4_Max/Cold test, the H3_Max/Cold test, and the Max/Extreme Power Input Only test, continuously monitor and record the power consumption, expressed in watts, of the entire HP, the indoor unit, the outdoor fan, and the compressor $E_h^{max}(T)$, $E_h^{ID,max}(T)$, $E_h^{ODF,max}(T)$, and $E_h^{Comp,max}(T)$ respectively.

For the Min/Mild test, continuously record all required parameters for $H1_1$ test specified in Appendix M1 to calculate the average space heating and replace reference to $Q_h^{k=1}(47)$ with $Q_h^{min}(47)$ and average electrical power and replace reference to $E_h^{k=1}(47)$ with $E_h^{min}(47)$.

For H2v_RH test, continuously record electrical energy consumed by the mechanical heating cycle and that by electric heating element(s) $e_{DEF}^{MH}(35)$ and $e_{DEF}^{RH}(35)$, respectively.

For H3_Max/Cold, H4_Max/Cold and Max/Extreme test, continuously record all required parameters as specified for $H4_2$ test specified in Appendix M1 to calculate the average space heating capacity and replace references to $Q_h^{k=2}(5)$ with $Q_h^{max}(T)$ and average electrical power and replace $E_h^{k=2}(5)$ with $E_h^{max}(T)$, where T is respective air entering outdoor dry bulb temperature.

During the CCHP-focused tests, record the additional data as specified in section Additional Data Collection for CCHP Verification to Confirm Demand Defrost Control.

H. Calculations:

Capacity and Power Input at -15 ºF using the Extrapolation Approach

Calculate the heating capacity using:

$$Q_h^{max}(-15) = Q_h^{max}(5) - \frac{5}{3} * (Q_h^{max}(17) - Q_h^{max}(5))$$

Where: $Q_h^{max}(-15)$ is the maximum capacity at -15 ºF, Btu/h;
$Q_h^{max}(17)$ is the capacity measured in the H3_Max/Cold test, Btu/h;
$Q_h^{max}(5)$ is the maximum capacity at H4_Max/Cold test, Btu/h;

Calculate the auxiliary power consumption for the H3_Max/Cold, H4_Max/Cold, and Max/Extreme Power Input Only tests, expressed in units of watts, using:

$$E_h^{Aux,max}(T) = E_h^{max}(T) - E_h^{ID,max}(T) - E_h^{ODF,max}(T) - E_h^{Comp,max}(T)$$

Where: T is the air entering outdoor dry bulb temperature;
$E_h^{Aux,max}(T)$ is the auxiliary power consumption for outdoor temperature T;
$E_h^{max}(T)$ is the total power consumption for outdoor temperature T;
$E_h^{ID,max}(T)$ is the indoor unit power consumption for outdoor temperature T;
$E_h^{ODF,max}(T)$ is the outdoor fan power consumption for outdoor temperature T;
$E_h^{Comp,max}(T)$ is the compressor power consumption for outdoor temperature T;

Calculate the total power consumption for operation at -15 ºF using:

$$E_h^{max}(-15) = E_h^{Aux,max}(-15) + \left(\frac{8}{3}\right) * \left(E_h^{max}(5) - E_h^{Aux,max}(5)\right) - \left(\frac{5}{3}\right) * \left(E_h^{max}(17) - E_h^{Aux,max}(17)\right)$$

Evaluate the coefficient of performance $COP2^{max}(-15)$ using the space heating capacity and power consumption as calculated above in this section.

Heating Performance Factor (HPF) at 5°F for Max/Cold test with Resistance Heating Elements

Evaluate the heating performance factor, $HPF^{RH}(5)$, for the H4_Max/Cold test with electric heating element(s) engaged, expressed in units of Btu/W-h, using:

$$HPF^{RH}(5) = \frac{Q_h^{RH,max}(5)}{E_h^{RH,max}(5)}$$

Where: $Q_h^{RH,max}(5)$ is the heating delivered with heating elements engaged, Btu/h; and

$E_h^{RH,max}(5)$ is the total power with heating elements engaged, W.

Evaluate the ideal heating performance factor, $HPF^{RH+}(5)$, for the H4_Max/Cold test with electric heating element(s) engaged, expressed in units of Btu/W-h, using:

$$HPF^{RH+}(5) = \frac{Q_h^{RH,max}(5)}{E_h^{max}(5) + \frac{\left(Q_h^{RH,max}(5) - Q_h^{max}(5)\right)}{3.412}}$$

Where: $Q_h^{RH,max}(5)$ is the heating delivered with heating elements engaged, Btu/h;

$Q_h^{max}(5)$ is the heating delivered with heating elements not engaged, Btu/h; and

$E_h^{max}(5)$ is the total power with heating elements not engaged, W.

I. Materials Incorporated by Reference:

The following standards are incorporated by reference into this test procedure:

(1) Appendix M1 to Subpart B of Part 430—Uniform Test Method for Measuring the Energy Consumption of Central Air Conditioners and Heat Pumps

(2) ENERGY STAR Central Air Conditioner and Heat Pump Specification Version 6.0

Appendix B: HSPF2 Adjustment for Measured Gaps in Turndown Capacity and COP

This appendix describes the development of the HSPF2 adjustments for measured gaps in turndown capacity and/or COP within the Challenge performance specification (see Section II.A.1).

Measured Gap in Turndown Capacity

Performance profiles (i.e. sets of capacities and power inputs for all relevant test points) were developed for HPs meeting or approaching the Challenge specifications and reflecting performance trends seen in tested HPs. Two such performance profiles are presented in Table C-1 for various test points in Appendix M1.

Table C-1: HP Performance Profiles

Test Name	HP 1		HP 2	
	Capacity (Btu/h)	Power (W)	Capacity (Btu/h)	Power (W)
A2	37,000	2,732	37,000	3,060
$H0_1$	11,000	571	11,000	515
$H1_1$	9,000	593	9,000	535
$H1_N$	37,000	2,732	37,000	2,732
$H1_2$	57,700	5,154	57,700	5,772
$H2_v$	25,200	2,131	25,200	2,131
$H2_2$	44,838	4,586	44,838	5,136
$H3_2$	38,000	3,910	38,000	4,379
$H4_2$	37,000	4,211	37,000	4,716

The trend of H1 test condition power as a function of capacity was determined for each HP profile based on the $H1_1$ and $H1_N$ test performance. This allowed determination of varying levels of minimum H1-condition capacity and associated power input to allow evaluating the impact of change in this minimum capacity.

The change in minimum capacity would be expected to impact seasonal efficiency only for those temperature bins for which the calculated minimum-speed performance factors into the power calculation. However, if the adjusted values of $H1_1$ are used directly in an HSPF2 calculation, many more of the bins would be affected, due to the influence of $H1_1$ performance on intermediate-speed performance through the equations in section 4.2.4.e of Appendix M1. In order to isolate the evaluated impact to only those bins for which the minimum-speed performance affects the calculation, the HSPF2 calculation for the initial system profile was established, and both full-speed and intermediate-speed performance were held fixed for

subsequent evaluation. Different minimum-speed performance levels were evaluated, using the H1-condition capacity/power trend mentioned above. For each nominal $H1_1$ capacity level, a revised HSPF2 value was calculated, increasing each minimum-speed capacity proportional to the $H1_1$ capacity, and increasing each minimum-speed power input proportional to the corresponding $H1_1$ power input. The $H1_1$ capacity and power levels and corresponding HSPF2 levels calculated in this fashion are listed in Table C-2 for each of the two heat pump performance profiles in Table C-1. The HSPF2 values are plotted versus the ratio of $H1_1$ to $H1_N$ in Figure C1.

Table C-2: Evaluated $H1_1$ Capacity and Power Levels and Corresponding HSPF2 Values

$H1_1$ Capacity (Btu/h)— % of $H1_N$	HP 1		HP 2	
	$H1_1$ Power (W)-- COP (Btu/Wh)	HSPF2 (Region V) (Btu/Wh)	$H1_1$ Power (W)-- COP (Btu/Wh)	HSPF2 (Region V) (Btu/Wh)
9,000—24%	593—15.2	9.28	535—16.8	9.00
12,000—32%	794—15.1	9.25	726—16.5	8.98
15,000—41%	999—15.0	9.23	924—16.2	8.95
18,000—49%	1,209—14.9	9.20	1,130—15.9	8.91
21,000—57%	1,423—14.8	9.13	1,346—15.6	8.85
24,000—65%	1,643—14.6	9.08	1,574—15.3	8.78
27,000—73%	1,870—14.4	9.00	1,814—14.9	8.69

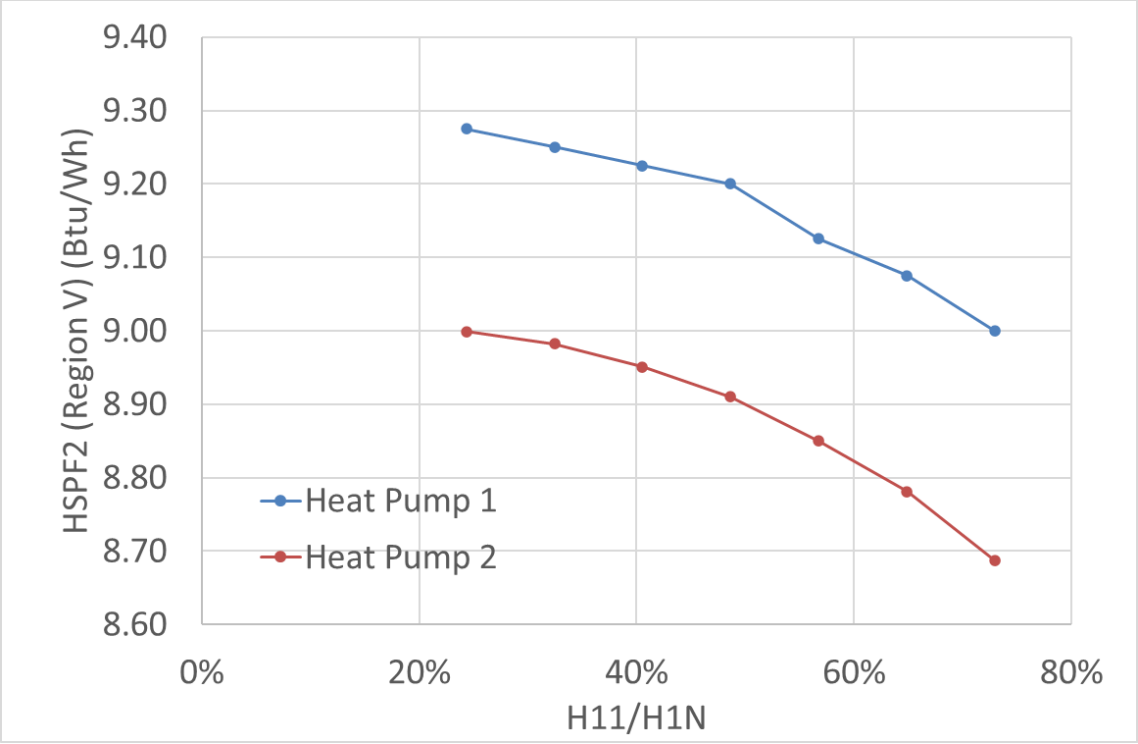

Figure C1: HSPF 2 (Region V) versus $H1_1/H1_N$

The HSPF2 trend data as the $H1_1/H1_N$ ratio varies was then evaluated for HSPF2 adjustment as a function of $H1_1/H1_N$ turndown gap. For example (for the Heat Pump1 curve), supposing the $H1_1$ capacity in the fixed-compressor test had been 15,000 Btu/h, and 18,000 in the native control test. This represents a turndown gap of 8%. The rated HSPF2 (Region V) would be 9.23 Btu/Wh, but the field performance might be expected to drift to a level of 9.20 based on the gap in the turndown. In order to have achieved the expected 9.23 performance level, the original HSPF2 (Region V) would have to be higher by 0.33% (equal to 9.23/9.20 - 1). This would suggest a requirement to increase the HSPF2 by 1% for every 24% turndown gap (24% = 8% X 1%/0.33%). This evaluation was conducted for a range of fixed-compressor values of $H1_1$, with results plotted in Figure C2. The results show that the percent $H1_1/H1_N$ gap that leads to a 1 percent HSPF2 adjustment ranges down to 10 percent, thus supporting the requirement in the specification that the HSPF2 value be raised 1 percent for every 10% $H1_1/H1_N$ gap.

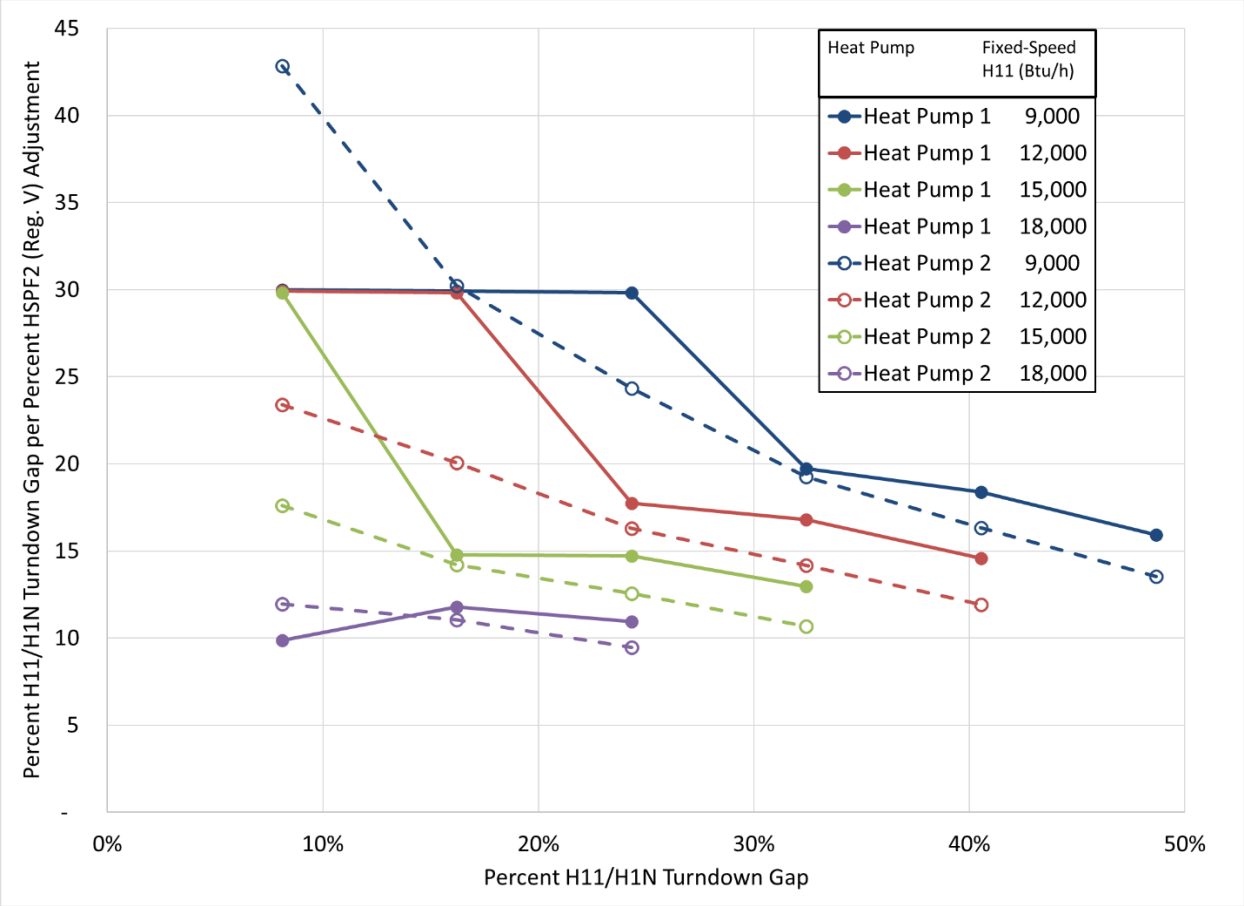

Figure C2: Percent $H1_1/H1_N$ Turndown Gap per Percent HSPF2 (Region V) Adjustment

Measured Gap in COP

Similar to the capacity gap adjustment, an additional HSPF2 adjustment may be necessary to account for the potential that the verified $H1_1$ test COP is significantly lower than the regulatory-test COP. The $H1_1$ verification test may have compressor speed fluctuations that reduce COP for the measured average capacity level, and an HSPF2 adjustment would help ensure good seasonal efficiency is not compromised as a result. The capacity-based adjustment in the verification test procedure already takes into consideration the COP vs. capacity trend typical for heat pumps, i.e. COP decreases as compressor speed and capacity increase. The COP adjustment would apply only if the verified $H1_1$ COP drops lower than a level that would be expected for a steep COP vs. capacity trend.

DOE developed the COP adjustment based on review of recent testing of variable-speed heat pumps. Figure C3 plots the COP values across the ratio of $H1_1$ to $H1_N$ capacity, expressed as a percentage. While ignoring the outlier System 3, the 95% confidence steepest slope of the COP trend results in the following relationship: Expected COP Reduction = $-6.5 \times (Q-Q_{11})/Q_{1N}$. This

would be the COP degradation that may be expected during $H1_1$ verification testing.[10] Using the Heat Pump 2 Performance Profile of Table C-1 and the same calculation approach described above, DOE then calculated the expected HSPF2 impact with an assumed $H1_1$ COP degradation of 10%, and determined that a 2% adjustment in HSPF2 would be required to overcome the excess COP degradation gap. If the validated $H1_1$ COP is lower than the regulatory $H1_1$ COP by more than the expected COP reduction, the HSPF2 requirement in the Challenge would be increased 2% for every 10% excess COP gap.

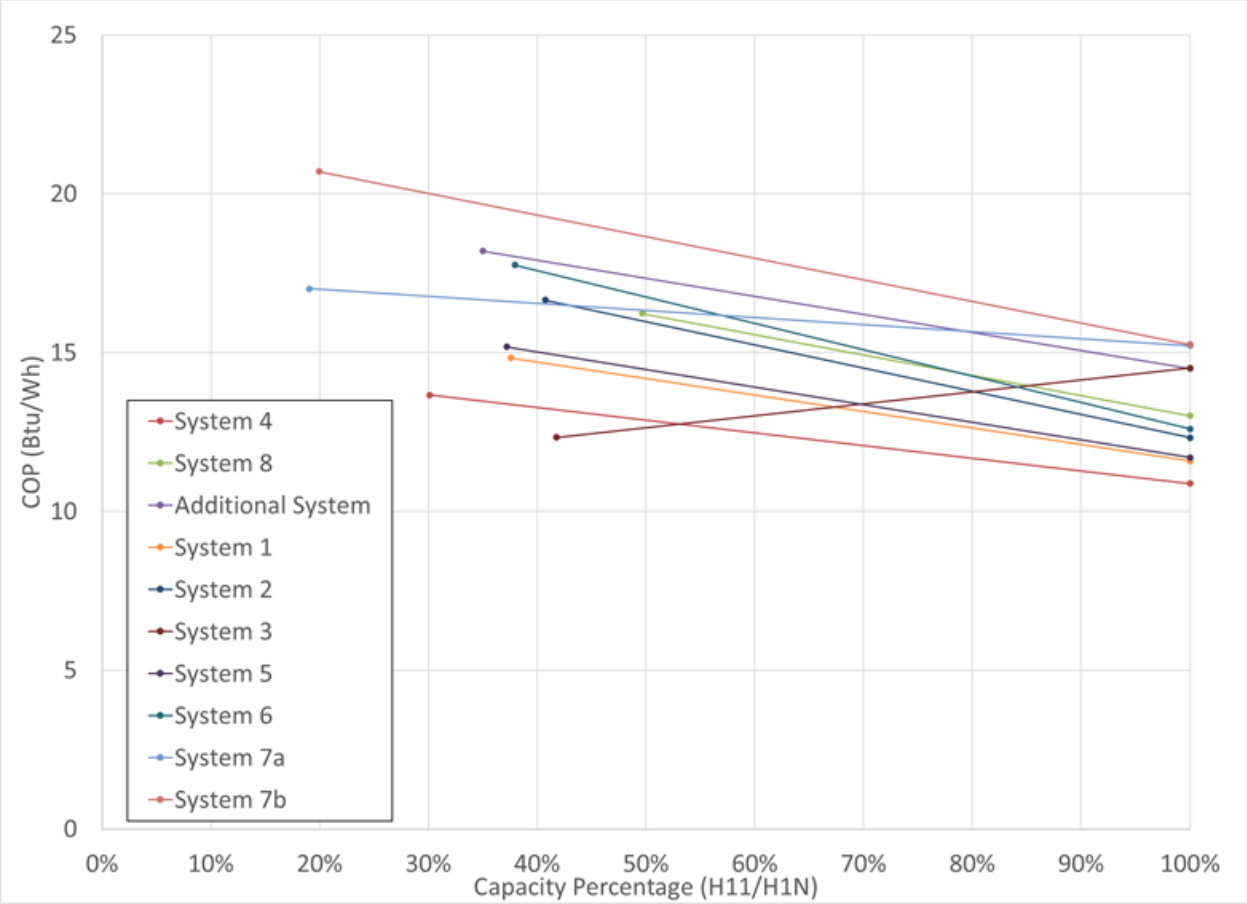

Figure C3: Ratio of $H1_1/H1_N$ Capacity vs. COP

[10] Presented another way, Expected COP = COP_{H11}-6.5 × $(Q-Q_{11})/Q_{1N}$, and Expected COP Reduction = COP_{H11} – Expected COP

Calculation of Final HSPF Adjustment

The final HSPF2 adjustment for the Challenge performance specification will account for the measured gaps in turndown capacity and/or COP according to the following equation. The HSPF2 (Region V) measured using Appendix M1 shall be equal to or greater than the adjusted HSPF2', calculated as:

HSPF2' = HSPF2 * (1 + Capacity factor) * (1 + COP factor)

Where,

HSPF2 = 8.5 (Region V);

Capacity factor = 1 percent for every 10% $H1_1/H1_N$ capacity gap

$= 0\ if\ \frac{Q\_H1_{1v} - Q\_H1_{1r}}{Q\_H1_{1r}} \leq 0.03;\ \frac{Q\_H1_{1v} - Q\_H1_{1r}}{10 \times Q\_H1_{Nr}}\ if\ \frac{Q\_H1_{1v} - Q\_H1_{1r}}{Q\_H1_{1r}} > 0.03;$

Q_H1_{1v} = Min/Mild Verification test capacity (Btu/h);

Q_H1_{1r} = Capacity measured for minimum-capacity 47 °F-ambient test conducted according to Appendix M1 (Btu/h);

Q_H1_{Nr} = Capacity measured for nominal-capacity 47 °F-ambient test conducted according to Appendix M1 (Btu/h);

COP factor = 2 percent for every 10% COP gap between the COP measured in the $H1_1$ verification test and the COP of the $H1_1$ regulatory test, adjusted for measured capacity

$= \text{Maximum}\ (0, \frac{COP*\_H1_{1r} - COP\_H1_{1v}}{5 \times COP*\_H1_{1r}});$

$COP*\_H1_{1r}$ = COP of minimum-capacity 47 °F-ambient test conducted according to Appendix M1, and adjusted for capacity gap = $COP\_H1_{1r} - 6.5 \times \frac{Q\_H1_{1v} - Q\_H1_{1r}}{Q\_H1_{Nr}}$;

COP_H1_{1r} = COP of minimum-capacity 47 °F-ambient test conducted according to Appendix M1.

Example Calculations

	Example 1	Example 2	Example 2
Appendix M1 Measurements			
$H1_N$ Capacity (Btu/h)	36,000	36,000	36,000
$H1_1$ Capacity (Btu/h)	13,500	13,500	13,500
Power Input (W)	220	220	220
COP (W/W)	17.98	17.98	17.98
HSPF2 (Region V)	8.8	8.8	8.8
Verification Test Measurements			
Min/Mild Capacity (Btu/h)	18,000	15,000	13,800
Power Input (W)	391	275	250
COP (W/W)	13.49	15.99	16.18
Capacity Difference (%)	33.3%	11.1%	2.2%
Turndown Gap (%)	12.5%	4.2%	0.8%
$COP^*\_H1_{1r}$	15.82	17.18	17.75
Capacity Factor	0.125	0.0042	0.0000
COP Factor	0.0294	0.0139	0.0178
Adjusted HSPF2 Requirement	8.86	8.65	8.65
Model Passes HSFP2 Requirement?	NO	YES	YES