Commercial Building Heat Pump Technology Challenge Specification

U.S. Department of Energy Building Technologies Office

National Renewable Energy Laboratory

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Introduction

The DOE Building Technologies Office is interested in advancing the adoption and increasing the technology readiness of heat pump rooftop units (RTUs) for cold climates. This specification was developed in discussions with various working groups, including manufacturers, building portfolio owners, and other stakeholders. Heat pump RTUs are available on the market today, but their adoption rate is less than 10%. The Commercial Building Heat Pump Accelerator works on increasing adoption through the Commercial Building Heat Pump Campaign, and the Commercial Building Heat Pump Technology Challenge works on product improvement.

Current products are effective in climate zones 1–4 with minimal backup heat operation but have not been effectively deployed. At the same time, cold climate heat pump technology adaptations are needed for more efficient operations in colder climate zones 5–7.

Several Better Buildings partners and other market leaders have expressed a demand for high-performing heat pump RTUs. Discussions with these partners have resulted in a set of critical objectives guiding the development of this specification:

- Improve cold weather performance and minimize heating capacity degradation
- Minimize electrical capacity upgrade requirements
- Minimize peak demand impacts
- Minimize global warming potential (GWP) impacts of refrigerant selection and management
- Balance weight and structural upgrade requirements with performance improvements
- Improve overall system reliability or keep equal to existing systems, e.g., 15- to 20-year lifetimes
- Design for ease of maintenance and component replacement
- Minimize the impacts on initial system costs and total cost of ownership
- Maintain safe and reliable operations.

The goal for Phase I of the Challenge is to have prototypes in the field by winter 2025/2026. The Phase II specification will be developed in 2025, and the goal for Phase II of the Challenge is to have prototypes in the field by 2030.

Phase I

1.1 Summary

The Offeror shall provide a detailed description of the rooftop unit (RTU) model developed in response to this Solicitation. The specification is divided into minimum performance requirements for meeting the specification and additional considerations based on feedback from stakeholders but not required for compliance. Performance of the RTUs will be determined with a separate method of test. This specification leverages the standards listed in order of precedence:

1. Appendix A1 to Subpart F of 10 CFR 431 ("Appendix A1")
2. Air Conditioning, Heating, and Refrigeration Institute (AHRI) 1340-2024
3. American National Standards Institute/American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ANSI/ASHRAE) 37-2009.

1.2 Minimum Performance Requirements

A. General

1. Unit(s) shall be a single zone package air-cooled direct expansion mechanical heating and cooling system with heating capacity of 10–25 tons as defined at 5°F outdoor air conditions. Units will be recognized for successfully meeting or exceeding the minimum requirements of the specification in either the 10- to 14.9-ton or the 15- to 25-ton category. Meeting the Challenge specification will require unique innovations, and DOE will recognize manufacturers that meet or exceed the minimum requirements of the Challenge. Additional recognitions will be provided for manufacturers that go beyond the Challenge specification for two categories. One category is for manufacturers that can increase heat pump capacity significantly above the challenge specification will be recognized for improved cold climate performance. Another category will be for manufacturers that meet or exceed the optional metrics defined in Section 1.3 in this specification. These additional recognitions will be handled on a case-by-case basis and will require a submission from the manufacturer for DOE to review.

2. Prototypes must comply with all applicable federal and state standards, regulations, and laws governing these types of heat pumps. This includes compliance with all applicable safety and environmental standards.

3. Units shall use refrigerants that are U.S. Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) approved and comply with the EPA Technology Transitions Program for light commercial air conditioning and heat pump equipment.

4. The prototype unit will be evaluated with one of two external control methods: thermostat and building management system (BMS). Controls verification will be

completed with a method of test (MOT) provided by DOE. In order to run the CVP test, a virtual zone temperature will be provided to the thermostat or BMS. The thermostat or BMS must be capable of reading this virtual zone temperature through digital (BACnet or Modbus) or analog (resistance, amperage, etc.) signals. Further detail will be provided in the MOT.

a) Thermostat control: Unit will run with a thermostat provided by the manufacturer.

b) BMS control: Unit will run via normal communication protocols such as BACnet or Modbus provided by the manufacturer.

B. Cooling performance

1. Cooling tests shall be completed to calculate the integrated ventilation, economizing, and cooling (IVEC) metric as specified by Appendix A1. All capacity values in this specification are normalized by the A cooling test in Appendix A1.

2. Dehumidification performance is evaluated at the C test conditions with the unit operating at minimum capacity as defined in the MOT for Dehumidification Bin C (DHC) test. The unit may include dehumidification technologies such as hot gas reheat, desiccants, or others that could provide adequate dehumidification at moderate outdoor air temperatures. Manufacturers will need to show systems can dehumidify at the 75°F outdoor air temperature condition for IVEC and account for cycling due to the low building loads at this outdoor air condition. The estimated SHR_{DHC} calculated based on measured $SHR_{DHC,SS}$ in DHC test and degradation to account for cycling shall be less than or equal to 0.95.

C. Heating performance

1. Minimum capacity and efficiency requirements for heating are shown in Table 1. Capacity and efficiency requirements to receive additional recognition are in Table 2. Efficiency will be evaluated based on the Appendix A1 integrated ventilation and heating efficiency metric for cold climates ($IVHE_c$) and the coefficient of performance metric (COP2). $IVHE_c$ is an annual efficiency metric for climate zones 5–8 that includes ventilation, standby, and heating energy. To promote innovative ideas to reduce the effects of defrost and standby losses, manufacturers can request that all the aforementioned energy losses be measured and incorporated into the $IVHE_c$ metric. Manufacturers will need to provide justification to request these tests.

Table 1. Minimum Capacity and Efficiency Requirements for Heating

HP Nominal Capacity [Btu/h][1]	Outdoor Air Temperature: -10°F		Outdoor Air Temperature: 5°F		Minimum $IVHE_c$[4]
	COP2[2]	Minimum Capacity Ratio[3]	COP2[2]	Minimum Capacity Ratio[3]	
≥65,000 and <135,000	1.3	0.7	1.7	1	7.1
≥135,000 and <240,000					6.9
≥240,000 and <760,000					6.7

Notes:

[1] Cooling Bin A tested capacity as defined by Appendix A1.

[2] COP2 as defined by Appendix A1, except at the outdoor air temperature provided in the table.

[3] Capacity ratio is defined as the tested capacity at the outdoor air temperature divided by the tested cooling capacity at 95°F outdoor air temperature (the Cooling Bin A test for IVEC).

[4] $IVHE_c$ as defined by Appendix A1.

Table 2. Optional Capacity and Efficiency Requirements for Improved Cold Climate Performance

HP Nominal Capacity [Btu/h][1]	Outdoor Air Temperature: -10°F		Outdoor Air Temperature: 5°F		Minimum $IVHE_c$[4]
	COP2[2]	Minimum Capacity Ratio[3]	COP2[2]	Minimum Capacity Ratio[3]	
≥65,000 and <135,000	1.3	1	1.7	1.4	7.1
≥135,000 and <240,000					6.9
≥240,000 and <760,000					6.7

Notes:

[1] Cooling Bin A tested capacity as defined by Appendix A1.

[2] COP2 as defined by Appendix A1, except at the outdoor air temperature provided in the table.

[3] Capacity ratio is defined as the tested capacity at the outdoor air temperature divided by the tested cooling capacity at 95°F outdoor air temperature (the Cooling Bin A test for IVEC).

[4] $IVHE_c$ as defined by Appendix A1.

2. The high heating capacity at 47°F (H47H Test) must be equal to or higher than the capacity from the H5Max test.

3. Cut-out temperature must be -15°F or lower and cut-in temperature must be -10°F or lower as defined in AHRI 1340-2024.

4. Supply air temperature must remain at 90°F or above down to 5°F outdoor air temperature with only the heat pump operating at maximum capacity. This requirement will be evaluated at 5°F, 17°F, and 47°F outdoor air temperature $IVHE_c$ tests and will be evaluated only at the maximum capacity for each temperature (boost2, boost, or high operating level—whichever provides the highest capacity at each outdoor temperature).

5. Backup heating performance requirements are detailed next.

   a) Manufacturers can offer electric resistance and/or natural gas backup heat.

   b) Control of backup heating shall be provided to allow continuously variable or staged heating levels. There is a requirement for peak demand, including defrost, that may drive heater staging design and control. Peak demand including defrost must remain below the following:

   $$\bar{P}_{CVP} \leq 2.5\ P_{hp,ss}$$

   Where $P_{hp,ss}$ is the power of the heat pump only from the $IVHE_c$ tests at -10°F, 5°F, and 17°F. $\bar{P}_{CVP}$ is the 15-minute rolling average total power, including heat pump and backup heat during the controls verification procedure (CVP).

   c) Control of backup heat shall maximize use of the heat pump and shall default to simultaneous operation for periods where the heat pump alone cannot meet the building load. Simultaneous heat pump and backup heat operation will be checked at the -10°F CVP test point as defined in the MOT.

6. The CVP described in the MOT is meant to validate and de-risk performance under native controls. Table 3 provides the requirements for heat-pump-only efficiency and capacity during the CVP. The instantaneous efficiency and capacity measured during CVP stable periods must meet the steady-state test values accounting for the tolerance described in Table 3.

Table 3. Heat Pump Capacity and Efficiency Thresholds for the CVP

Outdoor Air Temperature (°F)	COP2 Tolerance	Measured Capacity Tolerance	Steady-State Test
-10	-10%	±10%	H-10Max
5			H5Max
47			H47L

1.3 Requirements To Be Validated Separately After Field Evaluations

A. Minimum Circuit Ampacity Limiting

Manufacturers shall provide options to reduce minimum circuit ampacity (MCA) compared to an all-electric commercially available heat pump RTU.

B. Load Flexibility

1. Manufacturers shall provide load management functionality to shift or shed power consumption temporarily to help manage peak demand. Manufacturers will be required to demonstrate load shifting for winter and summer. The following load management functions—which may be commanded by an external entity such as a thermostat, BMS, aggregator or grid operator—should be supported:

   a) Direct thermostat adjustment (degree offset; degree setpoint)

   b) Peak demand limit (maximum kilowatts [kW])

   c) Load reduction/increase command (% or kW)

2. Depending on the controls implementation, these signals may be sent as absolute values or discrete levels. In either case, the performance expectations for individual units to these signals fall in the following levels:

   a) Tier 1 load shed: General curtailment is targeting a 15% reduction in power consumption.

   b) Tier 2 load shed: Critical curtailment is targeting a 40% reduction in power consumption.

   c) Load add: General load add is targeting a 15% increase in power consumption.

   Additional device-level control modes and sequences should be programmed and made available on the local network to support these demand management functionalities. For all-electric prototypes, a key issue found in the field has been defrost coordination, leading to peak demand issues even in mild outdoor air conditions. Any all-electric prototype units must allow for defrost triggering, defrost delays, and electric resistance heat lock-out that can be externally requested. Any dual-fuel prototypes must provide external control to switch between all-electric and natural gas heating. Local and external control implementation requirements will be further defined in the MOT.

C. Grid Edge Communication Interfaces

All units must support external communication with the power grid. For thermostatically controlled units, a communications interface that supports external communication to the grid must be available onboard the device or thermostat. For BMS-controlled units, this interface may be available on the device, thermostat, or as a module available on the BMS server or network. The hardware component of this communications interface must meet one of the following requirements:

1. Connection to IEEE Standard 802.11 compliant Wi-Fi network
2. Connection to IEEE Standard 802.3 compliant Ethernet network
3. Connection to IEEE Standard 802.15.4 compliant Zigbee network.

This communications interface should support open communication protocols as required by relevant standards and regulations:

1. OpenADR 2.0b or higher, as required by AHRI Standard 1390-20XX
2. IEEE 2030.5 (Smart Energy Profile 2.0)
3. CTA-2045

D. Embodied Carbon

Manufacturer shall provide an estimated embodied carbon value in kg CO_2e based on a product life cycle assessment, Chartered Institution of Building Services Engineers (CIBSE) TM65 North America, or equivalent estimation methodology.

E. (Optional) Automated Fault Detection and Diagnostics (AFDD)

Manufacturer shall provide AFDD beyond Title 24 and ASHRAE 90.1. Examples of AFDD beyond Title 24 and ASHRAE 90.1 include the following:

- Refrigerant charge
- Airflow
- Coil fouling
- Component failing
- System performance
- Fault filtering or prioritization.

F. (Optional) Interoperability

Manufacturers shall provide their RTU metadata in Project Haystack, Brick schema, or ASHRAE 223P, which will be validated using the BuildingMOTIF tool (https://buildingmotif.readthedocs.io/en/latest/README.html). The intent of this specification is to ensure building controls can correctly connect to every RTU and read and write to them.

G. (Optional) ASHRAE 205 Performance Data Validity Check

Manufacturers shall provide performance data in accordance with ASHRAE 205 to be validated by DOE.

1.4 Method of Test To Promote Innovation

DOE will work with manufacturers to determine a MOT so all manufacturers can design a heat pump RTU to meet the specification. DOE is considering the following test methods; one or all may be used in the challenge to verify performance at different stages of the Challenge:

1. Estimated performance verification: DOE and its national laboratories will provide a test procedure to evaluate the heat pump performance and determine if it meets the specification.

2. Controls verification: DOE and its national laboratories will set up a test procedure to be able to evaluate the controls of the RTU to determine if it meets the specification.