

CRADA NFE-22-09374 Final Report - Residential Cold Climate Heat Pump Technology Challenge (Rheem)



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September 2024

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Buildings and Transportation Science Division

**CRADA NFE-22-09374 FINAL REPORT - RESIDENTIAL COLD CLIMATE HEAT
PUMP TECHNOLOGY CHALLENGE (RHEEM)**

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September 2024

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ABBREVIATIONS

4AR	Fourth Assessment Report
ASHRAE	American Society of Heating, Refrigeration, and Air conditioning Engineers
BTRIC	Building Technologies Research Integration Center
CACHP	Central air conditioner and heat pump
CAP	Capacity
CCHP	Cold climate heat pump
CFR	Code of Federal Regulations
COP	Coefficient of performance
DB	Dry bulb
DR	Demand response
E3	Energy, Emissions, and Equity
EER	Energy Efficiency Ratio
EERE	Energy Efficiency and Renewable Energy
EH	Electric heat
ESP	External static pressure
GWP	Global warming potential
HSPF2	Heating Season Performance Factor 2
ID	Indoor
OD	Outdoor
OOT	Out of tolerance
RH	Resistance heating
RTD	Resistance temperature detector
SCFM	Standard cubic feet per minute
SEER2	Seasonal Energy Efficiency Ratio 2
STI	Supplemental test instructions
WB	Wet bulb

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ABSTRACT

The purpose of this CRADA was to test a nominal 3-ton capacity heat pump system supplied by Rheem Manufacturing to determine if it met the laboratory test requirements of the United States Department of Energy Cold Climate Heat Pump (CCHP) Technology Challenge (hereafter noted as “the Challenge”). Results of the laboratory testing completed at ORNL demonstrated that the system met all requirements of the Challenge. Rheem Manufacturing has successfully completed this aspect of the Challenge. This CRADA report will briefly describe the CCHP Challenge, the test plan created to measure the success of heat pump systems provided by CCHP Challenge participants, and the results of laboratory testing of the Rheem heat pump system.

1. STATEMENT OF OBJECTIVES

Heating homes using split system ducted heat pumps has a long history in the United States, but the use of heat pumps in colder climates is hindered by the inherent reduction in heating capacity and efficiency at reduced ambient temperature. The development of affordable heat pumps that can economically heat homes in northern climates with low GWP refrigerants is crucial to reach President Biden's goal of net-zero carbon economy by 2050. The Challenge is a key initiative of the United States Department of Energy's Energy, Emissions, and Equity (E3) Initiative. The E3 Initiative has the goal to transform heating and cooling in America by making affordable, clean, and efficient products easily available across the country. The Challenge (United States Department Of Energy, 2021) has three thrusts to meet the E3 Initiative goal. First, it will spur manufacturers to develop air source heat pumps that can deliver reliable heat even in the coldest areas of North America. Second, the Challenge will stimulate the use of next generation low Global Warming Potential (GWP) refrigerants. Third, it will encourage development of residential products that can communicate with electric utilities to manage demand to alleviate the new electricity generation peaks that may occur with changeover from fossil-fueled to heat pump heating. These are designed to equitably encourage the market to move toward heating homes with heat pumps, which will help to meet the national goals toward decarbonization.

Oak Ridge National Laboratory's role in the Challenge was to confirm the operation of the participants' prototypes in our equipment test chambers. The system from each participant in the Challenge was installed in the equipment chambers in the Flexible Research Platform of the Building Technologies Research Integration Center (BTRIC) at ORNL. The team executed a test plan demonstrating compliance with DOE regulatory tests as well as special tests showing cold climate operation (down to -15°F) and appropriate feedback to demand response signals. After passing all tests the products were then shipped to field trial locations, which is the second part of the Challenge.

The objective of this CRADA was for ORNL to confirm the operation and performance through test of a split system residential ducted heat pump system from the Challenge participant Rheem. The system consisted of an indoor air handler and outdoor unit that was designed to have a nominal 3-ton cooling and

heating capacity. In addition, a supplementary electric resistance heat kit and proprietary thermostat were provided by the partner for use in testing.

2. BENEFITS TO THE BUILDING TECHNOLOGY OFFICE'S MISSION

The Challenge is very clearly aligned to the Building Technology Office's mission to develop, demonstrate, and accelerate the adoption of cost-effective technologies, techniques, tools, and services that enable high-performing, energy-efficient and demand-flexible residential and commercial buildings in both the new and existing buildings markets, in support of an equitable transition to a decarbonized energy system by 2050, starting with a decarbonized power sector by 2035. Through the Challenge, manufacturers will achieve a jump start in the development and commercialization of products that can meet heating requirements in the coldest climates in new or existing homes. Though the products that will be tested in the Challenge will be very expensive one-off prototypes, the development process for each participant will allow them to learn details about the design of the product, which will prompt them to find lower cost materials and processes so these products will be available to all segments of the market in the future.

3. TECHNICAL DISCUSSION OF WORK PERFORMED BY ALL PARTIES

3.1 TECHNICAL SPECIFICATION

The Challenge specification document specifies the technical requirements for products. (Several aspects of this report refer to "Appendix M1". This is the section of the Code of Federal Regulations ("Uniform Test Method for Measuring the Energy Consumption of Central Air Conditioners and Heat Pumps," 2014) that describes the required method of test to determine the efficiency of a residential air conditioner or heat pump for sale in the US.) A summary of the requirements from the specification is shown as Table II-3 from that document and is copied below as Table 1. DOE noted in the original specification that a participant could choose to participate in the development of a CCHP either for use down to 5°F or for use down to -15°F or both. The choice leads to different technical requirements. Also, DOE specified different requirements depending on the type of product (i.e., triple-capacity Northern heat pump or variable-speed heat pump) the participant chose to submit for testing. (These heat pump types are defined in Appendix M1.) The Rheem system was of the variable-speed heat pump type, so the remainder of the discussion focuses on this type.

Some of the important characteristics are as follows. These characteristics are based on three different types of tests. First, the specification document required "regulatory" testing, where the system is running at steady state using a special regulatory test mode programmed into the unit control that is only meant to be accessible to the manufacturer and specified test labs that can access the manufacturer's supplemental test instructions (STI). Tests for this portion of the specification are therefore run without thermostatic control, but also do not allow operation of the supplementary electric heat. Second, the specification document requires "CCHP-focused" tests, which are to be run with the heat pump system using thermostatic control and with the operation of the supplementary electric heat enabled. Finally, the specification document requires "demand response" testing where the heat pump system receives a wireless signal requesting changes in operation representing electric utility demand response signals.

- The target efficiency as measured by Coefficient of Performance (COP) is specified based on the measured cooling capacity at the A₂ test condition from Appendix M1. The minimum is 2.4 for systems with cooling capacities between 24,000 and 48,000 Btu/h, but decreases to 2.1 for capacities greater than 48,000 Btu/h.
- The minimum HSPF2 value is modified based on two factors.

- A capacity factor that adjusts the minimum HSPF2 based on agreement between test results from the regulatory test at the H1₁ test condition and CCHP-focused test results at the same conditions.
- A COP factor that adjusts the minimum COP based on comparison of the COP measured at the two conditions noted in the description of the capacity factor above.
- The minimum heating capacity, validated while under control of a thermostat at the H1 conditions, can be no more than 70% of the nominal heating capacity resulting from the regulatory test at the same condition.
- The heating capacity measured when testing the unit under the control of a thermostat at 5°F will not be less than the capacity measured under the H1_N test conditions when tested in the regulatory test mode. If the participant selects that the system will be tested at -15°F, the capacity will be determined and recorded, but there is not a target value for meeting the specification.
- The system will continue to operate in heat pump mode down to a minimum temperature that is dependent on the minimum temperature (i.e., 5°F or -15°F) that the manufacturer selects. This temperature is referred to as the “cut-out” temperature. The system will then return to operation at a temperature slightly above the temperature specified as the “cut-out” temperature, which is referred to as the “cut-in” temperature.
- The manufacturer will specify an electric heat module with a minimum number of stages depending on the module’s heating capacity. In addition, no more than one electric heat stage will be active for a set of tests whose conditions specify that electric heat is enabled.
- The system designed and delivered to ORNL will use a refrigerant with a GWP value of less than 750 based on the definition in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers handbook (ASHRAE, 2017), which refers to 100 year GWP values from the Intergovernmental Panel on Climate Change Fourth Assessment Report (4AR).
- The system will comply with sections 3) C (Installation Capabilities), 4) B (Communications), 4) C (Consumer Feedback) and 4) D (Demand Response) of the ENERGY STAR® Product Specification for Central Air Conditioner and Heat Pump (CACHP) Version 6.0 (United States Environmental Protection Agency, 2021). These sections require the heat pump system to react to the demand response call by reducing the heating capacity such that the total power usage is reduced to a target percentage of the design power requirement of the system. There are two paths for the event to be concluded, either for the defined event time to elapse or for the temperature in the conditioned space to drop below a specified temperature difference from the temperature at the beginning of the event. Finally, the required amount of power decrease is different for two types of demand response events. During a “simple” curtailment, the total power cannot exceed 70% of the rated power, while during a “critical” curtailment, the total power cannot exceed 40% of the rated power of the system. The Challenge specification requires the participant’s system to meet these requirements for two Appendix M1 test conditions. Each of a simple curtailment and a critical curtailment will be sent during testing at the H1 conditions, while only a critical curtailment will be sent during the H4 conditions. For the latter, no operation of the electric heat is allowable during the demand response event.

Table 1: Summary of technical requirements for the Challenge.

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.								
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.							

3.2 LABORATORY SETUP

All equipment was tested in environmental chambers, consisting of an indoor (ID) and outdoor (OD) chamber. The test configurations followed the requirements specified in ASHRAE 37-2009 (ANSI/ASHRAE, 2019). The primary capacity measurement for all systems was the ID air enthalpy method. The secondary test method was the refrigerant enthalpy method.

Table 2 lists the instrumentation used for measurements.

3.3 TEST PLAN

The test plan was created to reflect the Challenge specification published by DOE. As mentioned above, the first part of the test plan is referred to as the regulatory portion of testing and consisted of the tests required by the DOE standard for determining SEER2 and HSPF2 in Appendix M1. The test plan for this portion is shown in Table 3. Tolerances for various test parameters as noted in Appendix M1 and shown in Table 4 were followed for this portion of testing.

The second portion of testing is referred to as the “CCHP-focused” portions. For these tests, the electric heat module and thermostat specified by the participant were installed and the system was set to operate by responding to the proprietary control algorithm of the thermostat depending on conditions in the indoor chamber. The system tested in this CRADA was a variable speed CCHP, so it followed the test plan shown in Table 5. Tolerances for the CCHP-focused tests are the same as in Appendix M1 except for those noted in Table 6.

The third and final portion of the testing was to measure the Demand Response (DR) capabilities of the system as specified in the Challenge specification. For this, the Challenge specification notes that the system shall comply with several sections of the ENERGY STAR® Product Specification for Central Air Conditioner and Heat Pump Version 6.0 (United States Environmental Protection Agency, 2021) dealing with installation, communication, consumer feedback, and demand response. For this portion of the test, the National Renewable Energy Laboratory (NREL) supplied the Demand Response signals, while the system was installed and operating in the ORNL laboratory. Personnel at ORNL observed the unit’s operation to determine compliance with the ENERGY STAR® specification.

Table 2: Instrumentation information

Measurement	Sensor description	Manufacturer	Model
ID unit power, ID unit voltage, ID unit frequency	Power meter and current transformers	Yokogawa LEM	WT310e IT-200-S Ultrastab
OD unit power, OD unit voltage, OD unit frequency	Power meter and current transformers (200:5)	Yokogawa GE	WT333e 750X133311
ID inlet dry-bulb temperature, ID inlet wet-bulb temperature, ID outlet dry-bulb temperature, ID outlet wet-bulb temperature, OD inlet dry-bulb temperature, OD inlet wet-bulb temperature	Platinum resistance temperature detector (RTD)	Rosemount	0078N01N00N060AB6
Comp. suction pressure, Service valve vapor line pressure, ID unit vapor line pressure	Pressure transducer 0–500 psi	GE Druck	PTX5072-TA-A2
Comp. discharge pressure, Service valve liquid line pressure, ID unit liquid line pressure	Pressure transducer 0–1000 psi	GE Druck	PTX5072-TA-A2
ID unit external static pressure	Differential pressure transducer (± 2 in. w.c.)	Foxboro	IDP10S-T22B01FA-MIL1
ID before nozzle pressure	Differential pressure transducer (± 5 in. w.c.)	Foxboro	IDP10S-T22B01FA-MIL1
ID nozzle delta pressure	Differential pressure transducer (0–4 in. w.c.)	Foxboro	IDP10S-T22B01FA-MIL1
Barometric pressure	Pressure transducer	Vaisala	PTB110
Refrigerant temperatures, OD inlet grid, OD outlet grid, ID inlet grid, ID outlet grid	Type T thermocouple		Special limits of error
Refrigerant mass flow	Coriolis mass flow meter	Emerson	CMF025M314N2GAEZZZ

Table 3: Appendix M1 Regulatory Test Conditions for Variable-Speed CCHP

Type of test	Test condition name (all cooling tests are with “wet coil”)	Air Entering Indoor		Air Entering Outdoor		Compressor speed	Indoor air flow rate
		DB (°F)	WB (°F)	DB (°F)	WB (°F)		
Cooling	A ₂	80	67	95	Not specified	Cooling full	Cooling Full-Load ¹
	B ₂			82		Cooling full	Cooling Full-Load ¹
	B ₁			82		Cooling minimum	Cooling minimum ³
	Ev			87		Cooling intermediate	Cooling intermediate ²
	F ₁			67		Cooling minimum	Cooling minimum ³
Heating	H0 ₁	70	60 (max)	62	56.5	Heating minimum	Heating minimum ⁴
	H1 ₂			47	43	Heating full ⁶	Heating full-load ⁵
	H1 _N			47	43	Heating full ⁷	Heating full-load ⁵
	H1 ₁			47	43	Heating minimum	Heating minimum ⁴
	H2 _v			35	33	Heating intermediate	Heating intermediate ⁸
	H3 ₂			17	15	Heating full ⁶	Heating full-load ⁵
	H4 ₂			5	3 (max)	Heating full ⁹	Heating full-load ⁵

¹ Defined in section 3.1.4.1 of Appendix M1.

² Defined in section 3.1.4.3 of Appendix M1.

³ Defined in section 3.1.4.2 of Appendix M1.

⁴ Defined in section 3.1.4.5 of Appendix M1.

⁵ Defined in section 3.1.4.4 of Appendix M1.

⁶ Maximum speed that the system controls would operate the compressor in normal operation in 17 °F ambient temperature.

⁷ Maximum speed that the system controls would operate the compressor in normal operation in 47 °F ambient temperature.

⁸ Defined in section 3.1.4.6 of Appendix M1.

⁹ Maximum speed that the system controls would operate the compressor in normal operation at 5 °F ambient temperature.

Table 4: Test Tolerances for Appendix M1 Regulatory Tests

	Test operating tolerance	Test condition tolerance
Indoor dry-bulb, °F:		
Entering temperature	2.0	0.5
Leaving temperature	2.0	-
Indoor wet-bulb, °F:		
Entering temperature	1.0	-
Leaving temperature	1.0	-
Outdoor dry-bulb, °F:		
Entering temperature	2.0	0.5
Leaving temperature	-	-
Outdoor wet-bulb, °F:		
Entering temperature	1.0	0.3 ¹
Leaving temperature	-	-
External resistance to airflow, inches of water	0.05	
Electrical voltage, % of rdg	2.0	1.5
Nozzle pressure drop, % of rdg		

¹ Only applies during Appendix M1 regulatory heating tests.

Table 5: 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_R H ⁶			5	4 (max)	Heating Full
Required for -15°F heat pumps if using the full-measurement approach	Max/Extreme ³	70	60(max)	-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 °F performance, the 5 °F test used for extrapolation must be run at maximum operation, and a second 5 °F 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 H4₂ test.

⁶ “RH” designates tests with electric resistance heat elements engaged.

Table 6: Test Tolerances for CCHP-focused tests

	Test operating tolerance ¹	Test condition tolerance ¹
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 regulatory requirement.

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

3.4 RESULTS

The Challenge participant, Rheem, developed a nominal 3-ton heat pump system to meet the requirements of the Challenge and delivered it to ORNL for testing. The results demonstrate that the system met all the requirements of the specification such that the Rheem heat pump system successfully passed the Challenge. Results from testing from this participant are broken down into the two parts of the test plan completed at ORNL: regulatory and CCHP-focused.

3.4.1 Regulatory test results

Results of the regulatory tests are shown in Table 7. The Rheem heat pump passed this portion of the test plan as reflected in Table 8 that shows the results of the SEER2 calculation. (A minimum SEER2 value is not explicitly part of the Challenge, but a primary requirement of the Challenge is to meet all other common performance and safety requirements for split system heat pumps.) Further calculations from the regulatory test results are supplemented by the CCHP-focused test results to find the overall test program results.

At the direction of Rheem, the optional regulatory H₂ test was not completed.

3.4.2 CCHP-focused test results

Results of the CCHP-focused tests are shown in Table 9. The results from the CCHP-focused tests demonstrated success for the Rheem heat pump system in meeting various targets of the Challenge. First, the COP at the H₄ and Max-Cold conditions are compared to the target of 2.4 as required for the capacity of the Rheem heat pump. The successful results are shown in Table 10. Second, the CCHP-focused test results were used with the regulatory results to calculate adjustment values for the measured HSPF2. The adjusted HSPF2 still met the minimum adjusted HSPF2 requirement of 8.5. As shown in Table 11, the Rheem heat pump system demonstrated an HSPF2 value of 9.4.

3.4.3 Demand Response test results

Results from the Demand Response tests are shown in Table 12. The system was able to recognize the demand response signals and react appropriately under the three conditions discussed above. Therefore, the system meets the demand response portion of the Challenge.

Table 7: Regulatory test results

Test Name	STI Compressor Speed (RPM) (Rotational Frequency)	STI Airflow (SCFM)	Capacity Btu/h			EER / COP	Compressor Speed (Hz) (Power Frequency)	Power (W)			Airflow	
			Airside	Refrigerant	Balance			Total Power	ID Power	OD Power	SCFM	Unit Static ("WC)
A ₂ -Regulatory	2700	1225	34,674	35,240	1.63%	12.7	22.5	2721	298	2424	1249	0.58
B ₂ -Regulatory	2700	1225	37,557	38,213	1.75%	16.2	45.0	2318	312	2006	1267	0.58
B ₁ -Regulatory	1400	525	18,763	19,076	1.67%	19.1	0.0	983	45	938	556	0.11
E _v -Regulatory		750	24,296	24,627	1.36%	16.7	10.2	1457	85	1371	777	0.23
F ₁ -Regulatory	1400	525	21,279	NA	NA	31.9	7.8	667	41	626	556	0.11
H0 ₁ -Regulatory	1800	970	28,263	NA	NA	5.8	30.0	1428	176	1252	998	0.38
H1 ₂ -Regulatory	4800	1300	54,761	55,297	0.98%	3.5	80.0	4637	403	4235	1320	0.67
H1 _N -Regulatory	2800	1300	36,002	36,335	0.93%	4.3	46.7	2426	400	2027	1337	0.67
H1 ₁ -Regulatory	1800	970	23,396	23,495	0.43%	4.9	30.0	1395	177	1219	991	0.38
H2 _v -Regulatory	2800	1300	28,403	NA	NA	3.6	46.7	2319	396	1933	1339	0.66
H3 ₂ -Regulatory	4800	1300	42,443	43,054	1.44%	2.8	80.0	4448	407	4040	1336	0.67
H4 ₂ -Regulatory	4800	1300	35,474	36,163	1.94%	2.5	80.0	4130	402	3727	1335	0.67

Table 8: SEER2 calculation results

SEER 2	Minimum	Measured	Pass/Fail
	14.3	17.8	Pass

Table 9: CCHP-focused test results

Test Name	Capacity Btu/h			EER / COP	Compressor Speed (Power Frequency)	Power (W)				Airflow		Pass/Fail
	Airside	Refrigerant	Balance			Total Power	ID Power	OD Power	RH Power	SCFM	Unit Static	
Min_Mild	23,033	24,688	7.19%	4.7	30.0	1430	193	1237		1013	0.39	
H2_RH	25,391	25,567	0.69%	2.5	49.0	3041	933	2096		1157	0.65	Pass
H4_Max/Cold	34,903	35,484	1.67%	2.5	80.0	4171	466	3706		1341	0.68	Pass
H4_Max/Cold_RH	45,753	46,130	0.82%	1.8	80.0	7306	3654	3636	4599	1344	0.68	Pass
Max/Extreme	27,644	28,379	2.66%	1.9	91.3	4289	451	3838		1354	0.67	

Cut out/Cut in validation	Cut Out			Cut In		
	STI value	Tested	Pass/Fail	STI value	Tested	Pass/Fail
	-30	-23	PASS	-25	-23	PASS

Table 10: COP calculation results

COP	Minimum	H4 ₂	Max_Cold
	2.4	Pass	Pass

Table 11: HPSF2 calculation results

HSPF 2	Minimum	Adjusted	Measured	Pass/Fail
	8.5	8.5	9.4	Pass

Table 12: Demand response results

Test Name	Capacity Btu/h					Power (W)						CCHP P/F Logic Test
	H1N	Pre DR	DR	Pre DR /H1N >95%	DR % Cap Reduction	H1N	Pre DR	DR	RH	DR /H1N<X%	RH Operation	
H1_General	36,002	35,714	25,943	99%	72%	2426	2481	1566	0	65%	No	Pass
H1_Critical	36,002	34,973	13,607	97%	38%	2426	2373	819	0	34%	No	Pass
H4_Critical(62)	36,002	34,703	26,003	96%	72%	2426	4151	2680	0	110%	No	Pass

4. SUBJECT INVENTIONS (AS DEFINED IN THE CRADA)

This CRADA did not result in any subject inventions. This was not unexpected, as noted in Clause 3 of the Technical Assistance Agreement (TAA) between Rheem Manufacturing and UT-Battelle, LLC that notes the Participant (Rheem) and Contractor (UT-Battelle) do not intend for the agreement to result in intellectual property.

5. COMMERCIALIZATION POSSIBILITIES

The results of the CRADA testing support that the Rheem heat pump system designated for the Challenge meets the requirements of the Challenge. Based on the performance of one sample, the product appears to be a strong candidate for commercialization.

6. PLANS FOR FUTURE COLLABORATION

Coincident with testing the Rheem heat pump system for the CCHP Challenge, ORNL researchers welcomed meeting with Rheem personnel. Their strong engineering abilities were evident during interactions before and during the short testing period. ORNL would welcome and will actively seek further collaboration with Rheem on other projects.

7. CONCLUSIONS

The purpose of this CRADA was to test a nominal 3-ton capacity heat pump system supplied by Rheem Manufacturing to determine if it meets the laboratory test requirements of the US DOE Cold Climate Heat Pump (CCHP) Technology Challenge. Results of the laboratory testing completed at ORNL demonstrate that the system met all requirements of the Challenge. Rheem Manufacturing has successfully completed this aspect of the Challenge. This CRADA report briefly described the Challenge, the test plan created to measure the success of heat pump systems provided by Challenge participants, and the results of laboratory testing of the Rheem heat pump system.

8. REFERENCES

- ANSI/ASHRAE. (2019). ANSI/ASHRAE 37-2009 (RA 2019) Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat-Pump Equipment. In. Atlanta: ASHRAE.
- ASHRAE. (2017). *2017 ASHRAE Handbook - Fundamentals (SI Edition)*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
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