Assessment of Residential and Small Commercial Air-Source Heat pump (ASHP) Installation Practices in Cold-Climates

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Cover Photographs courtesy of Boucher Energy Systems and Fujitsu

About NEEP

NEEP was founded in 1996 as a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate energy efficiency as an essential part of demand-side solutions that enable a sustainable regional energy system. Our vision is that the region will fully embrace next generation energy efficiency as a core strategy to meet energy needs in a carbon-constrained world.

Introduction

Air-source heat pumps (ASHP) have been installed in US homes and businesses for decades, and the latest generation of ASHP technology have increased their appeal – and market share – in colder climates of the US, including the Northeast and Mid-Atlantic regions (climate zones 4 and higher). Recent advancements in variable-speed ASHPs include commercially-available systems with high capacities and efficiencies in cold climates, with potentially significant energy and environmental benefits.

While many stakeholder groups are excited about the benefits that broader adoption of ASHPs can bring to cold climate regions, including energy, cost and emission reductions, there is concern that poor practices (improper sizing, selection and/or installation) may reduce these potential benefits. Numerous studies have found significant energy penalties resulting from installation problems[1]. Poor installation practices may also reinforce lingering perceptions, based on outdated technology, that air-source heat pumps don't work well in cold climates, already a barrier to both consumer and installer confidence in ASHPs. In addition, significant over- or under-sizing of heat pumps can lead to a number of problems, including increased cycling losses at low-load conditions, lack of comfort, higher energy costs, and/or ineffective summer humidity control.

Because installers represent the "front line" for ensuring best practices are adopted, Northeast Energy Efficiency Partnerships (NEEP) partnered with the U.S. DOE to develop clear installer guidance regarding sizing, selection and installation of ASHPs that is specific to cold climates. In support of this effort NEEP undertook this initial assessment of current installer practices for "residentially-sized" systems (< 65k btu/hr) related to these issues. That assessment is captured in this report and provided a foundation from which two Guides were developed.

In this report, NEEP summarizes the results of research that included direct industry outreach (contractors, distributors, manufacturers, and efficiency program administrators), as well as secondary literature review, to gather intelligence on existing practices, guidance tools and resources, especially any that are specific to cold climates. The assessment helped NEEP and DOE to understand the need for new guidance resources, based on a combination of existing best practice resources with new recommendations and a new approach to presenting the material.

The following assessment report includes four sections highlighting current practices and guidance:

- Contractor practices for data collection prior to heat pump selection;
- Contractor practices for sizing/selecting ASHPs in cold climates;
- Contractor practices for installing ASHPs in cold climates; and
- Guidance resources related to sizing, selecting and installing ASHPs in cold climates.

Each section provides information related to current practices and concludes with a summary of observations and findings. This assessment report served to inform the development of two new Air-Source Heat Pump (ASHP) installer resources that provide practical, best practice guidance related to sizing and selecting ASHPs in cold climates and installing ASHPs in cold climates. These two guides, Guide to Sizing & Selecting ASHPs in Cold

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[1] Two examples: "Increases of energy use by 30% due to improper installation practices seem to be plausible:" Sensitivity Analysis of Installation Faults on Heat Pump Performance, Piotr A. Domanski, Hugh I. Henderson, W. Vance Payne, 2014. Incorrect charge and airflow of 5-15%: *Measured Effect of Air Flow and Refrigerant Charge on Heat Pump Performance in Heating Mode*; Erin Kruse and Larry Palmiter, Ecotope, Inc., 2006 ACEEE Summer Study on Energy Efficiency in Buildings

Climates and Guide to Installing ASHPs in Cold Climates, published in March 2017, are available for educational and reference purposes.

Contractor Practices for Data Collection

Before ASHP contractors can select an appropriate system (size, model, manufacturer, etc.) for their customers, they must gather information about the customer and the customer's situation. Here is a summary of the different kinds of information being gathered today by HVAC contractors installing ASHPs in cold climates.

Determining Intended Application

Commonly seen as the key driver of sizing and selection, contractors typically determine the intended use of the system through an initial discussion with the owner of the home or building. Common applications include whole house versus or zoned solutions; primary cooling, heating or both; "green" HVAC technology that can reduce fossil-fuel based heating; and/or or cost-saving focus.

According to NEEP's interviews, most customers are looking for a zoned system rather than a central, whole house solution. Most cold climate ASHP customers also fall into one of two categories:

- Initially interested in cooling, although they find heating amenity as "nice to have"
- Interested in a heating to reduce cost and/or carbon emissions; cooling is "nice to have"

Evaluating Existing HVAC Systems

In many cases, new ASHP systems are being installed to provide a combination of supplemental heating and/or cooling to existing systems, which remain in place to provide primary or supplemental space conditioning. There are also a substantial number of ASHP systems installed to provide all heating and cooling to the entire conditioned space, or a substantial section of the building. Information gathered about existing systems includes the type, age, and fuel of existing heating systems, for example: forced hot air (gas/electric furnace), forced hot water (hydronic baseboard), or heat pump(s) (ducted or, rarely, ductless), and the type and age of existing cooling systems, for example: central air-conditioning, room air-conditioner(s), or no existing mechanical cooling.

Determining Heating and Cooling Loads

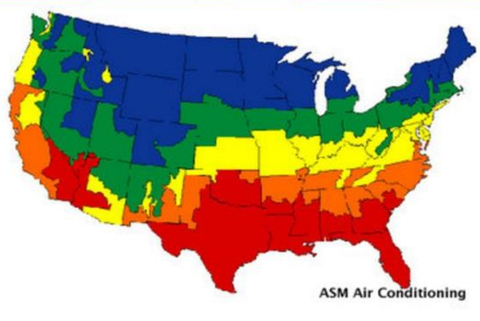
By far the most common approach installers use to determine heating and cooling loads is by simply estimating loads with simple "rule-of-thumb" methods. DOE materials cite "A commonly accepted old estimate is that an HVAC unit should provide one ton (12,000 Btu) of cooling for each 400 to 500 square feet of building area."[2] Mitsubishi's ductless heat pump web site offers a similar suggestion for roughly estimating load: 20-25 btu/h of cooling capacity/square foot (or 1 ton cooling for every 500 - 600 sq ft)[3]. Similar guidance, in the form of tables, calculators, or other descriptions, can be found on numerous web sites of mechanical contractors and supply houses[4]; some suggest slightly higher heating loads (30-40 btu/h per square foot), though for heat pumps other sources simply say to base the heating size on the estimated cooling load. Most offer a range of modest

[2] https://energy.gov/sites/prod/files/guide_to_home_heating_cooling.pdf
[3] http://mitsubishicomfortdealers.com/info/what-size-system
[4] Examples: https://asm-air.com/airconditioning/what-size-central-air-conditioner-for-my-house/ , http://www.acdirect.com/gas-heat-learning-center-furnace-sizing-calculator , https://www.furnacecompare.com/perl/estimate_heat_loss.pl

adjustments to be made based on very rough indicators of home efficiency and/or climate. (e.g. "Make allowances for such variables as typical number of occupants and any use of major appliances. As an approximation, when estimating the cooling load for bedrooms add 450 BTUs to the total for each person who

Heating Square Footage Range by Climate Zone

ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5
30 - 35 Btu's per square foot	35 - 40 Btu's per square foot	40 - 45 Btu's per square foot	45 - 50 Btu's per square foot	50 - 60 Btu's per square foot



Air Conditioning Square Footage Range by Climate Zone

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5
1.5 Tons	600 - 900 sf	600 - 950 sf	600 - 1000 sf	700 - 1050 sf	700 - 1100 sf
2 Tons	901-1200 sf	951 - 1250 sf	1001 - 1300 sf	1051 - 1350 sf	1101 - 1400 sf
2.5 Tons	1201 - 1500 sf	1251 - 1550 sf	1301 - 1600 sf	1351 - 1600 sf	1401 - 1650 sf
3 Tons	1501 - 1800 sf	1501 - 1850 sf	1601 - 1900 sf	1601 - 2000 sf	1651 - 2100 sf
3.5 Tons	1801 - 2100 sf	1851 - 2150 sf	1901 - 2200 sf	2001 - 2250 sf	2101 - 2300 sf
4 Tons	2101 - 2400 sf	2151 - 2500 sf	2201 - 2600 sf	2251 - 2700 sf	2301 - 2700 sf
5 Tons	2401 - 3000 sf	2501 - 3100 sf	2601 - 3200 sf	2751 - 3300 sf	2701 - 3300 sf

Figure 1: Examples of Simplified Sizing Guidance

will normally occupy the room. To accommodate major appliances when sizing a ductless unit for a kitchen, add 4,000 BTUs." Some suggest that for replacement systems, using the existing size is the correct approach. Many sites provide instruction on equipment sizing based on nominal tonnage, and often do not even mention manufacturer's specifications for capacities. There are some that suggest a full-scale load calculation such as ACCA Manual J to be the "best" approach, but the prevalence of simplified methods on web sites as well as HVAC trade chat rooms and bulletin boards supports what many suppliers and dealers have said for years—that simplified rules-of-thumb are the norm.

By contrast, the "industry standard" load calculation methods such as ACCA Manual J are widely cited, but in practice use of detailed calculations is the great exception. Manual J uses information about a building's design, orientation, insulation, windows, air leakage and climate to calculate heating and cooling load estimates for small residential structures. ACCA approved load calculation/Manual J software is available (e.g. Adtech, Wrightsoft); software tools to simplify the process and generally range from $500-$1000 per license. In addition to a load estimate, equipment selection using Manual S to match the loads to equipment specifications is then required to complete the process.

In interviews with contractors and suppliers, common perceptions regarding Manual J include the following:

- Most contractors complain that Manual J takes too much time (1-3 hours) and that simpler proxies such as rules of thumb, existing templates, or "speed sheets" come very close in a fraction of the time.
- Some contractors refer to Manual J as an "opinion" because there are many places to apply judgement during the process. This can lead to a self-fulfilling prophecy in which a contractor uses Manual J several times, tweaking the inputs until they get a result they feel is reasonable (which means it is close to their favorite rule-of-thumb). At that point, the contractor decides that the detailed procedure is not worth the time, and stays with their favorite method.
- Customers want correctly sized equipment, but don't always want to pay for the time to "do it right", and may not understand the drawbacks of oversizing. To offer a competitive price, contractors feel

pushed to expedite equipment selection, particularly in retrofit situations that are often essentially sales calls leading to a fixed price proposal. Some contractors express concern that if they do put in the time, competing bidders will use the results of their work to offer similar equipment at a lower price simply because they won't have to repeat the calculations.

- Many contractors would prefer to move to a simplified "short form" calculation, suggesting that answering 5-10 questions (rather than 2-3, or 20-40) could provide enough information to determine a reasonably accurate load. They feel that this approach may be reasonable, especially for applications where whole-house cooling and heating is not an objective.
- Some studies have shown that following Manual J carefully can still result in overestimating loads by up to 40%.[5] Manual J itself claims to be conservative: "Research studies and … experience…indicate that aggressive use of **Manual J** procedures provide an adequate factor of safety,"[6] where "aggressive" is defined as "taking full advantage of legitimate opportunities to minimize the size of the estimated loads" by taking "full credit for efficient construction features," accounting for interior shading, and avoiding arbitrary safety factors or manipulation of outdoor design temperatures.
- Infiltration has a significant impact on loads; but very few contractors use a blower door to test air leakage during equipment selection. By necessity, air leakage estimates in Manual J are highly conservative when no leakage test has been conducted.
- There are concerns that Manual J is not necessarily good for sizing mini-splits since it makes assumptions about load profiles - that may lead to significant oversizing for some zoned applications.
- ACCA's own promotional materials (for the $59 guide *Understanding Manual J*) state that the residential load calculation itself is "a complicated procedure that can be difficult to understand."

Determining Design Conditions

Some contractors identify design temperatures for the given location of the installation. A location's winter design temperature is the outdoor temperature above which a location stays for 99% (or 97.5%) of all the hours in the year, based on a "standard" statistical weather profile. Conversely, the summer design temperature is the outdoor temperature above which a location stays for only 1% (or 2.5%) of the hours in a year based on the same weather data. Design temperatures for many locations around the world can be found in Chapter 24 of *ASHRAE Fundamentals* as well as in Manual J. Design temperatures for U.S. locations are also posted online by the International Code Council. The range of design temperatures in a typical contractor's territory is usually small, so they often rely on one temperature for all locations. However, designers often push the design temperatures to farther extremes in the belief that the statistically-derived design temperatures "can't be right". For cooling loads, there may also be concern that climate change is driving design temperatures higher,

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[5] Comparison of Calculated and Measured Air Conditioning Design Loads For Alternative Glazing Options in Production Homes in California found Manual J 7th and 8th editions to be fairly close to actual loads with two glazing types in CA, though one application of the 8th edition led to loads 17-24% too high; ACCA's Manual "J" Residential Load Calculations Comments by Residential Products Division of Trane & American Standard compared 7th and 8th edition cooling loads in 3 hot/humid homes and found that the 8th ed. led to cooling loads 38% higher than the 7th ed., similarly large compared with existing equipment in the homes; Two-Stage High Efficiency Air Conditioners: Laboratory Ratings vs. Residential Installation Performance found that total cooling loads calculated by Manual J, 7th Edition were 42% above actual loads for five homes in NY and NJ.

[6] ACCA *Residential Load Calculation, 8th Edition,* Hank Rutowski, PE

though for both heating and cooling design temperatures contractors almost always push towards more–not less–extreme outdoor design temperatures.

Design cooling loads don't vary nearly as much by climate as design heating loads. Indoor-outdoor temperature difference is indeed the primary driver for heating loads at design conditions, but in most climates the design temperature difference is much larger for heating than for cooling. In addition, solar and internal gains are a much larger driver for cooling than the indoor-outdoor temperature difference. Orientation often has a bigger effect on total cooling loads than climate. For example: the difference in cooling load for the same house in Worcester, MA and Dallas, TX is between 22 and 28%, even though the design temperature difference is more than 2 ½ times larger in Dallas (98°F – 75°F = 23°F) than Worcester (84°F – 75°F = 9°F). The same house cooling loads vary by 31-36% in these climates depending on orientation (most glazing facing west versus most facing north).[7] The reality is that for cooling loads, a few degrees change in outdoor design temperature does not affect the result nearly as much as many other assumptions about the house performance.

Determining Energy Costs

Most installers have a basic idea of energy costs from personal experience and from living and working in a given geographic area. Most installers avoid offering operating cost estimates; they prefer to avoid making estimates that consumers will perceive as a promise. When they are offered at all, they are based on AHRI rated equipment efficiencies which can differ significantly from expected annual performance, depending on climate. The most likely source, when they are offered, is likely to be manufacturer's web sites that provide simplified tools, often for the purpose of selling efficiency upgrades. For example, the web site of one major HVAC manufacturer[8] estimates cost savings (for cooling only). Their savings "model" is based solely on state or province, and electric rate; examples of the tool's assumptions of "average" kWh for cooling range from 50% higher than national RECS data (national average), to 71% higher in Massachusetts, to 115% higher in Texas). In Vermont, the cooling assumptions were somewhat lower than RECS data indicates. Another manufacturer claims to have an "energy calculator"[9] that asks for address, home size, age, number of windows, and existing system type; but the recommendations provided are only for specific "good-better-best" product lines—the same ones, in fact, whether the home is located in Vermont or Texas—and it provides no information about energy or savings.

Evaluating Proposed ASHP Equipment

Installers typically use some form of manufacturer's performance data to match heat pump product(s) to the specific application. Table 2 summarizes the available information that characterizes ASHP performance.

Table 1: Equipment Performance Information

Equipment Performance Information	Source of Information
Heating Season Performance Factor (HSPF)	Energy Guide label, AHRI, design and technical manuals
Seasonal Energy Efficiency Rating (SEER)	Energy Guide label, AHRI, design and technical manuals
Cooling Capacity (Across range of temperatures)	Cooling capacity tables in design and technical manuals

[7] Example load calculations developed by Bruce Harley for home energy rater trainings, using Manual J-compliant software (unpublished).
[8] http://www.lennox.com/buyers-guide/tools/energy-savings-calculator
[9] http://www.goodmanmfg.com/resources/energy-calculator

Heating Capacity (Across range of temperatures)	Heating capacity tables in design and technical manuals
Heating Capacity ("Rated" at 47 F)	AHRI, manufacturer's listing
Heating Capacity ("Rated" at 17 F)	AHRI, manufacturer's listing
Heating Capacity (@ 5F)	Heating capacity tables (in some instances), NEEP's Cold Climate ASHP Specification Tables
Cooling Capacity (@ 95 F)	AHRI, manufacturer's listing, "nameplate" nominal value
Part load efficiencies (COP and EER)	Design and technical manuals (in some instances), NEEP's Cold Climate ASHP Specification Tables
Over-rating of multi-zone equipment (for peak load diversity)	Design and technical manuals

Findings and Observations: ASHP Contractor Data Collection

1. Formal/detailed load calculations are extremely rare.
2. There is an inherent conflict between the cost of the design process (which for residential retrofit is embedded in the sales process) and the need for accuracy of load estimates.
3. The most common approach to sizing of ASHPs is cooling load. Heating loads are usually only calculated in applications where the heat pump is being relied on to deliver full heating load, which is less common (but increasing).
4. Determination of shell efficiency is very rare; many installers overestimate building leakage as well as building heat loss and gain.
5. Load calculation software tools offer significant opportunity to ease the burden of load calculations for installers, but detailed calculations still take substantial time.
6. Installers utilize only a limited subset of potential information, regarding both the building side and equipment, to inform the system sizing/selection process.
7. Frequently, rules of thumb and equipment nominal size (based on AHRI rating in tons) are used to select equipment. This has relatively low risk for comfort complaints, especially for cooling; but it may lead to significant mis-sizing. This is especially true in cold climates, where actual equipment capacity at design conditions can vary much more from AHRI nominal capacity (though in a counter-balancing direction). These specifications are even more critical to selecting equipment for applications that depend on the heat pump as the sole heating source for all or part of a home.
8. A significant theme addressed by interviewees is the importance of assessing the intended purpose of the heat pump –the application – before deciding on a sizing approach. To correctly address the sizing and selection process across a range of heat pump types, the application question must be answered first, so that the appropriate sizing and selection approach may be followed. Based on the collection of interviews and in-person group discussions, stakeholders generally agreed that the various applications can be divided into the following broad categories:
    - Heating (or heating and cooling) displacement: a single- or multi-zone approach to offset existing fossil-fuel systems

- Full heating system replacement: with or without the use of existing ductwork
- Isolated zone: an addition, basement remodel, or a solution for isolated comfort problem(s)

- New construction or gut rehab: generally far more energy-efficient than existing homes, and often the heat pump is the sole heating/cooling source
- Targeted cooling solution

Sizing and Selecting ASHPs

The industry "best-practice" approach to sizing is ACCA's Manual S. For residential equipment selections, Manual S takes the results of a Manual J load calculation, and applies it to the selection of equipment that will deliver the necessary heating and cooling. Manual S, geared primarily toward centrally-ducted systems, involves setting design parameters, estimating system air flow, searching for equipment, and checking latent and sensible capacity against design loads. There is a trade-off between excess sensible capacity and shortfall of latent capacity. It is a complex procedure and few contractors follow these steps. Manual S also sets limits on equipment capacity based on a percentage of the design load, and sets absolute limits on oversizing for the cooling load even for heat pumps in heating-dominated climates.

Manual S: Summary

Manual S directs, for central air conditioners and heat pumps, that:

- The selected equipment will satisfy the building's total load requirements at design conditions
- Manufacturer's product data shows that latent loads are met
- Total equipment capacity is between: - 95% and 115% of total cooling requirements (for air conditioners and heat pumps) *or* - 95% and 125% of total cooling requirements (for heat pumps in heating dominated climates).
- It allows stepping up to the next largest nominal piece of equipment, per the desired product line, that is available to satisfy both the latent and sensible requirements.

Contractor Sizing Practices

Armed with some information about the building and the intended application, installers may utilize a number of strategies to select a specific system. The basic approach that most contractors take is to use the btu per square foot rules-of-thumb, often qualified, and apply them to the house, zone and/or or room(s) to be conditioned. In most cases, they take the load estimate and simply apply it to the nominal capacity of the indoor unit (central air handler or ductless unit), without regard to the more detailed requirements in Manual S. Typically this results in over-sizing.

Efficient, cold-climate heat pumps are defined as variable-speed, and in general, variable-speed systems may mitigate some of the issues around oversizing. In particular, they may be suited to address discrepancies between differing heating and cooling design loads. Of course, variable-speed equipment cannot make up for undersizing, but for heating applications that involved secondary heating sources the risk is much reduced. At the same time, variable-speed systems are not a panacea or a substitute for good design, and although more research is needed, there is some evidence that oversizing variable-speed systems does penalize efficiency[10].

Ducted vs. Ductless Systems

Since most installations are installed as zoned solutions versus whole house, ductless systems are seen as an effective approach to zoning. However, in cases where a home has existing ducts and the consumer is seeking a

[10] Ductless Mini-Split Heat Pump Impact Evaluation, The Cadmus Group, 2016; Field Performance of Inverter-Driven Heat Pumps in Cold Climates, CARB, 2015

whole house solution, ducted ASHPs are often recommended. Following is a summary of different techniques/strategies, first for ducted ASHPs and then for ductless ASHPs:

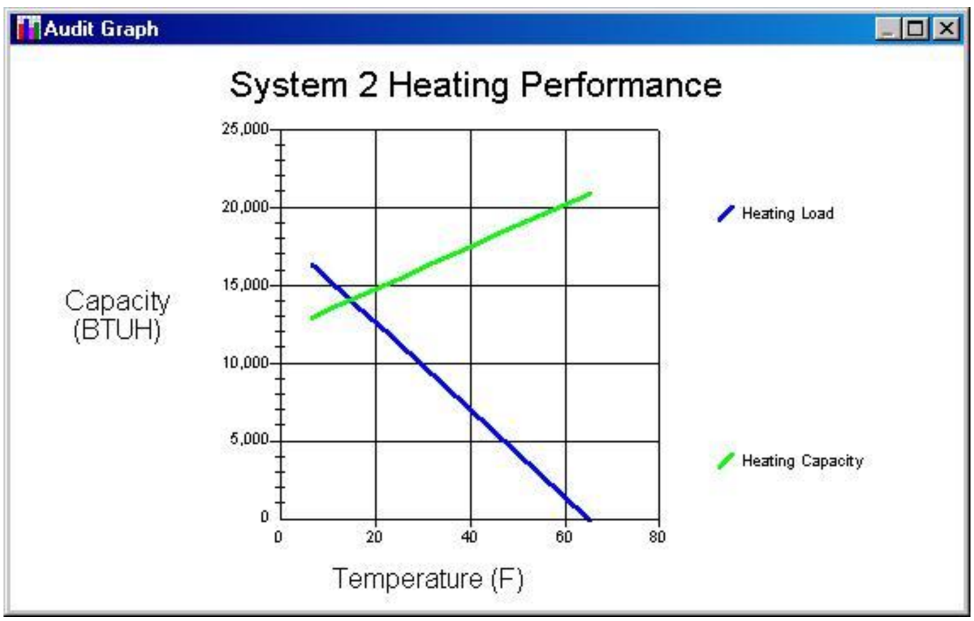
Sizing Practices for Fully-Ducted ASHPs

Ducted systems are almost always installed to provide the entire heating load of a home or major section of a home. Installers typically try to ensure that the heating load can be met by the ASHP capacity at design temperature, unless there is auxiliary heat. This is most often done for new construction; in existing homes, fossil-fuel furnaces have not typically been replaced directly with central ASHP systems using existing ductwork. If the heating system being replaced is an older central ASHP, most contractors will try to match the nominal capacity of the existing system.

Balance Point Temperature

ASHP heating capacity typically falls as outdoor temperature drops, at the same time the heating load increases as the outdoor temperature drops. These dynamic lines of system capacity and heating load can be plotted on a graph. The balance point is the temperature where these lines intersect.

Figure 2 Audit Graph from Elite Software, http://www.elitesoft.com/web/hvacr/elite_auditw_info.html



This is the temperature at which the output of the heat pump exactly matches the building load. Below this temperature, the heat pump capacity cannot satisfy the load or maintain the desired indoor temperature, so supplemental heat is necessary.

- Most contractors who utilize balance point to size systems aim for roughly between 30-35° F degrees, though lower balance points would provide higher efficiency by requiring resistance heat for fewer hours.
- “Conventional wisdom” on realistic or reasonable balance points are likely to be anecdotal, and to be based on warmer climates and conventional single-speed heat pumps.

Because many modern, variable-speed cold climate models hold heating capacity at much lower outdoor temperatures, balance point sizing (if used) should likely target lower temperatures to provide higher efficiency and less auxiliary heat use. In most cases, modern cold-climate installations will not use electric resistance as the supplemental heat, but rather an existing fossil-fuel system that remains in place after the heat pump installation.

Sizing Practices for Ductless ASHPs

Ductless systems are usually installed to provide only a portion of house/building heating and/or cooling needs, and for heating (often the more critical load in a cold climate) there is most often an existing central heating system (or resistance baseboards) left in place that is capable of fully heating the home when needed. This reduced the need to be careful about heating sizing of the ASHP.

Size to Cooling:

Most commonly, system selection is based on cooling load. The most common "size to cooling" approach involves establishing a cooling load of the applicable zone(s), typically with a rule-of-thumb or other simplified method, and matching that with a system with at least that amount of total rated cooling capacity (@95°F). There is a potential problem with this approach, besides the lack of either detailed load calculations or attention to actual equipment specifications. Even for medium or large rooms (other than main living areas), actual cooling loads are likely to be smaller than the smallest available ductless unit. If this is done for multiple separate zones in a house, the resulting system may be very substantially oversized.

Size to Heating

The most common scenarios where installers currently size specifically for heating include: a low-load home (new or gut remodel) without supplemental heating, or a heating load offset application with a customer who is looking primarily for a heating solution to reduce heating cost. In the latter case, because there is typically an existing central heat system sizing to the total heating load is much less critical, so it is rarely done, especially for the whole house.

The most common "size to heating" approach involves establishing a heating load of the applicable zone(s) at design temperature and matching that with a system with at least that amount of heating capacity at or near the design temperature.

Table 2: Common sizing methods for ducted and ductless ASHPs

Sizing method	Basic Process	Information utilized	Existing Tools/ Resources
	For Ducted ASHPs		
Dominant Load sizing (Heating in Cold Climates)	Selecting an ASHP with necessary capacities at design conditions	Heating load at design temperature of application/ location and design temperature capacity of ASHP	Rules of thumb, Manual S and manufacturer extended capacity tables
	For Ductless ASHPs		
Cooling Load Sizing	Match cooling load of applicable zone to cooling capacity of ASHP	Calculated/Estimated Cooling load, Cooling capacity of ASHP (Nameplate capacity)	Manual S, rules of thumb

Heating Load Sizing	Match heating load of applicable zone to heating capacity of ASHP	Calculated/Estimated Heating Load, Heating capacity of ASHP at design temperature	Manual S, rules of thumb
For Ducted or Ductless ASHPs			
"Economic balance point" Sizing	Temperature at which the supplemental heat is less expensive than the heat supplied by the heat pump	Fuel costs and equipment efficiencies, building heat load	Manufacturers' estimation tools

Selection of Specific ASHP Equipment

Multiple ASHPs will often satisfy the sizing requirements that the installer will determine. The last stage involves decisions related to efficiency and cost. Most manufacturers have a variety of products with varying ranges of efficiency and performance, with system costs increasing with higher efficiencies and/or better cold-weather performance. Final selection of a specific ASHP typically involves some consideration of customer budget and how important efficiency is to them. NEEP's ccASHP Specification, ENERGY STAR labeling, CEE listings, and especially local state or utility incentive programs may also drive decisions related to equipment choice.

Findings and Observations: Sizing and Selection of ASHPs

1. A large majority of ASHP systems newly installed in "cold climates" are ductless. Ducted systems are typically installed in new construction or in replacement applications with existing air distribution (ducts).
2. Designing a system that is appropriate for extreme heating and extreme cooling conditions is challenging in cold climate applications since heating load is often larger than cooling load. Variable-capacity equipment helps offset this difference. Careful equipment selection and/or the use of existing central heating equipment to offset peak heating loads can also help optimize the balance between heating and cooling needs; many contractors say that they feel more comfortable sizing heat pumps for heating knowing that there is a backup system in place.
3. Sizing practices vary and fall into two main camps, with some installers relying on heating requirement as the primary driver, while others focus on cooling loads as the driver. Even within the "primary heating" camp there are different methods, and there is no clear guidance on when it is most appropriate to use one or the other.
4. Use of heating design temperature and system capacity at design conditions is very uncommon, even when sizing for heating.
5. Oversizing- "Oversizing" for cooling is still the norm. Multiple sources also support 'oversizing' of heat pumps as being beneficial due to the advantages of inverter technologies and multi-stage compressors, as well as to reduce reliance on resistance heat (the latter based primarily on single-stage central heat pump technology). This is recognized in the current version of Manual S, allowing a larger range of oversizing for cooling in heat-dominated climates, though without full recognition of the added flexibility provided by variable-speed equipment.

6. HVAC contractors don't like to get called back because of comfort complaints, and oversizing reduces risk of comfort complaints, as well as (traditionally) masking other installation problems that may compromise delivered capacity (such as duct leaks, low air flow, etc.). Many of these problems are mitigated or eliminated with ductless split systems; at the same time, there is evidence that significant oversizing can still cause significant efficiency and dehumidification problems with variable-speed systems. When the heat pump is not the sole source of heating, the risk of undersizing is mitigated while the efficiency is likely to improve when sizing is conservative. When the heat pump is the sole source, it’s far more important to do a careful load calculation and ensure the equipment can meet the load under design conditions.
7. Another common observation is that when the ASHP will serve as primary heating with some backup heat, strategies to size, select and control the “back up” heating system are needed. In particular, integrated controls that can handle multi-stage heat-pump control when the second stage is an independent, central heating system are widely desired. The industry is beginning to respond to these needs, and one or more suitable products are likely to be available by 2017 or early 2018.
8. The industry is not receiving consistent messages related to when it makes sense to invest in a “cold climate” system. Is it wise to size for the worst-case scenario? Generally, heat pumps will be more conservatively sized than fossil-fuel heaters. Even in new construction, there may be a place for a range of back up heat options, including gas fireplace insert, electric baseboard or duct heaters. Some experts believe that the higher heating capacities coupled with lower fan speeds warrant the use of “cold-climate” units even in IECC zone 4 areas that may have heating design temperatures well above the coldest “rated” outdoor temperatures of the equipment.
9. The main Installer objective should be to provide comfort efficiently. However, a quick sale is often the bigger driver. Customers are not yet aware of, or willing to pay for, the time it takes to use sophisticated methods to properly size systems. There is also a cart-and-horse issue: to develop a firm price quote using a full Manual J / Manual S process, a contractor would have to complete those steps prior to providing a quote. That means significant time spent before a contract is signed, as well as allowing other competing contractors to benefit from the quote without spending the same time in advance. This is seen as a significant disadvantage in the sales process, especially for add-on, replacement or retrofit scenarios. For new construction or gut remodeling (the scenarios where sizing for the full load become more critical) there may be a bit more latitude to spend the time up front.
10. Many interviewees agreed that ACCA resources should be simplified/streamlined, or an alternative provided, to be better utilized by the contractor industry.

Contractor Installation Practices

Based on interviews, installation practices of ASHPs in cold climates varies broadly, from highly comprehensive approaches to those full of “short cuts,” and everything in between. Presented below is a summary of installation issues that the industry has emphasized as important to ASHP performance. Some are specific to ductless ASHPs while others are related to all ASHP system configurations. We do not have a clear indication for how prevalent each specific practice is with installers.

Table 3: Summary of Installation best practices for ASHPs in cold climates

Existing Guidance for ASHP Systems		Specific to ductless systems	Sources (See links below)
General Installation Directions	Install the heat pump in accordance with the manufacturers' instructions and relevant building codes/standards. Attend a manufacturer's training.		Green Mountain Power
Recommended Tools	Ratchet Flaring Tool, Programmable refrigerant charging scale, Torque wrench, R410A gauge and hose set, vacuum pump		Green Mountain Power
Line Set	Insulation must cover entire line set length to avoid condensation and decreased efficiency. Once insulated, protect the outdoor portion of line set with rigid line cover to avoid premature insulation damage. Add UV tape as needed to ensure entire length is UV protected. All penetrations through the shell of the home must be sealed with insulating sealant/spray foam; any insulation disturbed by installed line set must be returned to original (or better) condition (GMP, NEEA). Line set penetration should be made rodent-proof with PVC sleeve and cap drilled to the size of the refrigerant lines. Line set purged with nitrogen, pressure tested & evacuated with pump per mfg.'s instructions (Eff. ME)		Green Mountain Power, NEEA, Efficiency Maine
Refrigerant charge	Adjust refrigerant charge ONLY IF NECESSARY, many installations do not require adjustment from pre-charge levels. Gauges should not be used to verify refrigerant levels; if an adjustment is needed, use a scale when adding/removing refrigerant. Consult manufacturer's installation manual to verify refrigerant protocols as specifications change often. (GMP, NEEA)		Green Mountain Power, NEEA
Refrigerant Tubing	Create new flare fittings using appropriate R410A flaring tool and measurement gauge; DO NOT REUSE manufacturer provided tubing flares and fittings.		Green Mountain Power, NEEA

	Apply refrigerant oil to the end of each flare. Connect tubing with R410A nuts (supplied with your outdoor unit) and tighten to manufacturer's specifications (NEEA, GMP)		
Use of Drain pan heaters	Use a pan heater to avoid defrost discharge freezing inside compressor (GMP, NEEA) Only needed in situations where meltwater clearance is inadequate. If Drip cap and adequate ground clearance are provided, pan heaters may be of limited value.		Green Mountain Power, NEEA
Placement of Outdoor Unit (relative to other objects)	Unobstructed Airflow (Eff. ME) per manufacturer guidance on clearance from obstructions. Avoid stacking units above each other in any configuration—refer to manufacturer clearances for multiple units. Provide guidance to owner regarding air flow clearances to future construction intended to "hide" equipment.	**X**	Efficiency Maine
Placement of Outdoor unit (relative to building)	Whenever practically feasible, the outdoor units should be located at the rear of the building – primarily for aesthetic and for noise considerations (MA DHCD) Avoid noise-sensitive areas – interview customer to assess both degree of sensitivity and locations that might pose trouble. Avoid proximity to walkways or other areas where re-freezing defrost meltwater might cause a slip-and-fall hazard.		Massachusetts Department of Housing and Community Development
Placement of Outdoor unit (relative to drip line)	Ideally the outdoor units would not be installed directly under any drip line from the roof which would subject them to falling snow or extensive rain. Outdoor units need to be installed with shields approved by the manufacturer when there is any possibility of snow or water drip from the roof – i.e. under a roof valley or a roof without gutters (MA DHCD)		Massachusetts Department of Housing and Community Development
Placement of Outdoor unit (relative to ground)	Secure outdoor units to a pad, risers and/or the surface on which they are set using bolts and/or adhesive (MA DHCD) Ensure adequate clearance above snow line (>24 inches) (Eff. ME) – preferably using wall-mount brackets (see below)		Massachusetts Department of Housing and Community Development, Efficiency Maine
Placement of Outdoor unit (relative to windows)	Does not interfere with view through or operation of a window (Eff. ME)		Efficiency Maine

Use of wall mounting brackets	Use wall brackets when possible – noise is minimal issue for 2x6+ walls and/or walls with 1”+ rigid insulation. With 2x4 walls it’s important to ensure a non-sensitive area; the alternate is a ground-mounted stand. Setting unit on pad or short risers may lead to trouble with defrost ice build-up.	X	
When and where to use drip caps	Use drip caps when installing under drip line (MA DHCD)		Massachusetts Department of Housing and Community Development
Placement of Indoor unit	Indoor units should be installed as high on the wall as is practical to allow sufficient air flow around the units – typically approximately 8-12” below the ceiling (MA DHCD, GMP, NEEA)	X	Massachusetts Department of Housing and Community Development, Green Mountain Power, NEEA
Placement of thermostat(s)	Install a fixed, wall mounted thermostat with direct visual sight to the unit (MA DCHD) Use standard guidance for thermostat placement (i.e. interior wall, away from direct sunlight, appliances, drafts). For retrofit, main zone ASHP thermostat should be mounted adjacent to, or as near to the central system thermostat as possible. Indoor-unit sensing controls may be suitable in small, isolated rooms or zones without vaulted ceilings that have no significant thermal/comfort problems.	X	Massachusetts Department of Housing and Community Development
Condensate Drain	Slope downhill; can be routed with line set and run to a suitable termination point, away from crawl spaces and walkways (GMP, NEEA) Refer to manufacturer guidelines (some have limited vertical lift built-in).		Green Mountain Power, NEEA
Controls	Avoid “auto-comfort” controls with setbacks based on occupancy sensors—disable using installer menu settings. Avoid settings for continuous fan.	X	
Occupant education	Reinforce important points – consistent settings, avoiding auto-changeover (heat or cool as needed setting), do use auto-fan, do set ASHP heating temperature several degrees higher than central heating (or any resistance baseboard in same zone), clearing snow, other basic maintenance.	X	

Installation Guidance Resources for ccASHPs

- Massachusetts DHCD http://www.mass.gov/hed/docs/dhcd/ph/dcguidestandard/238000air.pdf
- Green Mountain Power Contractor Guide http://www.greenmountainpower.com/upload/photos/392Contractors_Guide_with_Logo_-_Web.pdf
- Efficiency Maine http://www.efficiencymaine.com/docs/Ductless-Heat-Pump-Installation-Checklist.pdf
- NEEA https://goingductless.com/assets/documents/uploads/DHP__BP-Guide_FNL.pdf
- Bonneville Power Authority (Performance tested comfort systems) https://www.bpa.gov/EE/Sectors/Residential/Documents/ASHP_Specifications_2013.pdf
- ACCA Standard 5 (HVAC Quality Installation Specification); https://www.energystar.gov/ia/home_improvement/home_contractors/qispec.pdf?baad-86f0
- NEEP workshop presentations by Bruce Harley and Marc Rosenbaum http://www.neep.org/sites/default/files/resources/ASHP_Workshop_Installation.pdf
- Marc Rosenbaum's Cold-climate minisplit training https://www.heatspring.com/courses/the-ins-and-outs-of-selecting-cold-climate-minisplit-heat-pumps/
- DOE https://basc.pnnl.gov/resource-guides/mini-split-ductless-heat-pumps#quicktabs-guides=0
  - Install the heat pump in accordance with the manufacturers' instructions and relevant standards including ACCA Standard 5: HVAC Quality Installation Specification and the ACCA's Technician's Guide for Quality Installations and ACCA Standard 9: HVAC Quality Installation Verification Protocols.
- EPA https://www.energystar.gov/index.cfm?c=hvac_install.hvac_install_contractors
  - The ENERGY STAR Quality Installation Program ("ESQI") launched in 2008. Since that time, significant changes have occurred in energy efficiency program design and implementation and within the HVAC industry. ENERGY STAR has also learned lessons about what has worked and not worked well within the ESQI program.

Findings and Observations: Installation practices

- Extensive sets of guidance related to ASHP installation exist, including resources with specific guidance related to cold climate installation.
- There is considerable overlap and relatively strong consistency in existing guidance materials. However, none to date cover all the concerns and requirements listed above.
- It is difficult to gauge how prevalent the complete list of recommended practices are in the current installer community.t

Summary of Existing Resources

Table 4: Existing Resources List

Title	Source	Link
ACCA Manual J Residential load calculation	ACCA	https://www.acca.org/store?webproductid=db68fdfc-bb20-e511-80f5-c4346bac9a78
ACCA Manual S Residential Equipment Selection	ACCA	https://www.acca.org/store?webproductid=18b6715f-bc20-e511-80f5-c4346bac9a78
NEEP Cold Climate ASHP Specification	NEEP	http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump
ASHRAE 99.6% HDB Temperature (°F)	2016 ASHRAE Handbook	https://www.ashrae.org/resources--publications/bookstore/handbook-online
Installer Guidance	Green Mountain Power	http://www.greenmountainpower.com/upload/photos/392Contractors_Guide_with_Logo_-_Web.pdf
Best Practices for installing Ductless Heating and Cooling Systems	NEEA	https://www.bpa.gov/EE/Sectors/Residential/Documents/Installer-BestPractices-Guide.pdf
Heat Pump Installation Checklist	Efficiency Maine	http://www.efficiencymaine.com/docs/Ductless-Heat-Pump-Installation-Checklist.pdf
DESIGN AND CONSTRUCTION GUIDELINES AND STANDARDS DIVISION 23- HEATING VENTILATION AND AIR CONDITIONING	Mass. DHCD	http://www.mass.gov/hed/docs/dhcd/ph/dcguidestandard/238000air.pdf
ACCA Standard 5: HVAC Quality Installation Specification	ACCA	http://www.energystar.gov/ia/home_improvement/home_contractors/qispec.pdf
Heat Pump Sizing Worksheet	Idaho Power	https://www.idahopower.com/pdfs/EnergyEfficiency/HVAC/HeatPumpSizingWorksheet.pdf
Heat Pump Sizing Calculator	BPA	https://www.bpa.gov/EE/Sectors/Residential/Pages/Heat-Pumps.aspx
Air Source Heat Pump Installation Specification (Updated June 11, 2013)	BPA	https://www.bpa.gov/EE/Sectors/Residential/Documents/ASHP_Specifications_2013.pdf
Variable Speed Heat Pumps and PTCS Specifications- How air flow Requirements apply to inverter technology	BPA	https://www.bpa.gov/EE/Sectors/Residential/Documents/Variable_Speed_Heat_Pumps_Fact_Sheet.pdf
PTCS Air Source Heat Pump Installation Form	BPA	https://www.bpa.gov/EE/Sectors/Residential/Documents/PTCS_Air_Source_Heat_Pump_form_2015.pdf
Performance Tested Comfort Systems® Air Source Heating Pump Installation Commissioning Procedure (2006)	BPA	https://www.bpa.gov/EE/Sectors/Residential/Documents/Heat_Pump_Commissioning_procedure_2007.pdf
Heat Pump Sizing Worksheet	Idaho Power	https://www.idahopower.com/pdfs/EnergyEfficiency/HVAC/HeatPumpSizingWorksheet.pdf

Best Practices Installation Webinar Slides	NEEA	https://goingductless.com/assets/documents/uploads/Best-Practices-Installation-Webinar.Updated.pdf
NEEP workshop presentations by Bruce Harley and Marc Rosenbaum	NEEP	http://www.neep.org/sites/default/files/resources/ASHP_Workshop_Installation.pdf
Marc Rosenbaum's Cold-climate minisplit training	HeatSpring	https://www.heatspring.com/courses/the-ins-and-outs-of-selecting-cold-climate-minisplit-heat-pumps/
Martin Holladay Green Building Advisor blog series; How to Perform a Heat-Loss Calculation	Green Builder Advisor	How to Perform a Heat-Loss Calculation
HVAC load calculation software tool	NEEA	Under construction