

Air-Source Heat Pumps: Metrics and Tools for Cold Climate Programs

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ABSTRACT

Technology can advance quickly, and reliable technology assessment methods often lag. The authors perused literature, consulted subject matter experts and stakeholders, and evaluated potential metrics that programs may use to qualify inverter-driven, cold-climate air source heat pumps (ccASHPs). This paper reviews several metrics and test procedures including:

- Heating Season Performance Factor (HSPF) and HSPF2
- Northeast Energy Efficiency Partnerships (NEEP) Specification v3.1
- ENERGY STAR v6
- CSA EXP07:19
- Various heating capacity ratios

Some of these metrics have shortcomings when applied to the selection of ccASHPs. Practically speaking, existing empirical data show no meaningful relationships between real-world ccASHP performance and any of these metrics. The short-term recommendation for ccASHP program administrators in colder climates is to use the NEEP Specification v3.1 to qualify incentive-eligible products. The NEEP specification has shortcomings, but additional, unproven requirements may unduly restrict equipment options without attendant benefits. The authors recommend that programs pay close attention to newer performance standards, especially ENERGY STAR v6 and EXP07:19. These may offer more reliable characterizations of ccASHPs in cold climates. Additionally, the authors recommend studies to assess relationships between newer metrics and real-world ccASHP performance.

Regarding installed performance of ccASHPs, proper system design, equipment selection, and installation are much more important than current equipment ratings or metrics. Program administrators would be well served in supporting contractors to design, select, and install the best system in each application. Education, practical quality management tools, and replicable case studies can lead to more program success than unproven equipment metrics.

Introduction

In support of the goals articulated in New York State's Climate Leadership and Community Protection Act (New York State 2019), the New York State Energy Research and Development Authority's (NYSERDA's) Carbon Neutral Buildings Roadmap (NYSERDA 2022) outlines a path toward electrifying home heating in 90% of New York State homes by 2050. In supporting the achievement of these goals, NYSERDA has a strong interest in establishing effective, consistent selection criteria for air source heat pump systems for both

programs and the market at large. Criteria should ensure occupant comfort is maintained, energy savings are maximized, and peak grid impacts are minimized.

In the summer of 2021, NYSERDA hosted a virtual expert stakeholder meeting focused on ccASHP ratings, certification, and testing. Approximately 35 subject matter experts attended the meeting including utility representatives, program administrators (PAs), manufacturers, engineers, trade groups, federal agencies, standard setting bodies, and others. The primary question considered by the group was: What equipment performance criteria should PAs use to ensure ccASHPs can perform acceptably in cold-climate homes? The focus was on applications where ccASHPs provide all (or a large majority) of space heating needs in homes.

This paper was strongly influenced by this stakeholder meeting as well as many other discussions, correspondences, research, and the references cited. The opinions presented here, however, are those of the authors; they do not necessarily reflect those of NYSERDA or a consensus of the stakeholders involved in the meeting.

Table 1. Summary of metrics considered

Rating / Metric	Appeal	Drawbacks	Proven Indicator of Installed ccASHP Performance?
HSPF, HSPF2	Well defined rating procedure; required in U.S. by statute	Manufacturers specify fixed speeds for lab tests. No tests of variable-speed operation. No tests below 17°F.	No, studies have found no correlation to installed performance
CSA EXP07:19	Rigorous tests using native controls over a wide range of conditions. Designed to characterize variable-speed equipment	Not yet in use. Likely costly and time-consuming to perform tests. Not yet applicable to multi-split systems	No, promising approach but not yet in use
NEEP Spec v3.1	Broad range of equipment data in an accessible database. Free to end users.	Relies on manufacturer data (non-standardized). Costly for manufacturers and programs to use	No, provides important information but not sufficient to ensure installed performance
ENERGY STAR v6	Requires test of capacity and efficiency at 5°F under native controls	Not yet in use. Relies on HSPF2 to gauge overall efficiency	No, promising approach but not yet in use
Capacity Ratios	Attempts to gauge capacity maintenance or modulating efficiency	Apples-to-oranges comparisons of non-standardized data	No, speculative, untested, may restrict equipment that could perform well in cold climates

ASHP Metrics

It is common for utility incentive programs to use equipment metrics within program eligibility requirements. The intention is to provide assurance that incentivized equipment will fulfill the utility program's energy savings and market transformation goals. Those goals

variously include customer satisfaction, energy use reduction, peak load mitigation, comfort, durability, and more recently decarbonization. For ccASHPs there are a growing number of equipment performance metrics for PAs to consider.

Short descriptions of some ASHP test procedures, certification standards, and other metrics are summarized in Table 1 and described below. The descriptions are intentionally brief; see references for more information. These metrics are used by various PAs to qualify equipment for program incentives, but there is little evidence relating any of these metrics to actual installed performance of ccASHPs. The most likely to have such relationships are EXP07:19 and possibly the ENERGY STAR v6 cold-climate certification, but these are not yet being used.

HSPF and HSPF2

The heating season performance factor (HSPF) is defined in AHRI (Air Conditioning, Heating, and Refrigeration Institute) 210/240 (AHRI 2017). The metric will soon change to HSPF2 as defined in the latest standards (AHRI 2020). HSPF was originally developed several decades ago as a rating method for single-stage ASHPs. Calculating HSPF and HSPF2 for variable-speed ASHPs requires five steady-state tests at prescribed temperatures. The coldest outdoor temperature used in these tests is 17°F. Recent versions of AHRI 210/240 include an optional test for variable-speed heat pumps at 5°F, but these results are not used for equipment ratings. With the five steady-state test results, a bin analysis is used to calculate HSPF or HSPF2 for various climate regions.

Several stakeholders have expressed concern about using HSPF or HSPF2 as a reliable metric for the performance of variable-speed ASHPs in cold climates for several reasons:

- Studies have not shown a significant correlation between HSPF and installed performance of ccASHPs (Cadmus 2016).
- No testing is required at outdoor temperatures below 17°F. Many ccASHPs can operate well below 0°F, but tests at such conditions are not included in HSPF or HSPF2 metrics;
- Discrete, steady-state tests likely do not adequately characterize performance of ccASHPs which are designed to modulate over a wide range of dynamic conditions;
- The compressor speeds used in these steady-state tests are largely specified by manufacturers. These speeds may not reflect common compressor speeds in real-world applications, and this leaves a critical element of “standardized” tests at the discretion of manufacturers;
- For ductless ASHPs, equipment is generally tested with indoor blower speeds that are much higher than blower speeds in real-world applications (resulting in tested efficiencies higher than real-world efficiencies);
- HSPF includes significant use of electric resistance heat in bin calculations – regardless of whether electric resistance heat is present in the specific equipment being tested;
- The commonly used HSPF value is specific to climate region IV, a moderately cold climate. While HSPF can be calculated for other regions, this is rarely done, and programs in all climate regions typically reference region IV values.

NEEP Specification

Recognizing that standard metrics for ccASHPs in cold climates were lacking, the Northeast Energy Efficiency Partnerships (NEEP) published the first “Cold Climate Air Source

Heat Pump Specification” in 2015. The current version 3.1 (NEEP 2021) includes the following minimum criteria:

- Coefficient of Performance (COP) ≥ 1.75 when operating at maximum capacity at 5°F outdoor dry bulb
- HSPF ≥ 10 (ductless); HSPF ≥ 9 (ducted)
- Seasonal energy efficiency ratio (SEER) ≥ 15
- Manufacturers must provide capacity ranges, power consumption, and COP at a set of defined conditions

The first bullet above (COP@5°F, maximum capacity) relies on values reported by manufacturers – not on standardized test procedures. This is a shortcoming that was (and remains) clear to the developers of this specification. There is an inherent disincentive for manufacturers to inflate maximum cold-weather capacity values, as failure to meet promised heat output could be a tremendous liability. The accuracy of manufacturer-reported COP values at 5°F, however, is much less certain. Load-based laboratory tests of ASHPs at maximum capacity at 5°F show that listed COP and tested COP can be significantly different (Harley 2020).

In the absence of relevant standardized test procedures, however, relying on manufacturer-reported values seemed like a necessary starting point to move the market forward. Drafts of future versions of the NEEP specification include reference to ENERGY STAR™ v6 cold-climate requirements which include more standardized tests (described below).

Manufacturers whose products meet criteria outlined in the NEEP spec can choose to have their equipment listed in NEEPs’ database. For many stakeholders, the most important and appealing feature of the database is that it is, indeed, a database (NEEP 2022b). Users can review and compare values for thousands of heat pumps in a consistent format.

While the database is available online at no cost to end-users (both contractors and consumers), a drawback of the NEEP specification cited by several larger stakeholders is the cost. NEEP, as a private, non-profit group, charges manufacturers and program administrators who use the specification and database. Manufacturers, for example, pay NEEP to list qualifying ASHP products. The cost to manufacturers is \$5,000 - \$14,000 per year depending on the number of products listed (NEEP 2021a). Program administrators who use the NEEP specification in their programs are charged \$5,000 - \$22,500 per year depending on the size of their program (NEEP 2022a).

ENERGY STAR v6: Cold-Climate Certification

ENERGY STAR v6 requirements for ASHPs will take effect January 2023 (EPA 2021b). These include specific requirements for cold-climate ASHP certification, including the following for split systems:

- HSPF2 ≥ 8.5
- SEER2 ≥ 15.2
- Energy Efficiency Ratio (EER)2 ≥ 11
- COP ≥ 1.75 at 5°F using the optional H_{4,Full} test from AHRI 210/240

- Capacity @5°F / Capacity @47°F $\geq 70\%$ using the test results from $H_{4,Full}$ and $H_{1,Nom}$, respectively, from AHRI 210/240
- COP ≥ 1.75 at 5°F using the Controls Verification Procedure (CVP), described below
- Capacity @5°F / Capacity @47°F $\geq 70\%$ using test results from CVP and $H_{1,Nom}$, respectively.

The ENERGY STAR v6 specification introduces the additional CVP test method to assess cold climate performance. The purpose of the CVP is to validate the certified performance of ENERGY STAR central heat pumps using the units “Native Controls” at the 5°F heating conditions (EPA 2021a). In theory, this is intended to be a standardized test for maximum heat pump capacity at 5°F. The compressor and blower speeds are not fixed, rather the heat pump uses native controls to provide as much heat as possible under defined conditions.

Some manufacturers have expressed concern that this added test requirement will be expensive and time consuming. Developers at the EPA envision tests will be performed in conjunction with the already required AHRI 210/240 testing and that added cost will be modest. At the time of writing, the authors are not aware of any CVP tests that could help assess the cost of testing or the difficulty in meeting revised ENERGY STAR requirements.

CSA EXP07:19

EXP07 is a Canadian test procedure which offers an alternative approach to the steady-state tests used to calculate HSPF and HSPF2. The title of EXP07 is “Load-based and climate-specific testing and rating procedures for heat pumps and air conditioners” (CSA 2019). A primary goal in developing the procedures was to create metrics that more realistically characterize real-world performance of inverter-driven ASHPs – including performance in cold climates. The procedure requires several standardized tests for ASHPs:

- Heating at six temperatures from -10°F to 54°F (continental climate conditions)
- Heating at four temperatures from 17°F to 54°F (marine climates conditions)
- Cooling at five temperatures from 77°F to 113°F (dry climate conditions)
- Cooling at four temperatures from 77°F to 104°F (humid climate conditions)

A key feature of the test procedures is that heat pumps and air conditioners are operated using “native controls” to meet a specified load applied to the test chamber. This differs markedly from AHRI 210/240 where tests are performed at fixed compressor speeds and fixed air flow rates (which are largely specified by manufacturers). With the array of load-based test results, the EXP07 procedure defines the calculation of seasonal coefficients of performance (SCOPs) for particular equipment in various climate zones.

While widespread implementation of the EXP07 procedure does not appear imminent, engineers have published results and findings from tests on several ccASHP products (Harley 2020). Insights from these tests include:

- Equipment with higher HSPF ratings do not necessarily have higher SCOPs;
- Equipment with higher COPs at 5°F (maximum capacity) do not necessarily have higher SCOPs;

- Measured COPs at 5°F do not necessarily match values reported by manufacturers (e.g. for the COP@5°F requirements in the NEEP Specification).

These initial EXP07 tests appear to address shortcomings in other metrics. However, there is not yet any empirical evidence that SCOPs as defined by EXP07 are valid indicators of real-world performance.

A key concern among many stakeholders – especially ASHP manufacturers – is the time and cost needed to perform testing for EXP07. More tests are required for EXP07 than for AHRI 210/240, though some savings may be achieved by performing both sets of tests at the same time in the same facility. It is also not yet clear how various multi-zone system combinations would be tested in future versions of EXP07. EXP07 appears to offer the most rigorous standardized assessment of ccASHP performance. As the test procedure is very new, however, there are too many questions to gauge the viability of the test procedure as an accepted metric for the industry.

Key parameters in the metrics discussed so far are listed in Table 2 and Table 3.

Table 2. Brief overview of ccASHP test procedures

	AHRI 210/240	CSA EXP07-19
Heating efficiency	HSPF/HSPF2 calculated from 5 tests under fixed capacity and airflow	Heating SCOP calculated from 4-6 dynamic tests using native controls
Cold temperature performance	Lowest required test at 17°F Optional test at 5°F (not used for HSPF/HSPF2)	Testing at -10°F required for cold climates
Cooling efficiency	SEER/SEER2 calculated from tests at fixed conditions up to 95°F	Cooling SCOP calculated from 4-5 dynamic tests using native controls up to 113°F

Table 3. Performance criteria summary

	NEEP ccASHP Specification v3.1	ENERGY STAR v6: Cold Climate Certification
Seasonal heating efficiency	HSPF ≥ 10 (ductless) HSPF ≥ 9 (ducted)	HSPF2 ≥ 8.5
Heating eff. at cold temperatures	COP ≥ 1.75 @ 5°F max capacity (mfr reported)	COP ≥ 1.75 at 5°F using $H_{4,Full}$ test, and COP ≥ 1.75 at 5°F using CVP
Heating capacity maintenance	Several ratios listed; none required.	Capacity @5°F / Capacity @47°F $\geq 70\%$ using $H_{4,Full}$ and $H_{1,Nom}$
Heating modulation	Several turndown ratios listed; none required.	none
Cooling efficiency	SEER ≥ 15	SEER2 ≥ 15.2 and EER2 ≥ 11

Capacity Ratios

In an attempt to address shortcomings in other metrics, several stakeholders and PAs have explored various heating capacity ratios to characterize or identify appropriate ccASHP equipment. These ratios are intended to serve one of two purposes:

- **Capacity maintenance** ratios are intended to ensure that a heat pump can meet all (or most) of the heating load near design conditions in cold climates. This can eliminate (or reduce) the need for backup heat. Eliminating backup heat can help mitigate peak impacts (for electric resistance) and carbon dioxide emissions (for fossil fuels).
- **Turn-down** ratios are intended to identify ccASHPs that can provide low levels of heat output with minimal short-cycling. Heat pumps that modulate over a wide range of conditions (rather than cycle on and off) can be more efficient.

Sometimes these two goals can conflict with each other. A heat pump with high capacity at cold temperatures may be more likely to short cycle at low-loads. The proper balance of these goals will vary with region, climate, program priorities, and building or system configuration. The proper balance can also be different from customer and program perspectives.

Both of these goals can be more effectively achieved by improving ccASHP design, sizing, and product selection methods. However, influencing design methods is much more difficult for a program administrator than specifying equipment eligibility criteria.

In the descriptions below, a shorthand is used when expressing ratios. “Max,” “Min,” or “Rated” refers to maximum capacity, minimum capacity, or “rated” output (this latter typically in accordance with AHRI 210/240). The numbers in the abbreviations refer to the outdoor dry bulb temperature. While some stakeholders consider the use of “rated” performance factors superior to voluntary manufacturer reported data, it is important to note that the AHRI 210/240 compressor speeds and air flow rates used during the tests are largely determined by the manufacturer. AHRI 210/240 defines “nominal” compressor speed as, “A heating mode compressor stage equal to or higher than Full Compressor Stage in cooling.” This may prevent testing cooling and heating performance at widely varying speeds in the same piece of equipment, but manufacturers still have tremendous leeway to select speeds at which their equipment is tested.

Max@5/Rated@47. Because there are not yet results from standardized test procedures to determine maximum heating capacity at 5°F outdoor dry bulb, at present this ratio must use manufacturer-reported values in the numerator. This situation may change as data from ENERGY STAR v6 testing become available. It should be noted, however, that manufacturers are likely to be somewhat conservative when publishing maximum heating capacity at cold temperatures. This is a fundamental criterion when selecting equipment to meet specific loads, and overstating cold weather capacity could lead to severe performance problems.

The denominator of this ratio is the capacity of the H_{1Nom} test from AHRI 210/240. This capacity is also published on AHRI certification sheets.

In conversations with stakeholders, most agreed this ratio is a fairly decent indicator of ASHPs which manufacturers designate as their best cold-climate equipment. There is some circular logic here, however, as some manufacturers use this exact metric to designate good cold-weather performance.

Figure 1 shows this ratio for all single-zone, non-ducted ASHPs listed in the NEEP database from six prominent manufacturers. Manufacturers are kept anonymous (A-F). The left chart shows Max@5/Rated@47 for products identified by *manufacturers* as their best cold-climate equipment. The chart on the right includes all other products from those same manufacturers. Note that equipment in both charts is listed in the NEEP database which includes

basic cold-climate requirements. In these box and whisker plots, the boxes denote the interquartile range, while the whiskers denote 1.5 times the interquartile range.

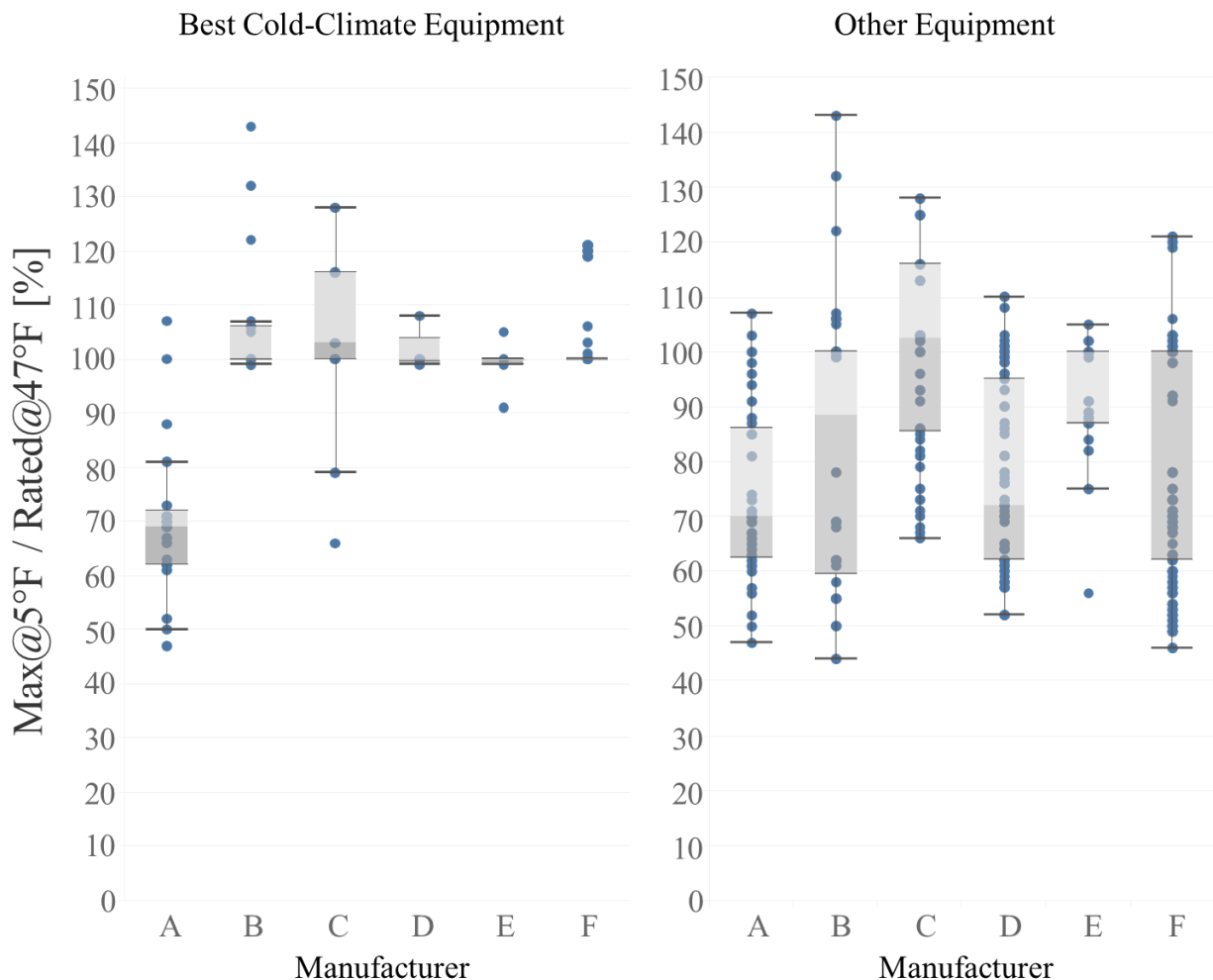


Figure 1. Comparison of capacity maintenance ratios (Max@5/Rated@47) from the NEEP database for 1:1 ductless heat pumps from six manufacturers.

It is clear that for manufacturers B-F, the vast majority of designated “cold-climate” equipment has Max@5/Rated@47 ratios of 100% or greater. Ratios in the right-hand chart are much more variable and lower overall. For manufacturer A, however, the median ratio in both charts is 70%. This does not necessarily indicate this equipment does not operate well in cold weather; it may indicate that this manufacturer “rates” its equipment at or near maximum capacity in the 47°F test. It is worth reiterating that some manufacturers—including some represented in this data set—use a 100% Max@5/Rated@47 ratio as a criterion for their best cold-climate equipment. Manufacturers may set their compressor speeds for the 47°F test to achieve this ratio.

Rated@17/Rated@47

This metric has been adopted by some programs to determine equipment eligibility for cold climate heat pump incentives. The appeal of this ratio is that it uses two “rated” values

defined in AHRI 210/240 that are readily accessible. These values are the two primary heating capacities listed on AHRI certificates:

- $H_{1\text{Nom}}$ test (47°F outdoor dry bulb)
- $H_{3\text{Full}}$ test (17°F outdoor dry bulb)

While this ratio uses two "rated" values from standardized test procedures, there is no reason this ratio would be indicative of good performance in real world applications. AHRI 210/240 specifies "nominal" compressor speed and air flow for $H_{1\text{Nom}}$ and "full" compressor speed and air flow for $H_{3\text{Full}}$. For any given heat pump, the manufacturer specifies the compressor speeds used in the tests. These "full" and "nominal" speeds may or may not be similar, and information on tested speeds is not published. Even if the fixed speeds for these tests were published and representative of real-world operation, the ratio still would not indicate how equipment might perform over the full spectrum of operating conditions, particularly when outdoor temperatures drop below 17°F.

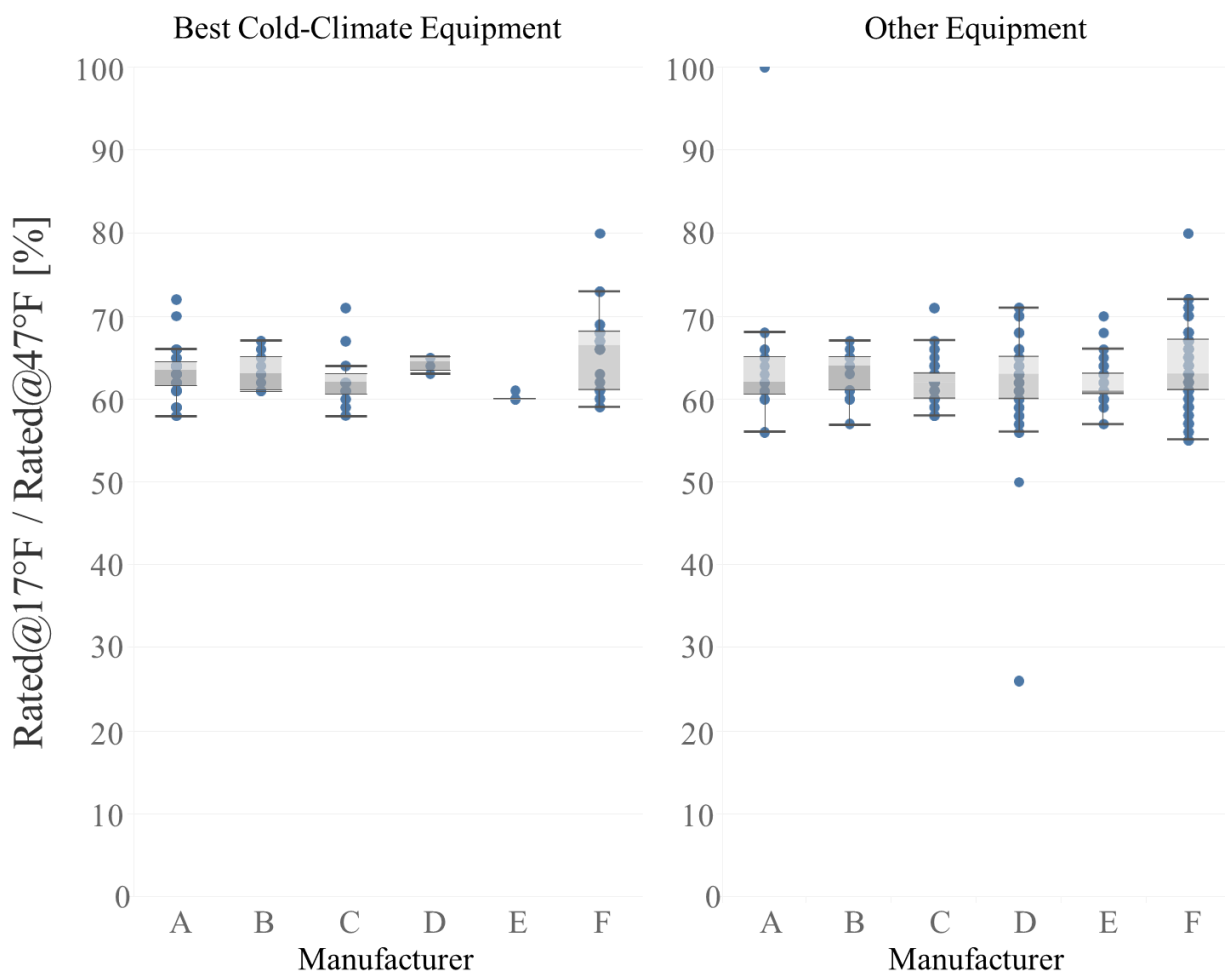


Figure 2. Comparison of capacity maintenance ratios (Rated@17/Rated@47) in NEEP database for 1:1 ductless heat pumps from six manufacturers.

Figure 2 compares Rated@17/Rated@47 ratios for single-zone ductless ASHPs from six manufacturers. On the left are ratios for equipment designated (by manufacturers) as their best cold-climate models. On the right are ratios for other equipment listed in the NEEP database (which also requires some cold-climate performance criteria). There is virtually no difference in median ratios between these sets of equipment. There is more spread in the “other” equipment because it is a larger sample set.

Due to the design of the test method, the Rated@17/Rated@47 ratio is an arbitrary, apples-to-oranges comparison. The authors are not aware of any data suggesting this ratio leads to better equipment selection in any application. In fact, depending on what minimum ratio is established, program requirements based on this ratio may decrease overall quality of ASHP installations by unnecessarily limiting eligibility of viable products.

Turndown Ratios. Inverter-driven ASHPs can modulate to meet varying heating loads, but the range of modulation is limited. If the load is lower than the range of the ASHP capacity, the heat pump must overheat the space, turn off entirely, or cycle on and off. Excessive cycling can lead to considerably higher energy consumption. Cycling can be limited by right-sizing heat pumps and selecting heat pumps with a wider range of modulation. Quantifying this range of modulation is the goal of “turndown ratios.” Two such ratios are:

- **Max@5/Min@47.** This ratio is currently listed in the NEEP database and requires two manufacturer-reported values: maximum heating capacity at 5°F and minimum heating capacity at 47°F. The appeal of this ratio is that it includes two values that should be key for design and system selection: maximum capacity near design temperatures (in a cold climate) and minimum capacity at a very mild outdoor temperature.
- **Max@47/Min@47.** This ratio is similar in that it relies on two manufacturer-reported values. Some stakeholders have suggested that comparing maximum and minimum capacities at the same outdoor conditions could be a more reliable metric.

Modulation is an important consideration, but there are some shortcomings in the proposed metrics, including:

- The proposed ratios rely solely on manufacturer-reported values. While manufacturers have incentive not to overstate maximum capacities (at least near design temperatures), minimum capacities are still quite questionable. Some laboratory tests could not duplicate minimum capacities listed by ccASHP manufacturers (Winkler 2011).
- Some types of equipment have inherent limitations on modulation. Multi-zone ASHPs, for example, generally modulate over a more narrow range than 1:1 ASHPs.

While modulation and turndown should be considered during design and equipment selection, there are too many uncertainties for programs to mandate metrics such as these. The authors feel that mandating ratios could restrict viable equipment in some applications without proven benefits. This certainly could change as test standards evolve and more performance data are collected.

Quality Design and Installation

While studies have not shown a relationship between current equipment metrics and real-world ccASHP performance, there are studies that show proper equipment selection and installation do result in better performance. In one evaluation (Cadmus 2016), a single contractor was responsible for a very large fraction of installations. Program administrators had reports of consistent poor quality design and installation from this contractor, and evaluators found that ccASHPs installed by this contractor did indeed perform less efficiently: COPs were approximately 0.5 lower. In another study (Cadmus 2017), evaluators consistently found high quality installations, and average, seasonal heating COPs were 3.0.

Programs and policies can only do so much. At the end of the day, it is the responsibility of an HVAC designer and/or contractor to design and install appropriate heat pump systems. Heat pump applications are different: buildings are different, loads are different, customer goals are different, budgets vary widely, etc. With so much variability, requiring unproven metrics for qualifying products can limit choices and even adversely affect performance. While metrics on their own don't provide a silver bullet for ccASHP equipment selection, many of the parameters referenced in metrics are absolutely relevant to ccASHP contractors and designers. For example:

- Maximum heating capacity at cold temperatures (e.g. 5°F and 17°F) is crucial when selecting equipment to meet design loads.
- Maximum heating capacity at colder temperatures (e.g. below 0°F) is key for sites with lower design temperatures. It also may be useful when considering extreme events (e.g. polar vortices) and the need for auxiliary heat.
- Examining minimum capacity at milder temperatures (e.g. 47°F) can provide an indication of how well equipment can modulate without cycling. Designers may find one of the turndown ratios discussed above useful for this purpose.
- Examining COP at a range of operating conditions is useful: maximum COP near the design temperature, and COPs while modulating at warmer temperatures. Higher COPs at common operating conditions have a substantial impact on overall efficiency.

The NEEP Specification and database contains all of the above information, and most manufacturers provide much more detail in their engineering literature. NEEP's heat pump sizing visualization tool (described below) can help contractors apply this information. In the near future, the authors are hopeful that the ENERGY STAR v6 CVP can offer standardized comparisons of maximum capacity and the associated COP at 5°F. Looking ahead further, EXP07 testing may provide meaningful seasonal COP values for many climate zones. There is certainly a need for field evaluations to assess how well any of these metrics reflect (or predict) installed ccASHP performance.

In the meantime, PAs may find it worthwhile to educate and empower contractors to design and install excellent systems. The importance of good load calculations, design, equipment selection, and installation cannot be overstated. An assessment of common practices (NEEP 2017A) found that good design is rare and ASHPs are usually sized using archaic rules of thumb. Supporting contractors can be more challenging than mandating simple equipment criteria, but several stakeholders have already begun to invest in resources to support contractors and the ccASHP market overall.

- Manufacturer led ccASHP Sizing and Design training:** In 2020, NYSERDA developed a training course curriculum and example training deck with the intention that manufacturers would create their own versions of the training and make it available as a standard training offering to contractors nationwide (NYSERDA 2020). Thus far, manufacturers have responded positively with many market-leading manufacturers now offering qualifying trainings. The training focuses on design principles for properly sized and selected ccASHPs. Massachusetts and New York state utility programs require participating contractors to show proof of this training. Other states and utilities could leverage the same.
- Utility program training courses:** Many utility programs have developed their own trainings, program orientations, and resources designed to support and educate contractors appropriately design ccASHP systems. For example, ComEd has a pilot ASHP training program (ComEd 2021). Others leverage NEEP resources such as their installation guide (NEEP 2017C).
- Improved access to and use of extended performance data:** Properly sizing a heat pump requires multi-variable review and balancing sometimes conflicting goals. Comparing maximum capacity, minimum capacity, and COP at multiple temperatures as they relate to a home's heating load (that also varies by temperature) is complicated. To support this challenge, NEEP has developed a sizing visualization tool, free to use, that allows a contractor to compare a specific product's min and max capacity curves to a load line (see an example in Figure 3). The tool provides helpful metrics to evaluate if the heat pump is a good fit for the home's needs. It allows the user to visualize the need for backup heat and how much of the home's load falls within the heat pump's modulating zone.

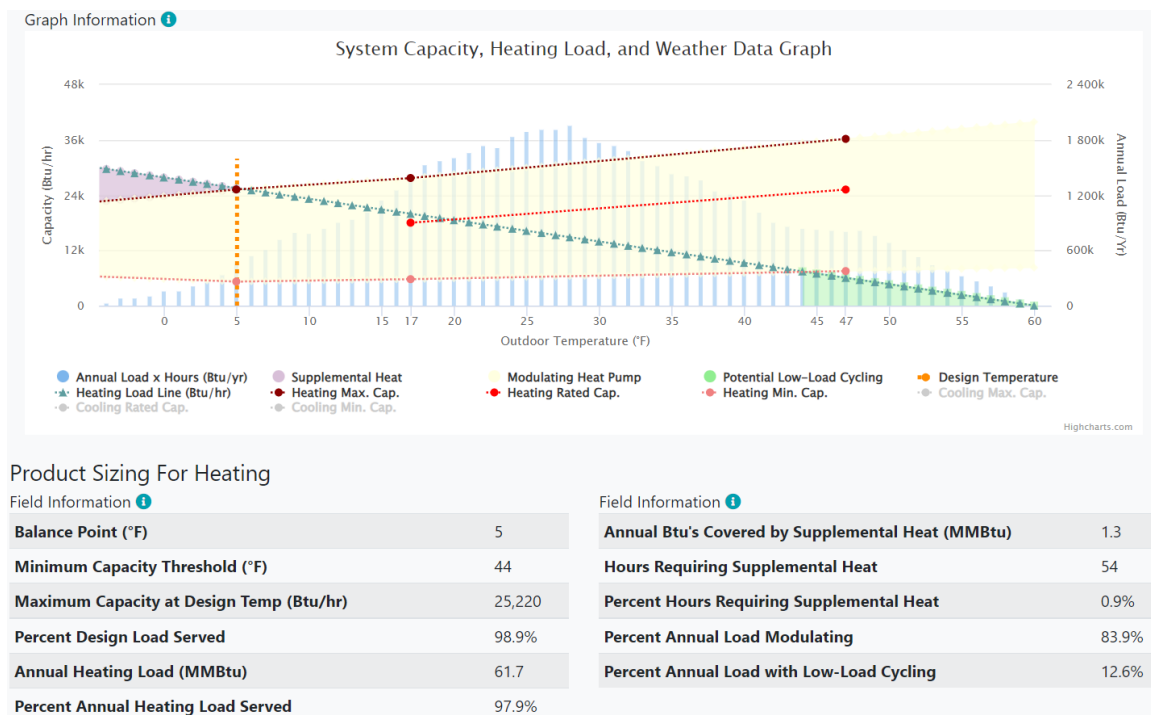


Figure 3. Example screen shot from NEEP ccASHP sizing visualization tool

- **Simplified load calculation approaches:** Many stakeholders are exploring simplified or streamlined methods to assess design loads. Examples include the Northwest Energy Efficiency Alliance's (NEEA) BetterBuiltNW load calculation tool (NEEA 2020) and load estimates from historic fuel usage (Denholm 2021). Programs can create program rules and support contractors in assessing which scenarios are appropriate for load assessment methods. Programs can also provide training and support to help contractors integrate load assessments into their standard procedures.

Conclusions and Recommendations

Cold-climate ASHP technology has advanced more quickly than have methods to effectively characterize its performance. Older metrics such as HSPF were developed for single-stage heat pumps and do not translate well to variable-speed equipment. Even when used to characterize variable-speed heat pumps, HSPF and HSPF2 require five steady-state tests where the compressor speeds are specified by manufacturers.

The NEEP Specification responded to gaps identified in HSPF by requiring reporting of maximum capacity at 5°F, minimum COP at that maximum capacity, and modulation ranges at several conditions. Efficiency and capacity in cold weather are important when selecting a heat pump for a cold climate. These data are self-reported by manufacturers and are not standardized, and this is certainly a short-coming in the voluntary specification. The authors believe, however, that as a set of minimum criteria, the NEEP specification provides a reasonable, base level of performance when selecting equipment for cold climate applications. This is a minimum bar, and it does not necessarily indicate performance in a range of applications, nor does it necessarily indicate year-round performance. Another limitation is the expense for manufacturers and programs to use the voluntary product list. Still, the NEEP specification may be the most meaningful metric we have at this point in time.

The upcoming ENERGY STAR v6 cold-climate ASHP requirements and CSA EXP07:19 test procedures may address gaps in both HSPF and the NEEP Spec. At the time of writing, however, no empirical data is available. There are also concerns related to the time and cost to conduct these tests – especially for EXP07. The authors recommend that stakeholders keep track of these metrics moving forward.

The absence of meaningful equipment metrics has led some frustrated PAs to create and require various capacity ratios. There seem to be no data linking such ratios to better installed performance, and in some cases the rationale itself seems unsound. Examining modulating ranges or turndown ratios can be a good practice when selecting equipment, but including ratios in eligibility criteria has questionable benefits. In fact, it can decrease performance overall by dramatically limiting eligible equipment.

While it's questionable that current equipment metrics will result in better installed performance, better performance certainly is possible through better ASHP design and installation. Program administrators may be much better served focusing on education and support for designers and contractors. Load calculations, system design, equipment selection, installation, and commissioning are vital for consistent comfort and efficiency. Addressing these factors may be much more challenging for PAs than adopting simple equipment eligibility requirements, but the impacts will be much more meaningful.

References

- ACCA (Air Conditioning Contractors of America). 2014. *Manual S Residential Equipment Selection*, Second Edition. Alexandria, VA: ACCA.
- ACCA (Air Conditioning Contractors of America). 2016. *Manual J Residential Load Calculation*, 8th Edition. Alexandria, VA: ACCA.
- AHRI (Air Conditioning, Heating, and Refrigeration Institute). 2017. *2017 Standard for Performance Rating of Unitary Air-conditioning & Air-source Heat Pump Equipment*. Arlington, VA: AHRI.
- AHRI (Air Conditioning, Heating, and Refrigeration Institute). 2020. *2023 Standard for Performance Rating of Unitary Air-conditioning & Air-source Heat Pump Equipment*. Arlington, VA: AHRI.
https://www.ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard_210-240_2023.pdf.
- ASHRAE (American Society for Heating, Refrigeration, and Air Conditioning Engineers). 2017. *ASHRAE Handbook: Fundamentals*. Atlanta, GA: ASHRAE.
- Cadmus Group. 2016. *Ductless Mini-Split Heat Pump Impact Evaluation*. <https://ma-eaac.org/wp-content/uploads/Ductless-Mini-Split-Heat-Pump-Impact-Evaluation.pdf>.
- Cadmus Group. 2017. *Evaluation of Cold Climate Heat Pumps in Vermont*.
https://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/Reports/Evaluation%20of%20Cold%20Climate%20Heat%20Pumps%20in%20Vermont.pdf.
- CSA Group. 2019. *CSA EXP07:19: Load-based and climate-specific testing and rating procedures for heat pumps and air conditioners*. Toronto: CSA Group.
<https://www.csagroup.org/store/product/CSA%20EXP07:19/>.
- ComEd (Commonwealth Edison Company). 2021. *Air Source Heat Pump Training*.
<https://comedemergingtech.com/project/air-source-heat-pump-training>.
- Denholm, P., Ong, S., Booten, C. 2012. *Using Utility Load Data to Estimate Demand for Space Cooling and Potential for Shiftable Loads*. Golden, CO: National Renewable Energy Laboratory. <https://www.nrel.gov/docs/fy12osti/54509.pdf>.
- EPA (Environmental Protection Agency). 2021a. *ENERGY STAR Cold Climate Heat Pump Controls Verification Procedure (CVP)*. Washington, DC: EPA.
<https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Cold%20Climate%20Heat%20Pump%20Controls%20Verification%20Procedure.pdf>.
- EPA (Environmental Protection Agency). 2021b. *ENERGY STAR® Program Requirements Product Specification for Central Air Conditioner and Heat Pump Equipment Eligibility Criteria Version 6.0*. Washington, DC: EPA.
<https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Version%206.0%20>

[Central%20Air%20Conditioner%20and%20Heat%20Pump%20Final%20Specification%20and%20Partner%20Commitments.pdf](#).

Harley, B. 2020. *EXP07:19 Load-based and Climate-Specific Testing and Rating Procedures for Heat Pumps and Air Conditioners, Interim Lab Testing and Rating Results*. NEEA Report #E20-314. <https://neea.org/resources/exp0719-load-based-and-climate-specific-testing-and-rating-procedures-for-heat-pumps-and-air-conditioners>.

ICF Canada. 2019. *Heat Pump Best Practices Installation Guide for Existing Homes*. http://www.homeperformance.ca/wp-content/uploads/2019/12/ASHP_QI_Best_Practice_Guide_20191209.pdf.

NEEA (Northwest Energy Efficiency Alliance). 2022. BetterBuiltNW HVAC Sizing Tool. <https://betterbuiltinw.com/hvac-sizing-tool>.

NEEP (Northeast Energy Efficiency Partnerships). 2017a. *Assessment of Residential and Small Commercial Air-Source Heat pump (ASHP) Installation Practices in Cold-Climates*. <https://neep.org/sites/default/files/AssessmentofResandSmallCommASHPInstallationPracticesinCold-Climates.pdf>.

NEEP (Northeast Energy Efficiency Partnerships). 2017b. *Guide To Installing Air-Source Heat Pumps in Cold Climates*. https://neep.org/sites/default/files/resources/InstallingASHPinCold_edits.pdf.

NEEP (Northeast Energy Efficiency Partnerships). 2017c. *Guide to Sizing & Selecting Air-Source Heat Pumps in Cold Climates*. https://neep.org/sites/default/files/resources/ASHP%20Sizing%20%26%20Selecting%20-%208x11_edits.pdf

NEEP (Northeast Energy Efficiency Partnerships). 2021a. *2021-2022 Database & Manufacturer Listing Process*. <https://neep.org/heating-electrification/ccashp-specification-product-list#Pricing%20Schedule>.

NEEP (Northeast Energy Efficiency Partnerships). 2021b. *Cold Climate Air-Source Heat Pump Specification (Version 3.1)*. https://neep.org/sites/default/files/media-files/cold_climate_air-source_heat_pump_specification-version_3.1_update_.pdf.

NEEP (Northeast Energy Efficiency Partnerships). 2022a. *ASHP Initiative Subscription Details*. <https://neep.org/heating-electrification/ashp-initiative-subscription-details>.

NEEP (Northeast Energy Efficiency Partnerships). 2022b. *CCASHP Specification & Product List*. <https://neep.org/heating-electrification/ccashp-specification-product-list>.

New York State. 2019. *Climate Leadership and Community Protection Act*. <https://climate.ny.gov/Our-Climate-Act>.

NYSERDA (New York State Energy Research and Development Authority). 2020. *Clean Energy Training Resources*. <https://www.nyserda.ny.gov/All-Programs/Clean-Energy-Workforce-Development/Clean-Energy-Training-Resources>.

NYSERDA (New York State Energy Research and Development Authority). 2022. *Carbon Neutral Buildings*. <https://www.nyserda.ny.gov/all-programs/carbon-neutral-buildings>.

Winkler, J. 2011. *Laboratory Test Report for Fujitsu 12RLS and Mitsubishi FE12NA Mini-Split Heat Pumps*. <https://www.nrel.gov/docs/fy11osti/52175.pdf>.