Not Your Parents' Heat Pump: Training and Tools to Size Heat Pumps for Heating

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ABSTRACT

Historically, heat pumps have been sized to the cooling load rather than the heating load of a space, therefore relying on inefficient auxiliary electric resistance or fossil fuel during the heating season and making them largely unsuitable for cold climates. With the growing need for efficient electrification and the widespread availability of variable speed heat pumps, HVAC contractors need to know how to size heat pumps to maximize their use in cooler climates. Pacific Northwest National Laboratory (PNNL), supported by the U.S. Department of Energy (DOE), has developed open-source training modules with input from industry experts on how to size heat pumps for heating. Approaches include sizing the heat pump to meet 100% of the heating load, sizing to meet most the heating load (to balance first cost and operating cost/decarbonization performance), and sizing for cooling but using a variable speed system to maximize heat pump use for efficient electric heating. The scope of these training modules pushes beyond the current guidance from traditional training organizations, preparing residential contractors for their crucial role in decarbonizing the residential space through widespread quality heat pump installation.

Introduction

Historical best practice for sizing heat pumps was to right-size the heat pump for the cooling load (ACCA, 2014). This practice minimized short-cycling and allowed effective dehumidification in cooling mode. Because the heating capacity of a traditional single-stage heat pump is directly related to its cooling capacity, right-sizing a unit for cooling meant in most instances it was undersized for heating. This required these heat pumps to rely on auxiliary heat in colder temperatures. Because these units were mostly installed in warmer climates, however, use of auxiliary heating was not excessive, and the approach was practical and reliable.

Variable-capacity compressors and other technologies allow modern heat pumps to be right-sized for heating while still minimizing short-cycling and allowing dehumidification when cooling. Newer technologies and refrigerants also allow heat pumps to maintain high heating capacities at very cold temperatures, allowing them to drastically expand their regional applicability to virtually any location in the United States. New training materials are needed in the industry to address the new abilities and applications of these "cold climate air-source heat pumps" (ccASHP). Widespread and rapid distribution of this training material into colder regions is vital.

Open-Source Training Materials

Training resources to meet this need have been developed by Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy's (DOE) Building Science Education Solution Center (BSESC). The training material was developed from existing DOE resources, national laboratory staff expertise, and donated curricula from various partner organizations. The material includes training modules such as Cold Climate Heat Pump Sizing, Introduction to Heat Pumps, Smart Diagnostic Tools for HVAC, and Thermostats for Heat Pumps and Dual-Fuel Heat Pumps.

For many workforce training instructors, updating or revising curricula is a daunting task. It requires researching new content, fitting the content into the course schedule, finding proper homework, and creating exams. Many instructors simply don't have the budget or time to add these tasks to their busy schedules.

The BSESC includes a library of educational resources and training modules that are intended for direct insertion into existing training programs, greatly reducing an instructor's barrier to curricula updates. The free, open-source modules are designed such that an instructor could pull any of the materials and augment their existing courses.

In 2022 and 2023, PNNL training development efforts have focused on upskilling the HVAC, electrical, and plumbing workforce toward electrification. In parallel with the development of heat pump sizing and installation training modules, PNNL curated open-source instructor resources covering other key decarbonization topics such as heat pump water heater design and installation, electrical panel assessment, and business development using heat pumps and heat pump water heaters. All of these resources are hosted on the BSESC.

Curricula Adoption by Existing Training Programs

After developing and curating open-source curricula, the focus turned toward adoption of these materials by training providers. PNNL began working with several national training certification organizations to encourage inclusion of all heat pump technologies. The desire to upskill current HVAC workforce also required the development of course extensions and packaging them such that seasoned HVAC professionals would be motivated to return to a classroom and polish their skills. The effort to upskill existing workforce is still unfolding today but materials and pathways have been developed to promote the business-case for heat pump education and incorporating high performance heat pumps into HVAC contractors' standard offerings for customers.

Energy Skilled Recognition Program

In 2023, DOE launched the Contractor Training Grants program (DOE 2023), which assigns $150,000,000 to upskilling contractors in key fields, including HVAC, plumbing, electrical, and home performance contractors. This program requires states to partner with training organizations that meet DOE requirements on training, which has been formalized as the DOE Energy Skilled recognition program (Energy Skilled 2024). Energy Skilled-recognized credentials are certifications or training programs that meet DOE goals for decarbonization. This recognition allows training programs to leverage federal incentives more readily, and also distinguishes them as leading the curve when it comes to decarbonization and newer technologies.

A training program looking to meet Energy Skilled recognition criteria can use the new open-source training material curated on the BSESC to quickly update their curriculum. The critical training topics for updating existing heat pump curricula are:

- Basics of variable speed heat pumps and ccASHPs in particular
- Sizing approaches, including sizing for heating
- Tools for heat pump sizing and selection

The following sections summarize key content in the new, open-source training modules. This new content equips HVAC contractors to install variable capacity heat pumps that can heat in colder temperatures, reduce reliance on fossil fuel heating systems, and provide consumers with the latest technology.

Understanding Cold Climate Heat Pumps

The term "cold climate air-source heat pumps" (ccASHP) has been adopted to differentiate the new class of cold-weather-capable variable-speed heat pumps from traditional single-stage heat pumps. The distinction indicates equipment that incorporates specific advancements in technology as well as expectations of demonstrated capacity and efficiency performance in cold weather. The term, along with associated specifications, has also been adopted to address perceived failures of the current metrics used for traditional heat pumps in the U.S. market.

A key feature of ccASHPs is their ability to provide near-full capacity heating at low ambient temperatures. While the capacity of traditional heat pumps drops sharply as ambient temperatures get lower, ccASHPs have a much flatter capacity curve across a wide range of temperatures. Data from multiple manufacturers as listed in the Northeast Energy Efficiency Partnerships (NEEP) Cold Climate Air-Source Heat Pump List show that it is common for these units to provide 80% or more of their AHRI-rated capacity (47°F) at an ambient temperature of 5°F (NEEP 2024). Some models can maintain nearly 100% capacity well below 0°F (NEEP 2024).

Definitions of Cold Climate Heat Pumps

Several definitions exist to classify equipment as a ccASHP, including those by NEEP, DOE, ENERGY STAR, Northwest Energy Efficiency Alliance (NEEA), and the Consortium for Energy Efficiency (CEE). All these organizations' ccASHP definitions include minimum ratings for Seasonal Energy Efficiency Ratio 2 (SEER2), Heating Season Performance Factor 2 (HSPF2), and coefficient of performance (COP) at 5°F, though some certifications set higher minimums than others. These minimum ratings are slightly higher for ductless equipment than centrally ducted HPs. The lowest minimum ratings noted in this paper are from the NEEP ccASHP Specification v4.0:

- HSPF2 ≥ 7.7
- SEER2 ≥ 14.3
- COP at 5°F ≥ 1.75

Several definitions also include requirements on capacity retention at low temperatures. Key characteristics and differences of various definitions are highlighted below.

- NEEP: see minimums above
- ENERGY STAR: 70% capacity retention to 5°F
- CEE: 70% capacity retention to 5°F and demand response requirements (Advanced Tier Specification)
- NEEA: 80% capacity retention to 5°F (ductless heat pumps)
- DOE Cold Climate Heat Pump Challenge: 100% capacity retention to 5°F, low global warming potential (GWP) refrigerant, COP at 5°F ≥ 2.1 or 2.4 (depending on equipment size)

Cold Climate Heat Pump Performance

In addition to having high heating capacities and efficiencies at low ambient temperatures, ccASHPs can typically vary their output significantly at a given temperature. Each model has a minimum and a maximum capacity at any given temperature. These capacities can be obtained as tabular data and can be plotted on a graph showing heating capacity on the y-axis and ambient temperature on the x-axis (Figure 1). Adding the heating load characteristics of a specific home to the plot can be vital to proper equipment selection, as discussed below.

Sizing and selecting a heat pump with a focus on heating relies heavily on proper heating and cooling load calculations (BTU/hr). Air Conditioning Contractors of America (ACCA) Manual J procedures offer a reliable method to obtain these loads. The load calculation results not only provide peak loads at heating and cooling design temperatures, but also allow a designer to estimate a heating load line for the home or a specific space. A heating load line approximates a space's heating needs over a full range of outdoor temperatures. This line is plotted on a capacity versus temperature graph as shown in Figure 1. As heating load and heating capacity have the same units (BTU/hr), they can utilize the same y-axis. Two points on the graph are needed to create the heating load line: the design heating load at the design outdoor temperature, and the point of zero heating load. The design heating load is obtained from Manual J calculations. The point of zero heating load is the outdoor temperature at which the home has no need for heat; heat losses to the outside are balanced by internal and solar heat gains. This point is often estimated to be about 60°F, though this is dependent on the specific home's level of insulation, air sealing, and other factors. The heating load line is created by simply plotting a straight line between these two points.

Note that the heating load line is only a characteristic of the home or space; it is not affected by the heating and cooling equipment. Note also that it is a simplification of the actual heating load, which can vary at any given outdoor temperature based on variables such as solar gains, internal gains, and infiltration rates. Nonetheless, by comparing the heating load line to the performance data for the heat pump, a designer can gain vital insight into how appropriate a particular heat pump model is for a particular home.

Consider Figure 1 along with the annotations following it. The plot was generated through NEEP's Cold Climate Air-Source Heat Pump List, then enhanced slightly by PNNL to highlight key information. The information gained through this type of plot is of great value in sizing and selecting equipment for a specific home.

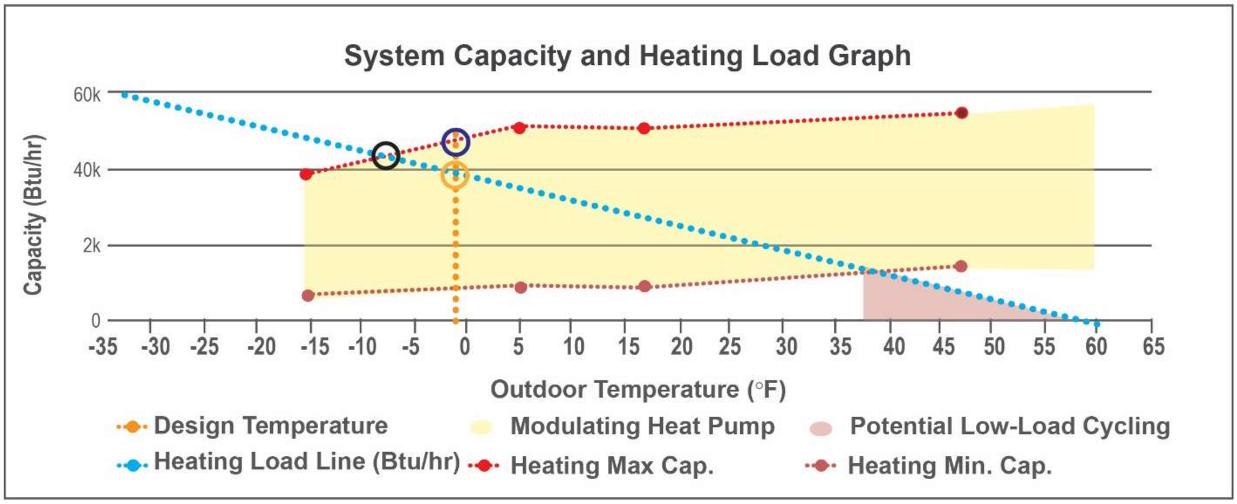

Figure 1. Heat pump minimum and maximum heating capacities overlaid with a home's heating load line for a range of outdoor dry bulb temperatures. This plot represents an example of a specific heat pump model and a specific home. *Source*: NEEP 2024 (Modified by PNNL).

Design Temperature. The vertical orange line indicates the design outdoor temperature for the location of the house. This line depends only on the weather data for that location; it is not affected by the characteristics of the house or the characteristics of the heat pump.

Heating Max Cap. The mostly horizontal red line in the upper area of the plot indicates the maximum heating capacity of the heat pump at different outdoor air temperatures. This is obtained from the equipment manufacturer's extended performance tables.

Heating Min Cap. The mostly horizontal brown-red line in the lower area of the plot indicates the minimum heating capacity of the heat pump at different temperatures. This is obtained from the equipment manufacturer's extended performance tables.

Modulating Heat Pump. The yellow area between the maximum and minimum heating capacity lines shows the modulating zone of the heat pump. The heat pump can perfectly match the heating needs of the home by continual operation when conditions are within this zone.

Potential Low-Load Cycling. The red triangular area to the lower right of the plot indicates the temperatures at which the heat pump will cycle on and off to meet the home's heating needs. In this zone, the heat pump cannot modulate low enough to run continuously without overheating the space.

Heating Load Line. The sloping blue line is the heating load line for the house. This line indicates how much demand the heat pump will have to meet at various temperatures. It is generated based on the characteristics of the home; it is not affected by the characteristics of the heat pump.

Design Heating Load. Highlighted on the graph by an orange circle, the design heating load is found at the intersection of the heating load line and the design temperature line. The design heating load is the heating load of the home at design conditions. This is the design heating load resulting from Manual J load calculations.

Heat Pump Capacity at Design Conditions. The capacity of the heat pump at the design outdoor air temperature is highlighted by the uppermost dark blue circle. It is found at the intersection of the maximum heating capacity line and the design temperature line. This point can be compared to the design heating load of the home to understand whether the heat pump will have sufficient capacity to meet 100% of the home's heating needs.

Balance Point Temperature. The balance point temperature is highlighted by the black circle toward the left of the plot. It is found at the intersection of the heating load line and the maximum heating capacity line. When outdoor temperatures are below the balance point, the heat pump cannot fully meet the home's heating needs without a backup heat source. It is valuable to understand the balance point temperature when intentionally sizing a heat pump to only meet a portion of the home's needs, such as with dual-fuel systems.

Sizing Approaches

Heat pumps have historically been sized based on cooling needs and performance. This ensured efficient operation in cooling and allowed proper dehumidification but resulted in undersized heating capacities for most locations. Though technological advances have changed the performance characteristics of heat pumps and allowed them to spread to colder climates, sizing methods used by many contractors continue to focus on cooling performance. Organizations operating in colder climates have worked to develop guidance focusing on heating. In 2024 ACCA released the 3rd Edition of Manual S for Residential Equipment Selection. Heat pump sizing tolerances in the 3rd Edition, expanded for variable capacity heat pumps, allow for heating-focused sizing (ACCA 2024). Prior editions focused on sizing for cooling.

An important component of the sizing process involves understanding consumer motivations for installing new equipment. This requires a conversation with the consumer as well as an understanding of the existing equipment. Learning why the consumer is interested in a heat pump rather than another technology may help determine the best sizing approach. A conversation can also reveal the consumer's expectations or appetite around efficiency, emissions, first cost, and operating costs. Purposes that a heat pump may serve for a consumer include:

- To primarily provide cooling, but to also provide heat in mild weather.
- To primarily provide cooling, but to provide as much heating as reasonable.
- To primarily provide heating, but a backup system or significant auxiliary heating source is available.
- To primarily provide heating with no backup.

Reasons for choosing a heat pump over conventional furnaces, boilers, or other forms of heating equipment can vary. For many early adopters, benefits related to climate change mitigation may be top of mind. Others may be more interested in lowering utility bills or improving comfort. These motivations are important to consider during the sizing and selection process as well.

Based on the homeowner’s goals, one of the four following approaches to sizing and selecting equipment can be used (NRCAN 2020). Table 1 summarizes these four sizing approaches.

Approach 1: size to the design cooling load. This approach is appropriate if the homeowner is primarily interested in the heat pump for air-conditioning. The unit may be used to provide some heat in mild weather but is not the primary heating system. A ccASHP is not necessary. A standard variable-capacity unit can be used, or even a traditional single-stage unit.

Approach 2: size for cooling but maximize heating potential. If the primary purpose of the heat pump is to provide cooling, but the homeowner would like to get as much heating out of the unit as reasonable, a variable capacity or multi-stage unit should be sized and selected such that the mid- or low-end of its cooling capacity range will meet the design cooling load. The unit may technically be oversized for cooling, but the modulating or staged capacity will mitigate oversizing issues. This approach allows a larger unit with more heating capacity to be selected.

Approach 3: size to meet most of the heating load. This approach is appropriate if the primary purpose of the heat pump is to provide heat, but a backup heating system or significant auxiliary heat is available, or the system is a dual fuel system. In this case the heat pump is designed to provide most, but not all, of the heat. A ccASHP is appropriate. The heat pump would be deliberately undersized for heating. This could be done by targeting a certain percentage of the design heating load (for example 80%). Another approach is to target a specific balance point temperature (potentially based on a cost-optimized fuel-switching strategy). A unit with a minimum cooling capacity that is lower than or equal to the design cooling load should be selected.

Approach 4: size to meet all of the heating load. This approach is used when the heat pump is intended to provide all or nearly all the heat. The unit is sized to meet the design heating load at the location’s design heating temperature. Incorporating a safety factor to slightly oversize the unit for heating is acceptable, especially if no backup heat source is available. A ccASHP should be used. The specified unit’s minimum cooling capacity should be lower than or equal to the design cooling load.

Table 1. Summary of heat pump sizing approaches for cold climates

	Cold climate sizing approach	Heating capacity	Cooling capacity	Heat pump type
1	Size for cooling	Significantly undersized	Right-sized	Single-stage will work
2	Size for cooling, but maximize available heating	Undersized	Oversized at max capacity, but right-sized within capacity range	Multi-stage or variable capacity, possibly ccASHP
3	Size to meet most of the heating load	Somewhat undersized	Oversized at max capacity. Try to right-size within capacity range	ccASHP with wide enough turn-down ratio for proper cooling
4	Size to meet all the heating load	Right-sized	Oversized at max capacity. Try to right-size within capacity range	ccASHP with wide enough turn-down ratio for proper cooling

The sizing approach used will shift the balance point temperature of the system. Approach 1 will have the warmest balance point temperature, and Approach 4 will have the coldest. The balance point temperature dictates when the home can take full advantage of the heat pump and when it must use an alternate heating source. Approaches 1, 2, and 3 will generally require an auxiliary source of heat during the colder parts of the winter.

Figure 2 illustrates a hypothetical example of how many hours per year a heat pump could meet most or all of a home's heating load using each sizing approach for a home located in Minneapolis, MN. In these examples, Approach 1 has a balance point temperature of 40°F, Approach 2 has 30°F, Approach 3 has 0°F, and Approach 4 has -15°F. Below these temperatures, the heat pump could meet some, but not all, of the home's heating load. Note that the balance point temperature for Approach 4 is colder than the heating design temperature for Minneapolis, which ensures the heat pump will meet the full heating needs of the home without relying on auxiliary heat. Design temperature data were obtained from the ASHRAE Handbook of Fundamentals (ASHRAE 2021).

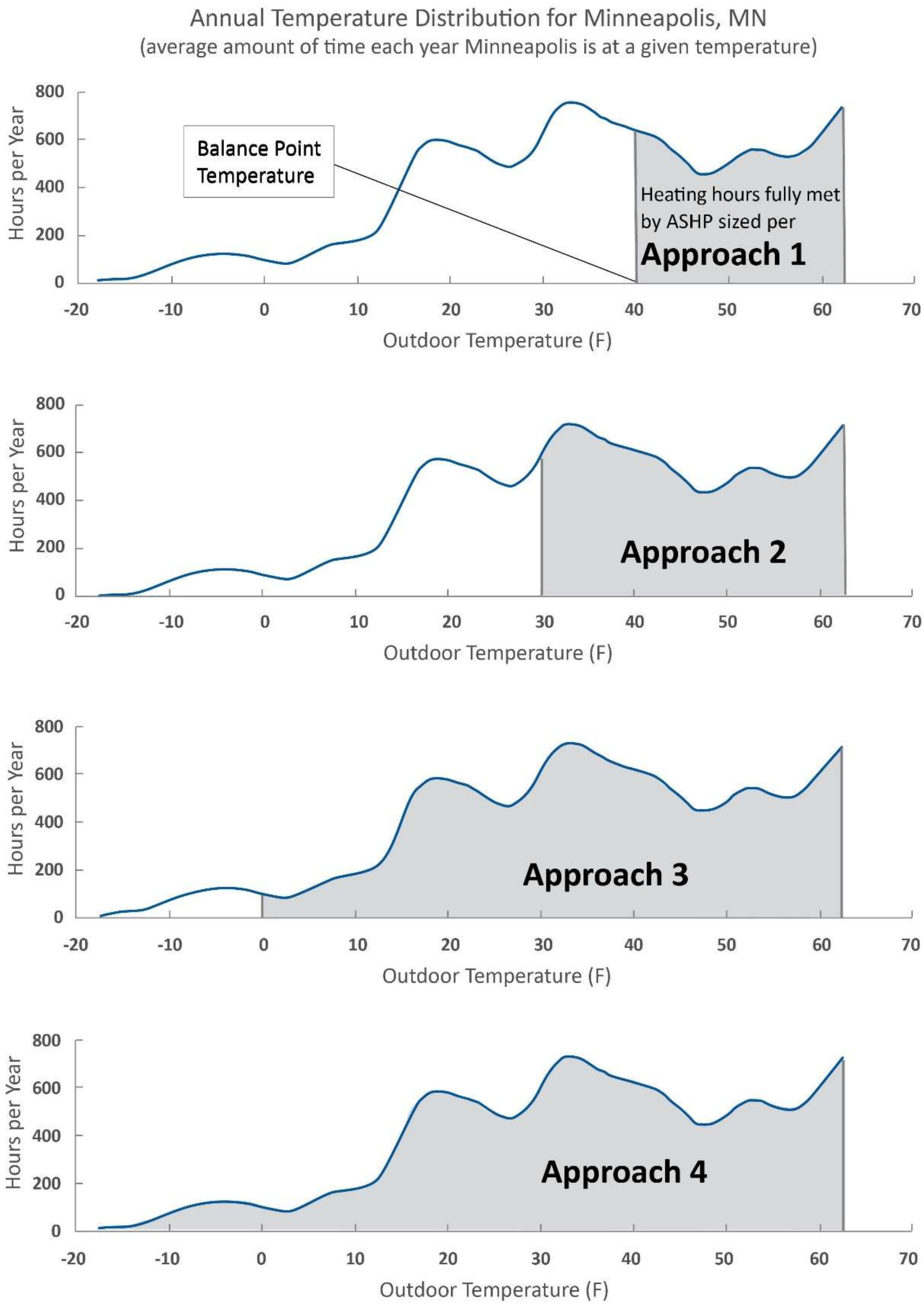

Figure 2. Annual heating hours fully met by a heat pump sized using each of the 4 approaches for a hypothetical home in Minneapolis, MN. Outdoor temperature distribution was generated from TMY3 Data (Wilcox 2008).

While heating hours per year is illustrative in understanding the effect of each sizing approach, a more useful metric is heating load-hours per year. Heating load-hours are the hours per year at a given temperature multiplied by the home's heating load at that temperature. This metric allows a better understanding of the energy consumption and equipment utilization impact of the different sizing approaches. Figure 3 illustrates the same hypothetical example presented in Figure 2, but with heating load-hours as the metric in lieu of heating hours. This visualization better represents the energy impact of sizing per Approach 3 or 4 as compared to Approach 1 or 2. The plot was generated through NEEP's Cold Climate Air-Source Heat Pump List, then enhanced by PNNL to show the effect of using each of the four sizing approaches. Note that these plots only indicate the temperatures at which the heat pump could meet all of the heating load. Below the balance point temperature for each approach, the heat pump could still meet a portion of the load.

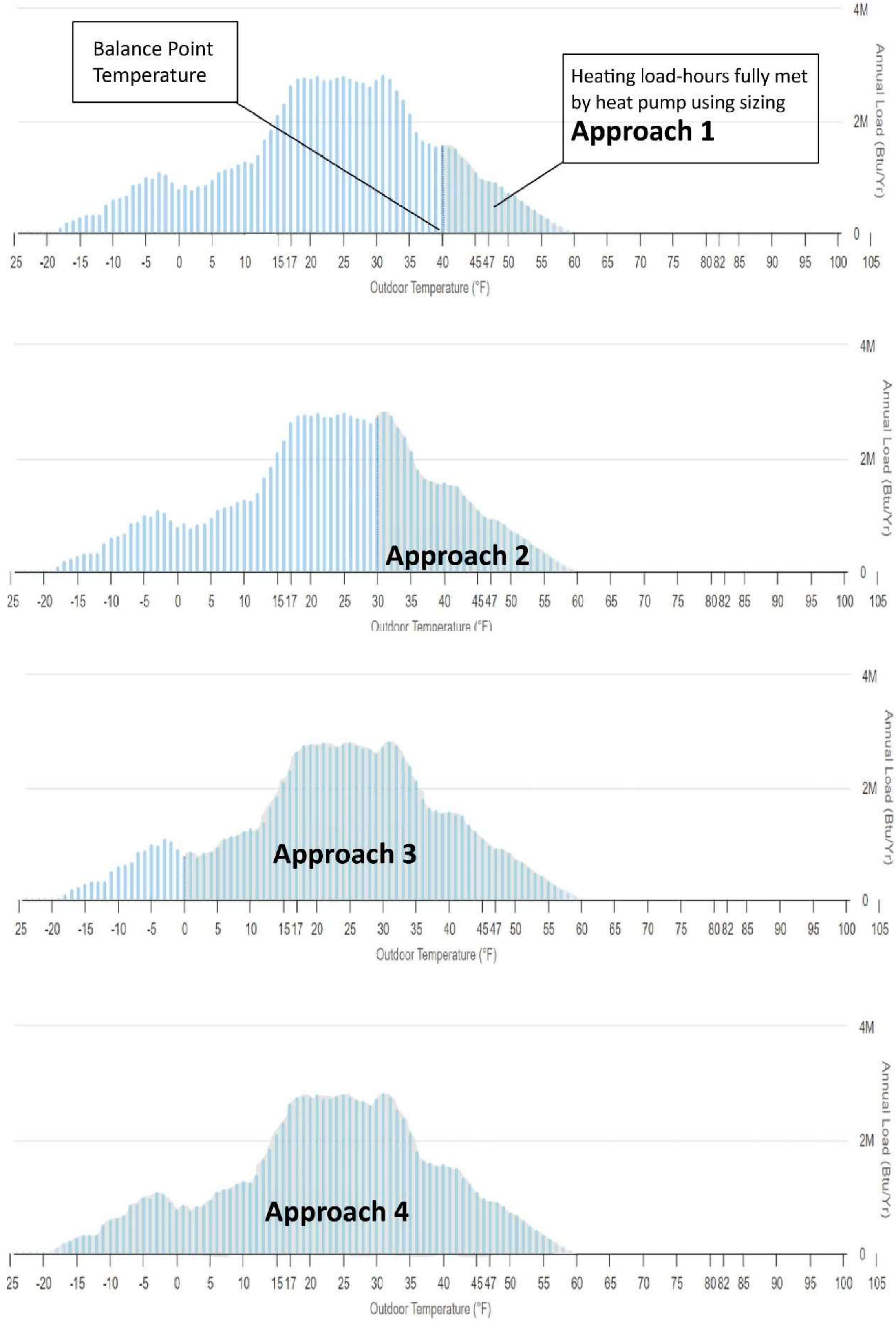

Figure 3. Annual heating load-hours fully met by a heat pump sized using each of the 4 approaches for a hypothetical home in Minneapolis, MN. *Source*: NEEP 2024, modified by PNNL.

Tools for Heat Pump Sizing and Selection

Contractors frequently make use of tools to aid in the process of sizing and selecting heat pumps. Many equipment manufacturers create tools that their licensed contractors can use. Several free tools have also been developed by non-profits or governmental bodies that are available for the public. The NEEP Cold Climate Air-Source Heat Pump List includes an "Advanced Search – Sizing for Heating and Cooling" functionality that adds sizing capability to its extensive database of ccASHP models. PNNL is currently developing a tool that will work synergistically with the features of the NEEP List.

Aspects of the NEEP List sizing functionality are shown in this paper in Figure 1. NEEP's sizing search collects contractor inputs such as the type and configuration of the heat pump, brand preference (if any), preference for ENERGY STAR certification, and tax credit eligibility. The tool then layers on design temperature and load information based on zip code and load calculation results input by the user.

Users can then sort through the list of products in the database that meet the criteria. Results include useful product metrics such as:

- Maximum heating capacity at heating design temperature
- Heating capacity balance point temperature
- Percentage of heating design load served
- Percentage of annual heating load served
- Percentage of annual load served in modulation range
- Minimum heating capacity threshold temperature

Users can filter and sort through these metrics to identify equipment that best meets the needs of the project. Then the detailed sizing data for each system can be viewed individually. This provides a very intuitive way to visualize the equipment performance in the house in which it will be installed. Aspects especially relevant to the sizing and design process include supplemental heating needs, cycling and modulating zones for heating and cooling, and annual load hours for heating and cooling.

The soon-to-be-released PNNL Cold Climate Heat Pump Decision Tool also makes use of the powerful sizing features of the NEEP List. It walks users through some of the key decision points in a HP design process and helps them sort through real-world equipment in the NEEP ccASHP List.

Conclusions

Cold climate heat pumps play a critical part in the decarbonization movement. This well-established technology allows home occupants to heat their homes using electricity, which is increasingly composed of renewable energy sources.

While heat pump sizing was historically based primarily on the cooling load, variable speed systems with cold climate capability now allow heat pumps to be sized to the heating load without negatively impacting cooling performance. Sizing a heat pump to handle different heating load levels allows the HVAC contractor and consumer to balance first cost, operating cost, environmental concerns, and other priorities. In many cases, sizing a heat pump to handle most of the heating load allows the system to run with high efficiency electric heating for most of a home's heating hours.

Properly applying these systems requires new approaches to sizing heat pumps. New open-source training materials presenting these approaches have been developed for the DOE's Building Science Education Solution Center. These training materials allow HVAC instructors to quickly adopt the new methodologies and teach incoming HVAC technicians and those seeking continuing education the skills needed to stay relevant as the nation moves toward electrification.

Cold climate heat pump technology, and the open-source training resources and tools to effectively implement that technology, open the doors for HVAC contractors to expand their offerings to consumers, more easily take advantage of federal incentive money, and use heat pumps to their full potential.

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