April 20, 2022

REPORT #E22-327

Variable Speed Heat Pumps – Technical Best Practices Gap Analysis

Prepared For NEEA:
Christopher Dymond,
Sr. Product Manager

Prepared by:
Matt Christie, Sr. Project Manager

TRC Engineers, Inc.
2 Liberty Square, 6th Floor
Boston, MA 02109

Northwest Energy Efficiency Alliance
PHONE
503-688-5400
EMAIL
info@neea.org

Table of Contents

Tables

Executive Summary

This report captures the status of best practices for variable speed heat pump[1] (VSHP) installations. It provides a literature review and identifies gaps of technology understanding, contractor awareness, contractor capability, and where existing resources are needed to accelerate contractor best practices required to accelerate market adoption of variable speed heat pumps. It is part of the Northwest Energy Efficiency Alliance's (NEEA) market transformation strategy development to accelerate market adoption of variable speed heat pumps.

This report is the result of the synthesis of a resources inventory, literature review, industry knowledge, and TRC's internal engineering and heat pump market experience working with residential electrification and VSHPs in multiple states—work that contributed to identifying and describing gaps in technical knowledge. Chapter 2 outlines the resources inventory and TRC's approach to the literature.

Chapter 3 describes VSHP installation best practices where gaps in the industry's knowledge have significant negative impacts on energy efficiency, installation cost, and/or market adoption rates. TRC sorted these knowledge gaps into three categories: 1) system sizing, design, and product selection, 2) installation and commissioning, and 3) operations and maintenance.

Chapter 4 looks at how those best practices gaps play out practically with recommendations on approaching each scenario and improving it. The gaps are not strictly limited to variable speed heat pumps, nor are they universal to all situations. For simplicity of description, this report divides these into the following three types of best-practice gaps: knowledge, resources, and practice:

1. **Knowledge:** The data necessary to inform the market on best practices are missing. Additional research would help steer the market toward better comfort and efficiency outcomes.
2. **Resources:** Utility programs, trade organizations, and/or manufacturers do not provide material resources that support heating, ventilation, and air conditioning (HVAC) contractors, such as training, guides, technical manuals, checklists, and/or calculators. This category includes situations in which a utility program does not create or enforce program requirements that compel the use of best practices.

[1] Variable Speed Heat Pump and Variable Capacity Heat Pump are used synonymously.

3. **Practice:** HVAC installation contractors do not put available knowledge into practice consistently or appropriately. This is most commonly due to either lack of awareness or because contractors are neither rewarded for following best practices nor penalized for not using best practices.

The following table summarizes these gaps and the recommendations to address them.

Table 1. Overview of Best Practices Gaps and Recommendations

Best Practices Gap	Type	Description	Recommendations
Load Calculations	Practice	Contractors do not perform accurate load calculations when they would be impactful.	Develop guidance on when load calculations (and the of detail) are needed and support tools that reduce contractor burden. Support mechanisms to pay contractors to perform load calculations. Integrate free easy to use load calculation tool that is integrated with product performance database (QPL)
Sizing for Heating	Practice	Contractors do not understand and/or apply concepts, such as capacity degradation and turn-down when selecting a product in a heating-dominated climate.	Support uptake of sizing, design, and product selection training specific to VSHPs modulating performance. Incent heat pumps based on capacity at winter design conditions. Steer contractors to leverage the Northeast Energy Efficiency Partnerships (NEEP) variable speed, cold-climate air source heat pumps (ccASHP) product database, or manufacturers' expanded performance tables, to get a holistic view of heat pump performance across various conditions.
Lockout Control	Practices	Contractors set controls of supplemental heat to minimize call backs rather than maximizing system efficiency.	Work with manufacturers to incorporate efficient lockout control options as default setup. Provide utilities and training organizations with guidelines and clarity on why new VSHPs do not require as much supplemental heat and how safely avoid callbacks.
Breaker Upgrades	Resources	Utility programs do not understand or consider the impact of adding breakers or upgrading electrical panels.	Provide training and/or resources to participating contractors to better understand when electrical upgrades are required. Provide additional incentives to offset added costs of breaker/panel upgrades when necessary. Provide incentives for panel-management products that remove the need for a service upgrade.

Best Practices Gap	Type	Description	Recommendations
Heat Distribution Design Impacts	Knowledge	Insufficient knowledge about situations in which an individual room can maintain year-round comfort without its own heat source. For multi-split systems, sufficient knowledge is lacking regarding the relationship between the number of connected indoor heads to efficiency.	Conduct studies to assess comfort in indirectly-heated residential rooms. Study the relationship between the number of connected indoor units and energy use.
Duct Design	Practice	Contractors do not properly design or redesign ducts for ducted VSHP installations.	Support mechanisms to pay contractors to follow duct design best practices, including recognizing homes where converting to a ductless application may be better.
Heat Distribution Design	Resources/ Practice	Most HVAC installers are not practiced in considering, evaluating, and optimizing across heat pump distribution options.	(Resources) Develop decision trees and application guides contractors can use to evaluate VSHP distribution options for a home based on its layout, the existing heating system, and the customer's intentions. (Practice) Support uptake of training for VSHP heating distribution design options.
VSHP System Design in Homes with Existing Heat	Knowledge/ Resources/ Practice	Retrofit scenarios provide a myriad of challenges that span sizing, system selection, distribution design, controls, and customer expectations.	(Knowledge) Continue to expand on research that quantifies energy use and the underlying causes of inefficient energy use in homes with redundant heating systems. (Resources) Improve upon integrated control specifications and program requirements that provide precedence to the heat pump. (Practice) Court and develop all-star contractors with a deep understanding of VSHP systems and their interactions with backup/supplemental heat.
Duct Losses with Variable Speed Fan	Knowledge	Insufficient knowledge exists regarding how convective and conductive heat loss in ducts impacts energy use with variable speed fans and variable capacity heat output.	Research heat loss in ducts across VSHP operating conditions and determine lower bounds at which duct losses outweigh efficiency gains from VSHP modulation.
Hearts and Minds	Practice	Contractors do not believe heat pumps are a viable year-round heating technology in cold climates.	Demonstrate case studies of successful year-round comfort from heat pumps. Use peer-to-peer messaging to show HVAC contractors that heat pumps can fulfill year-round heating needs.

Best Practices Gap	Type	Description	Recommendations
Defrost Information	Knowledge/ Resources	VSHP product manuals do not reveal enough information regarding defrost methods, control options, and their energy impacts.	(Knowledge) Conduct research on energy impacts of defrost methods and control options. (Resources) Encourage manufacturers to disclose each product's defrost method and any data they have on the impacts on energy use in product manuals and technical guides.
Efficiency Ratings	Resources	The standard efficiency ratings—Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER)—are not indicative of efficiency performance in the field for VSHPs.	Continue to develop, test, then promote the use of dynamic voluntary efficiency rating structures such as CSA-EXP-07.[2]
Sales Based on HSPF and SEER	Practice	Contractors select and sell products based on their HSPF and SEER rather than actual whole system performance.	Train (and incent) contractors to conduct proper load calculations, system selection, and distribution design—and to include quality whole-home design as a key sales differentiator.
Refrigerant Line Connections	Practice	Contractors do not properly flare or braze refrigerant line connections due to lack of knowledge, practice, or l quality tools.	Support flare, brazing, and compression fitting training focuses on why refrigerant leakage is so problematic. Buy down the cost of higher quality flaring and brazing tools for contractors participating in training.
Snow Protection	Practice	Contractors do not ensure outdoor units are protected from snow.	Enforce outdoor-unit snow-protection requirements in incentive programs and/or energy codes, considering snow accumulation below the unit and snowslide from a roof eave above the unit.
Installation Quality	Practice	Contractors cut corners during installation on items such as refrigerant line insulation/UV protection, unit clearances, vibration-dampers, and unit-leveling.	Determine which installation failures have actual impacts on efficiency, comfort, or customer acceptance and conduct rigorous training and quality control inspections to enforce them.
Integrated Controls	Knowledge	Sufficient information is lacking regarding which integrated control methods successfully prioritize the heat pump and under which conditions they may fail.	Conduct research studies on various integrated control setups.
Daily Setback Data	Knowledge	Sufficient information is lacking regarding which daily setback	Conduct research to quantify annual VSHP energy use under various thermostat setback setups.

[2] https://www.csagroup.org/store/product/CSA%20EXP07%3A19/

Best Practices Gap	Type	Description	Recommendations
		methods and home conditions lead to higher energy use.	
Improper Refrigerant Charge	Knowledge	Sufficient information is lacking regarding the frequency of improper refrigerant charge and its impact on VSHP operation in heating mode.	Perform post-install quality control inspections that test refrigerant charge and quantify the frequency of improper charge. Conduct research that quantifies the energy use impact of improper charge with VSHPs in heating mode.
Airflow/Power Testing	Resources/ Practice	Industry-standard airflow and operating power test methods do not adequately apply to VSHPs that respond dynamically to conditions.	(Resources) Develop new testing protocols that measure airflow and power draw for VSHPs and allow the technician to diagnose issues accurately. (Practice) Support contractor training on appropriately using and interpreting currently available test methods when applicable.
Consumer Expectations	Resources	Consumers have inaccurate expectations of how their heat pumps should operate, leading them not to use them or to request unnecessary service calls.	Create consumer education materials that contractors and/or programs give to customers to reduce misperceptions.

1 Introduction

This report captures the status of best practices for variable speed heat pump (VSHP) installations. It provides a literature review and identifies gaps of technology understanding, contractor awareness, contractor capability, and where existing resources are needed to accelerate contractor best practices required to accelerate market adoption of variable speed heat pumps. It is part of the Northwest Energy Efficiency Alliance's (NEEA) market transformation strategy development to accelerate market adoption of variable speed heat pumps.

This report synthesizes a resources inventory, literature review, industry knowledge, and TRC's internal engineering and heat pump market experience working with residential electrification and VSHPs in multiple states—work that contributed to identifying and describing gaps in technical knowledge.

1.1 Goals

The goals of this research are to capture the current state of best practices for residential VSHP installations, identify where gaps of knowledge exist, and provide a reference to influence future research and market support work that improves standards of practice for VSHPs.

The focus is on technical knowledge useful to contractors, utilities, distributors, and manufacturers across three topic categories:

1) system sizing, design, and product selection
2) installation and commissioning
3) operations and maintenance

TRC's research effort included compiling a resource inventory of best practice-related guides, tools, and documents and conducting a literature review on research studies and evaluations. TRC, in collaboration with NEEA, Bruce Manclark of CLEAResult, and Bob Davis of Ecotope, performed a gap analysis to identify best-practice technical knowledge gaps that impact the market's ability to expand as rapidly as necessary to meet the carbon reduction and energy efficiency goals set by utilities and state agencies. TRC correlated the identified best-practice technical knowledge gaps with the body of research knowledge revealed by the literature review. This report notes areas where research exists to inform the market and those for which more research is needed. Chapter 4: Gap Analysis assesses specific gaps and gives recommendations to resolve or mitigate them.

This project's scope includes only VSHP products appropriate for single-family residential settings, though these products may be used in small commercial or multifamily buildings.

This report builds from similar research conducted for other utilities, efficiency organizations, and state agencies, plus best practices knowledge gleaned from working directly with utility programs, contractors, manufacturers, and distributors who work with VSHP products.

2 Resources Inventory and Literature Review

2.1 Resources Inventory

Associated with this gap analysis, TRC created a resources inventory focused on the residential air source heat pump (ASHP) trade, included as Appendix A. The inventory lists the resources applicable to HVAC contractors involved in selling, installing, and servicing ASHPs:technical guides, training, best practices guides, installation checklists, support tools, and other materials relevant to a contractor's business operations. These resources come from trade organizations, utility programs, energy efficiency organizations, and manufacturers.

TRC categorized resources as belonging to one of three categories: market actor resource, utility program resource, or technical manual/guide. In all, the resource inventory comprises 22 market actor resources, 47 utility program resources, and 14 technical manuals/guides, as outlined in Table 2 below.

Table 2. Resource Categories

Resource Category	Definition	Number of Resources Listed
Market actor resource	Peer-to-peer or business-to-business resources meant to share best practices knowledge among manufacturers, distributors and installing contractors	22
Utility program resource	Publications from utilities or efficiency organizations that support participating contractors in incentive programs and define program requirements	47
Technical manual/guide	Technical manuals or practical guides for performing specific tasks related to sizing, design, and product selection; installation and commissioning; or operations and maintenance.	14

TRC further classified resources based on the target audience, building sector, level of detail provided, and the resource's applicability to cold climate locations. The resources identified include technical documents and guides, software, videos, and services. Certain inventory items are proprietary or specific to use in certain states/regions; these resources are listed as examples of potential tools and resources that might be co-opted or reproduced to serve the broader market. TRC used the inventory and market insights learned while researching and developing the inventory, to identify market needs and materials or resources that can help bridge technical best-practice knowledge gaps.

2.2 Literature Review

TRC conducted a targeted literature review of research documents that explored and quantified various aspects of VSHP performance. Appendix B includes a list of these documents. In contrast to the resource inventory discussed above, which focuses on practical guides and support resources whose target audience is contractors, the documents studied in this literature review are research documents targeted toward regulators, utility program managers, and other researchers. HVAC contractors typically do not directly read such evaluations and research studies. The data and findings presented in the recent research reports would ideally be incorporated into practical guides and resources targeted to contractors. Studies were limited to those directly relevant to residential-grade VSHP technologies and conducted since 2000.

Broadly, TRC performed its literature review for the following purposes:

- Identify gaps in the VSHP market
- Highlight technical knowledge available to the market
- Assess topics that are receiving the most research attention and topics that are not

TRC sought studies, papers, and evaluations by contacting industry professionals, conducting internet searches, and following source citations in reviewed resources. Industry professionals included members of the Advanced Heat Pump Coalition;[3] heat pump experts at Daikin, Mitsubishi, and Fujitsu; and staff at the New York State Energy Research and Development Authority (NYSERDA). TRC reviewed technical research papers, market characterizations, evaluation studies, and conference and webinar presentations pertinent to best practices for VSHP installations. TRC focused on three topics to capture the state of best practices for VSHP installation: 1) system sizing, design, and product selection, 2) installation and commissioning, and 3) operations and maintenance. The research team found a breadth of information on these topics throughout the literature review. The team reviewed a total of 39 sources for this study, 18 of which are referenced directly within this report, as summarized in Table 3 below.

[3] The Advanced Heat Pump Coalition is an informal group of staff from utilities, efficiency organizations, state agencies, and consultants deeply engaged in the accelerated adoption of heat pumps in Canada and the United States.

Table 3. Literature Review Topic Overview

Aggregated Sources and Documents by Topic	Sources Reviewed in this Topic and Referenced in this Report
System Sizing, Design, Product Selection	10
Installation and Commissioning	5
Operations and Maintenance	3

Table 4 below shows a few high-level findings from the literature review from resources that best highlighted technical gaps in the VSHP market. Chapter 3: Current Body of Knowledge, provides additional details of the gaps and other technical gaps identified through the literature review in the VSHP market.

Table 4. Literature Review Sources that Best Highlight Technical Gaps

Resource	Type of Gap	Technical Gaps
Bertsch, S.S., & Groll, E. A. *Two-stage air-source heat pump for residential heating and cooling applications in northern US climates.* 2008.	Knowledge	Limitations of heat pump capacity not captured in U.S. DOE ratings, especially in lower ambient temperatures.
Margolies, J.G. (2019). *Dual Fuel Air-Source Heat Pump.* Michigan Electric Cooperative Association (MECA).	Knowledge	VSHPs only result in substantial energy savings when other system factors are optimized, which is not always the case.
	Contractor behavior	Dual-fuel heat pump operating hours may be limited by a configured lockout temperature.
	Resources	The industry needs a modeling tool that better accounts for different factors that influence system performance.
Nadel, S. *Energy Savings, Consumer Economics, and Greenhouse Gas Emissions Reductions from Replacing Oil and Propane Furnaces, Boilers, and Water Heaters with Air-Source Heat Pumps.* Washington, DC: American Council for an Energy-Efficient Economy, 2018.	Knowledge	Barriers to heat pump adoption affected by contractors' and consumers' "hearts and minds."
Schoenbauer, B., Kessler, N., Haynor, A., & Bohac, D. *Cold Climate Air Source Heat Pump.* Washington, D.C.: ACEEE, 2017.	Resources	Variable speed ccASHPs need variable speed fans in the air handler unit to guarantee the ideal performance of the system; however, older furnaces have only a single-stage fan.
	Resources	Additional/improved information/data regarding defrost run time is needed.
	Resources	Need for lowered switchover or lockout temperature to increase ccASHP usage in the market.

During the literature review, TRC found no resources that specifically spoke to the following topics, each flagged as marketplace gaps by TRC, NEEA, and industry experts:[4]

- Cost/benefit tension between Manual J[5]-based load calculations and simpler approaches
- Break panel upgrade needs assessment when a VSHP is installed
- Duct design and redesign with VSHP installation

[4] Bruce Manclark of CLEAResult and Bob Davis of Ecotope.
[5] Air Conditioning Contractors of America's Manual J, Residential Load Calculation https://www.acca.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=df4aaf8b-c82b-4337-bb95-081f67444222

- Refrigerant line connection fitting with VSHP installation
- Refrigerant line insulation and ultraviolet protection for VSHP
- Unit clearances for VSHP
- Snow protection for VSHP
- Duct insulation and sealing
- General controls of VSHPs[6]
- Commissioning
- Operator education and expectations

Despite not finding specific information in the literature review relating to technical gaps for the above topics, Chapter 3: Current Body of Knowledge outlines each of the gaps pertaining to the above topics and explains what is currently known about each gap in the market based on subject matter expertise. TRC used this subject matter expertise with information from the resources outlined in Table 3 to compile a current body of knowledge for VSHPs.

[6] The literature review found information on gaps relating to integrated controls, defrost controls, and lockout controls.

3 Current Body of Knowledge

TRC, with support from Bob Davis (Ecotope, Inc.) and Bruce Manclark (Clearesult), identified VSHP installation best practices where gaps in the industry's knowledge have significant negative impacts on energy efficiency, installation cost, and/or market adoption rates. TRC sorted these knowledge gaps into three categories within each section of this chapter: 1) sizing, design, and product selection, 2) installation and commissioning, and 3) operations and maintenance.

Knowledge Gap - Some of these gaps are due to information or evidence missing from the overall VSHP knowledge base, for which additional research would add value and benefit the industry. Those gaps are summarized in Chapter 4.1: Knowledge Gaps: Recommendations for Future Work.

Resource Gap - Another type of gap arises when the technical information needed to address these issues exists, but the contractors are unaware of it and thus do not apply it during VSHP installation. Those gaps are summarized in Section 4.2: Resource Gaps: Utility, Trade Organizations, and Manufacturers.

Practice Gap - Finally, utility programs can play an important role in creating and enforcing program rules that motivate best practices and then educating participating contractors about those rules. Gaps can exist here because contractors are neither rewarded for following best practices nor penalized for not using them. Of all the stakeholders, utility programs typically prioritize long-term energy use the most. Section 4.3: Practice Gaps: HVAC Contractors discusses those connections.

Each of the following sections presents a gap, describes its technical details, and identifies the specific connections from the literature review that speak it when applicable. The gap descriptions come from the consensus knowledge of this report's authors and contributors based on VSHP subject matter expertise. As discussed above, the gaps identified fall under three categories, as shown in **Error! Not a valid bookmark self-reference.** below, to orient the reader to the relevant market opportunity and which area to develop solutions. Addressing each of these will help to guide future program plans, research, and resource allocation in order to grow the residential VSHP market.

Figure 1. Technical Gap Categories

Knowledge	Resources	Practice

3.1 System Sizing, Design, and Product Selection

Proper sizing, design, and product selection for a specific site's installation is essential to ensure optimal performance. Determining which heat pump to use for a given home requires a detailed understanding of heat pump technology and a thorough understanding of heat distribution options. Practitioners lack the appropriate training and awareness to determine the optimum system, and a lack of performance data and research that could differentiate among product options is also missing. The following section describes specific technical knowledge gaps related to VSHP sizing, design, and product selection.

3.1.1 Load Calculations

	Resources	Practice

Though the industry is aware of the importance of load calculations for proper VSHP product sizing and selection on efficiency performance, it is not generally motivated to bother if customer comfort and profits are achieved. Subject matter experts also note that accurate load calculations take substantial time and functional knowledge to determine. To save time, contractors will repurpose/reuse previously-created load calculations (of different buildings), simplify their analysis, or skip load calculations altogether in favor of rule of thumb approaches. For residential and small commercial applications, the industry standard method for load calculations is the Air Conditioning Contractors of America's Manual J, Residential Load Calculation methodology.[7] Alternative and more straightforward load calculation tools exist, though some codes and utility programs require Manual J and do not allow alternative approaches.

The ability of VSHPs to modulate performance to meet a home's load across a range of outdoor air temperatures masks the impact of inaccurate sizing. A minor mismatch can be a valuable benefit of choosing VSHPs—they can provide efficient comfort across a wide range of operating conditions. However, a major mismatch can lead to substantial efficiency reductions, peak load exacerbation, and home comfort failures. The line between *good-enough* and *problematic* can be difficult to determine as it is machine- and site-specific.

[7] https://www.acca.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=f70b9778-19be-4577-8c72-5adae8c6d0ed

Several questions need to be addressed to understand the knowledge gap of which sizing and load calculations fall under the *good-enough* category versus the *problematic* category:

1. In which situations does performance suffer enough for sizing to matter?
2. What level of sizing details are required for different system types (hybrid, zonal, etc.)?
3. When are alternative and/or simpler tools sufficient for these load calculations?

Several viable, common installation practices can be considered depending on the home with these questions in mind. For example, simpler homes do not require a detailed Manual J calculation. Existing historic-fuel-usage based load estimators for retrofit scenarios may deliver the needed accuracy for these scenarios. Knowing the system application's distribution choices or coverage intentions ahead of time, such as knowing that it will be a partial load displacement scenario with a ductless heat pump, can significantly impact the appropriate depth and specificity of the load calculation effort.

As discussed above, the use of Manual J is seen as the best practice for load calculations in the industry if done accurately. The problem is that Manual J calculations face accuracy questions of their own. Making mistakes with Manual J inputs is common, and many users may also build in their own safety factors. Inputs commonly entered inaccurately include infiltration estimates (air changes per hour (ACH)), duct multipliers (especially when ducts are outside the conditioned space), window thermal properties, and mechanical ventilation systems. The overall accuracy of Manual J results thus come into question. Since Manual J calculations are time-consuming and expensive, while also often inaccurate, it becomes even more apparent that simpler, less expensive, and *good enough* load calculations may be preferable in many situations.

3.1.2 Sizing for Heating

		Practice

Many heat pump installers started as installers of gas, propane, or oil heating systems, and they learned sizing norms from that field. Sizing for natural gas, propane, or oil furnaces[8]heating, compared to heat pumps, is more straightforward and a less dynamic challenge. If applied to heat pumps, some of the sizing norms and rules of thumb from natural gas systems can result in substantial problems in sizing determinations. Key differences include the following:

[8] For ease of reading, "natural gas" is used as a proxy for heating and supplemental heating systems which use natural gas, oil, propane or electric resistance to provide space heating.

1. Heat pump capacity degrades at colder temperatures from its nominal rating. When sizing for cold climates, understanding this degradation and then matching design loads with reduced heat pump capacity at the colder design condition is critical.
2. Many heat pumps in cold climates are designed to fulfill only a part of the full design load for a portion of the building (partial load). Those situations' sizing decisions are significantly different from what is needed to size for a whole-home application. This applies both to homes with centrally-located ductless systems—meant to supply heat only in specific zones—and for homeowners that opt for an intentional dual-fuel whole-house heating system. Sizing also relies on the type and number of living spaces and the occupant's usage patterns and behaviors. Heat pump size constitutes an important conversation between a contractor and homeowner before installing a dual-fuel heat pump system because it will impact the configured lockout temperatures, upfront costs, and expected energy savings (Margolies, 2019). This points to a gap in contractors' technical knowledge and expertise in heat pump installation, which then affects the heat pump's performance and, in turn, negatively impacts customers' perceptions of heat pumps in the market.
3. Oversizing systems is generally common with residential natural gas-based heating systems and multi-head heat pumps—installing a system that produces more heat than is necessary, even on the coldest days. With VSHPs, this can lead to short cycling in the shoulder season or on mild days, which, if substantial, can deeply reduce the heat pump's overall efficiency. Oversizing also results in higher install costs, hurting consumer uptake and cost effectiveness. The Trade Ally Network Northwest further stresses the importance of an installer correctly sizing each heat pump unit to avoid short cycling while also determining the best location for its installation (Trade Ally Network Northwest, 2021).
4. Annual energy savings can hinge on mild weather performance. The coefficient of performance (COP) when operating at minimum output between 35-50°F has been identified in recent analysis work by NEEA as a critical indicator of variable speed heat pump performance in many climates. Using HSPF and nominal capacity can steer design choices to products that perform worse than lower-cost alternatives with superior mild weather performance even in cold climates.
5. HVAC contractors' first exposures to heat pumps may have trained them to size them solely from a cooling-load approach, treating any heating benefit as purely ancillary. Sizing norms are distinctly different for heating. For a contractor, changing perspective to size for heating load first can be challenging.

In all these cases, a large portion of the market is not sufficiently aware of or educated in the nuances of sizing a VSHP and how different they are from single-speed ASHPs. Current training, resources, and tools that support HVAC installers do not yet focus on teaching these aspects to the extent needed. Though new training that could fill this gap are coming into the market now, pushed by utilities, state agencies, and manufacturers, the breadth of their usage is yet to be determined.

Easy access to product performance data is also a challenge. Performance data are typically buried in expanded performance tables and are difficult to access and apply, even if the designer understands the need. Designers who rely on HSPF, SEER, and nominal capacity as the core basis of their product selection process, as is typical for other heating technologies, will choose suboptimal VSHP products and overlook better options.

3.1.3 Breaker Panel Upgrade Needs Assessments

	Resources	

In some homes, particularly those with gas/oil/propane heat but no air conditioning, a new VSHP system represents a sizeable new electric load on the building. For some applications, the installer uses multiple heat pumps to cover the home's total load and heat distribution needs. The added electrical load created for a home through installing a new VSHP system may necessitate an upgraded electric system due either to insufficient open breaker spaces on a home's existing panel or the need to upgrade to a higher amperage limit for a home's overall electric service needs. Typical cost estimates for these upgrades are $200 for adding a breaker and $2,000 to replace a panel.

These concerns are exacerbated for a home with electric vehicles or a home battery for backup power and in jurisdictions where sub panels and disconnects for HVAC and hot water systems are required. Many HVAC contractors lack the electric system knowledge to make a consistent and appropriate determination as to the impacts of this added load and the potential need for a system upgrade. They would need to work with an electrician, triggering additional project costs even just for the assessment support. Anecdotally, some HVAC contractors cite lack of electric system knowledge and fear of costly upgrades as reasons to refrain from specifying heat pumps to replace an existing natural gas furnace or boiler. The market would benefit from a better understanding of the intersection between heat pump installations and electric system upgrade needs—the frequency, the triggering conditions, and the costs.

3.1.4 Heat Distribution Dynamics

Knowledge	Resources	Practice

Similar to sizing for heating, distribution design with heat pumps is significantly different than the design options for traditional natural gas systems. Unlike a large central plant heater needing distribution through forced air or hydronic pumping, the heat pump system design is much more modular. Heat pump designs can leverage various distribution approaches from central air handlers to ductless wall sconces, floor mounts, and/or in-ceiling inserts. They can also use either full duct systems or compact duct runs. Refrigerant line set planning might also impact distribution system choices as the designer tries to limit line lengths and quantity of runs, adding another constraint on indoor unit locations. A common design entails using one distribution system on one floor and another on other floors.

This market gap is twofold: 1) technical knowledge to understand the comfort implications of certain heat pump design choices and 2) contractor knowledge to understand the options and how to apply them appropriately. If a single room lacks its own direct source of heat (a ducted register or ductless head), under which conditions are comfort and safety still sufficiently met? Some evidence exists that with sufficient door undercuts and similar thermal pathways between rooms, some rooms can maintain indoor air temperature without a direct source. However, some codes require, and common practice dictates, that each bedroom have its own heat source—a requirement that can lead to higher costs. With ductless systems, it can lead to oversizing when the smallest available heat pumps have too much capacity for an individual room's load.

Another technical knowledge gap is knowing how many separately zoned heads on a multi-split system is too many and in which situations over-zoning leads to substantial efficiency impacts. When multiple independently controlled zones are connected to a single outdoor unit, and only a single zone calls for heat, often well below the minimum capacity of the outdoor unit, short cycling can ensue. However, data is insufficient to determine the extent of this issue, or when exactly the line is crossed, and short cycling occurs. Manufacturers themselves vary on the guidance they give contractors regarding multi-split zoning.

Literature Review Connections

The literature review identified a common theme with difficulties heating certain rooms, especially in large houses. Such challenges need to be assessed on a case-by-case basis. For example, some rooms may have unfavorable geometries and may benefit from duct redesign. Ueno also noted that the issue with temperature distribution is most typical for rooms with closed doors, such as bedrooms, compared to first floors that often have open floor plans

(Ueno, 2014). The Building Science Corporation described a particular case in which a heat distribution problem in a home was resolved by adding a 3:1 indoor unit/outdoor unit mini-split heat pump with indoor heads in all three bedrooms (Ueno, 2014). Overall, the study found that a simplified space conditioning distribution with mini-split heat pumps can allow for excellent performance. However, this poses thermal comfort challenges in houses without distributing hot and cold air to every room, limiting the adoption of mini-split heat pumps.

3.1.5 Ducted Delivery Systems

		Practice

The intersection of ducts and heat pumps is more complicated than many market actors initially think. A common view is that existing ducts can be repurposed as-is for the heat pump to provide whole-home heating and cooling for retrofit scenarios. However, the use of ducts with heat pumps can present multiple challenges, some of which are general to all ducted heating and cooling systems and some of which are specific to their use with heat pumps.

Residential duct design is an ongoing challenge, most notably for heat pump systems. Minimal design (rules of thumb) typically works fine for natural gas systems, especially those without central mechanical cooling, but heat pump systems depend more on adequate airflow to deliver expected capacity and efficiency. Understanding duct location, duct sizing, grille, and register selection and placement; understanding and reducing impacts of static pressure in ducts; and understanding filter selection, placement, existing duct leakage, and static pressure impacts are all design considerations that take a knowledgeable and practiced professional to address. Due to the time and effort required to design an exemplary system, duct systems are often poorly designed (or not designed at all), leading to negative comfort and efficiency impacts.

With VSHPs, designing for ducts is even more complicated. Most duct systems can safely presume a constant supply temperature and fan speed (which dictates airflow rates). In contrast, VSHPs operate with variable supply temperatures and air flow rates. The efficiency and comfort impacts of these variabilities are neither well-researched nor well-understood in the market to date. TRC discovered some research related to low airflow rates associated with cooling but not with heating (Amarnath, et al., 2021). Most design methods presume highest-speed fan operation at max capacity and supply temperature; however, VSHPs spend most of their operating hours modulating at lower capacities, lower fan speeds, and more moderate supply temperatures. The literature (Margolies) generally acknowledges that with low fan speeds, more mechanically-created heating and cooling energy will be lost in ducts. At some point, those losses can overwhelm efficiency gains made available by the VSHP's modulation (Modera, 1994). When moving slowly through the ducts, a greater proportion of heating or cooling energy will be lost via conduction before it reaches the conditioned area; however, the specific conditions that define those lower bounds are not well-researched, well-understood, or adequately applied by heat pump duct designers.

When using existing ducts for a heat pump application, contractors/designers must ensure that the existing ducts are sufficient to deliver the heating and cooling output of the heat pump. If the existing ducts were designed for a system where delivered air temperatures were higher during heating or lower in cooling it is possible that the ducts are not adequately sized to work well with a heat pumps. This challenge is especially prevalent for systems with ducts designed for gas or oil furnaces that have smaller duct sizes than are needed for heat pumps. In addition, return air plenums may have been inadequately sized or draw air from locations that are sensitive to thermal stratification.

Many heat pump contractors either do not recognize these issues or choose to ignore them. In these cases, their work bids may be significantly lower than competitors who properly account for duct redesign. Suppose a contractor with a lower-cost bid is selected. In that case, the customer will be left with insufficient heating and cooling delivery that they may never correctly associate with poor duct design but instead associate it with heat pumps generally, thus hurting their adoption rates in the market. These challenges are exacerbated when the existing ducts themselves are not properly designed or installed to fulfill their original intention, let alone the additional needs of a new heat pump system.

With VSHPs, duct design or redesign can become even more complicated when the home is served by a combination of ductless heads and ducted sections or when short-duct (also called compact-duct) runs are employed. These are short (typically under 12 feet), simple (generally straight) duct runs that allow one heat pump head to serve two to four closely-connected rooms, in lieu of providing ductless heads in each. It is difficult in a home with existing ducts to repurpose some of the existing ducting and optimize short duct runs and ductless heads to other parts of the building. Furthermore, there are very few rules of thumb or detailed design tools available to assist the installer of mixed ducted and ductless systems.

Finally, determining the party responsible for duct design in many construction scenarios is not always clear. The HVAC contractor often lacks control over location options to place ducts. The general contractor or architect infrequently consider duct location and layout needs in their design. This general issue can make duct design an afterthought, forcing the design to adapt to the physical limitations of the building structure rather than being optimized from the beginning.

3.1.6 Hearts and Minds

		Practice

While not strictly a technical limitation that can be resolved with improved technical knowledge or research studies, contractor and customer "hearts and minds" present a significant functional limit on the acceleration of heat pump installations. Two opportunities can significantly improve if market actors had better access to, and a compelling reason to pay attention to, the existing body of knowledge.

First is the confidence of contractors in the viability and applicability of VSHP heat pumps for heating. Contractors must overcome misperceptions of the cold-weather performance and unlearn rules of thumb from legacy technologies on sizing, design, and product selection. Some contractors conflate or over-apply actual product capability concerns, turning a kernel of truth into a total abandonment of VSHP products. Examples include capacity degradation at cold temperatures, cooler supply temperature norms, ducting and indoor-head location challenges, and intersections with a home's electric system, including panel size and available breaker space. Additionally, many contractors' heat pump knowledge is based on when products were less capable and efficient and were not sufficiently functional in cold climates for heating applications. Many still see heat pumps as a niche application only for mild climates or seasonally-used spaces, not as an efficient year-round heating and cooling technology for the whole home.

Second is consumer awareness. Many consumers simply have never heard of heat pumps; therefore, they do not have them on their list of potential heating solutions. Others have negative preconceptions of heat pumps coming from contractors themselves, neighbors, or their exposure to heat pump technology from many years ago. Many heat pump myths persist with consumers, including their function in colder climates, the ability to use them year-round for the whole home, conflation with ground-source heat pumps, and concerns about fuel and installation costs relative to other technologies. Contractors working with such customers face a substantial sales challenge; this leads to more familiar system type sales that do not need the same level of customer education and convincing.

In both cases, market research to better understand the depth of contractor and consumer knowledge gaps, the impact of each on adoption rates, and the efficacy of various "hearts and minds" stylized information campaigns targeted to each would contribute valuable insights for the creation of more effective future initiatives.

Literature Review Connections

In its 2020 study, the Minnesota Commerce Department further discussed the lack of customer awareness and hesitancy in installing ccASHPs. Only 18% of survey respondents recognized the term ccASHP by name and description. Among these ccASHP-aware respondents, only 22% rated themselves as "familiar" with the technology (ratings of 8-10 on a 10-point scale); 45% rated themselves as unfamiliar (ratings of 1-4 on the same scale). This same survey subset of ccASHP-aware respondents largely felt that ccASHPs could keep a home warm and comfortable in colder weather (71% agreed "strongly" or "somewhat" on a 5-point scale); a much smaller percentage disagreed (12% "strongly" or "somewhat" on the same scale). This further proves the uncertainty that exists surrounding heat pump efficacy in colder temperatures and the continued need to change "hearts and minds" about heat pumps in the market (Pickard, 2020).

Nadel discussed heat pump perceptions among customers specifically, and the challenges the heat pump market has faced in gaining customer acceptance (Nadel, 2018). Perhaps unsurprisingly, this study found that comfort at cold temperatures, reliability, and operating costs were among the concerns expressed by customers when it came to heat pump adoption. Nadel reviewed 11 studies on consumer satisfaction with heat pumps and found that complaints included the heat pumps blowing cold air and failing to reach the desired temperature on colder days (Nadel, 2018). The study also mentioned that proper system design and customer education could combat these customer issues. However, it also noted that customer hesitancy surrounding heat pumps could hinder the market, as discussed above (Nadel, 2018).

For states interested in pursuing heat pump programs, Nadel recommended several strategies to combat challenges with "hearts and minds" surrounding heat pump technology (Nadel, 2018). The first strategy is for program implementers to conduct more field monitoring of heat pump performance and then refine performance metrics based on monitoring results. For this monitoring, Nadel mentioned developing more precise tools to predict energy, greenhouse gas, and cost savings associated with heat pump use to combat further negative customer perceptions of heat pumps (Nadel, 2018). This recommendation aims to change perceptions on both the customer and contractor sides, though this alone may not be enough to make a lasting impact on "hearts and minds." That said, Nadel recommends another analysis of heat pump performance soon since heat pumps' costs, performance, and adoption rates are changing rapidly (Nadel, 2018).

3.1.7 Product Capabilities and Differentiation

Knowledge		

Heat pump energy efficiency metrics, particularly for VSHPS, are a contentious subject. Ample, but not entirely conclusive, evidence exists that the U.S. Department of Energy's (DOE's) national standards of HSPF, SEER, and energy efficiency rating (EER) are not representative of efficiency performance in the field. Most of the concerns point to the fact that those metrics are measured with a fixed testing protocol, and a load-based test that relies on the heat pump's own controls would more accurately measure system performance.

In 2023, the DOE and U.S. Environmental Protection Agency will begin enforcing a switch to HSPF2 and SEER2 rating systems for all heat pumps and air conditioners. This new rating system employs new testing procedures and rating criteria, such as testing systems at different static pressures in ducts; requiring lowest possible COP/performance data at actual temperatures below 17˚F instead of extrapolating that data from above 17˚F ranges; and generating two HSPF2 numbers, then using the one with the best-aligned "heating load line slope." However, this is still not a dynamic testing protocol. The load based test procedure and rating under development by the Canadian Standards Association, "Load-based and climate-specific testing and rating procedures for heat pumps and air conditioners" (CSA-EXP-07), as a possible voluntary testing standard may be more appropriate (U.S. Department of Energy (DOE), 2021), (U.S. Department of Energy, 2016). Given that many contractors use high HSPF and SEER as the basis for pricing quotes to make customer sales, changing this marketing use of these metrics will be difficult.

On top of the overall efficiency metrics challenge, increasing evidence indicates that many of the most energy-use-impactful features of heat pump products are not systemically captured by DOE ratings. Various researchers and industry experts point to defrost systems, crank-case heaters, on-board electronics' vampire loads[9], and fan overruns as impactful on overall energy use. The CSA-EXP-07 load based test procedure captures these impacts. Unfortunately, this procedure is not used currently by industry nor required in US or Canada, and therefore only limited manufacturer-reported data is available on these energy uses or measurements. Product brochures or technical manuals rarely list the specific functional and control methods for these extraneous energy loads. There are no normalized metrics, terms, or standards of disclosure, nor are there sufficient studies segmenting the energy impacts of specific methods or control strategies. Further, manufacturers consider some of the technical details surrounding extraneous energy use as proprietary knowledge that could, perhaps, lead to a competitive

[9] parasitic loads that are not directly associated with a primary function

advantage. They are reluctant to provide additional information for fear they believe may incorrectly—and negatively—showcase their product's performance.

In particular, defrost cycles can have an outsized impact on seasonal performance. Both the defrost method, and its control strategy, impact energy performance. A review of technical manuals from multiple manufacturers suggests that the manuals rarely detail the standard defrost method or control strategy. Though the option often exists to override default control strategies to customize a specific application, minimal information is provided on how this choice impacts energy use. Defrost is typically fulfilled with electric resistance strip heat, hot-gas bypass, or reverse-cycle operation. Among VSHPs, the reverse-cycle operation is the most common. Within these methods, certain approaches may be more effective. Often, much of the heat applied can be inadequately directed to the coils, resulting in long defrost times and substantial heat waste. Defrost controls that set the defrost duration time, and initiation triggers can also substantially impact overall energy use. Systems may enter into defrost mode on a simple timer or leverage various temperature and humidity sensors to determine when defrost is needed. The duration of the defrost period may likewise be based on a simple timer or the reading of sensors. In each case, the lack of standardized disclosure of defrost methods and controls, as well as minimal research data comparing the impacts of different approaches, means that technicians seeking to optimize for overall energy use lack critical data for an informed choice.

Literature Review Connections

Limitations of heat pump performance capacity not captured in DOE ratings, especially in lower ambient temperatures, need to be better understood. A VSHP will produce inadequate heat output as the required heat increases, whereas the heat pump capacity decreases due to the refrigerant mass flow rates provided by the compressor at high pressure ratios. The COP also decreases rapidly for high pressure ratios, which occur at low ambient temperature conditions (Bertsch, 2008, p. 1283).

One report reviewed by TRC described a ccASHP prototype in Fairbanks, Alaska, that used tandem vapor injection compressors and successfully operated down to -30°F (Shen, 2017). Although this prototype was in a much harsher climate than most of the continent, an important lesson learned in prototype testing is that a redesign of the indoor blower or reconfiguration of the blower speed setting would have increased the supply air temperature and the indoor comfort level (Shen, 2017, p. 8). This is an extreme example, but contractors or consumers who looked only at HSPF and nominal capacity would not be aware of the tested product's specialized capabilities.

3.2 Installation and Commissioning

The following section on the installation and commissioning of heat pumps is split into three subcategories: the installation itself, the controls setup, and the commissioning/testing process. Many of the installation challenges identified below are also common to non-VSHP and split air conditioners. The report makes a note of where VSHP-specific nuances exist.

3.2.1 Heat Pump Installation

Refrigerant Line Connection Fitting

Knowledge		Practice

Three common styles of refrigerant line connection are currently in use: flaring, brazing, and compression/press fittings. Refrigerant line contamination and refrigerant leakage can deeply impact long-term performance, including to the point of system failure and product damage if not done properly. A brazed connection creates the highest caliber of seal but is also the most difficult to learn to do right. Flare fittings are generally easier in the field but are also seen as more prone to leakage. Compression fittings are relatively new to the market and are the simplest and quickest connection method. Data to show the long-term efficacy of this connection type are limited, though the general expectation and initial data indicate compression fittings provide a highly-reliable quality seal. Compression fittings are typically only applicable to midpoints along the refrigerant line and not at the connection point to the outdoor or indoor units where brazing or flaring would still be necessary. The quality of the flaring and brazing tools can also impact the refrigerant seal and installation time, though many of the issues with installed refrigerant lines are a byproduct of the installer working too fast, rather than their tool quality or personal skill.

With refrigerant line connections, any level of failure constitutes a significant problem; there is no *good enough*. The market challenge comes down to the combined labor, tool, and product cost that is least likely to result in installation failures. Compression fittings cost more for each product but provide high-quality connections at a very low labor cost. Many market experts anticipate that compression fittings will become more commonplace, including connection options for indoor and outdoor units, completely displacing the need for flared or brazed connections. However, some jurisdictions still require brazed connections, a potential misunderstanding of the typical success and longevity of compression fittings (Chicago, Illinois, for instance, still requires brazed connections). Currently, many contractors use compression fittings on all between-unit connections and brazing or flaring at the units.

One technical knowledge gap is the quality and accessibility of flaring and/or brazing training. Most installers learn and practice these skills on the job under the tutelage of more seasoned professionals rather than through formalized training or practice sessions. Another is the impact on installation quality based on the use of certain tools. Finally, more data are needed to confirm the compression connections' quality and compare the fully-installed cost differentials—including product, labor, and tools (amortized)—across the three techniques.

Refrigerant Line Insulation and Ultraviolet Protection

		Practice

The New York State NYS Clean Heat program's[10] quality control inspections observed a common installation failure in the proper protection of refrigerant lines. All heat pump lines, indoors and outdoors, should be insulated to reduce heat transfer. Poorly-insulated refrigerant lines lead to efficiency losses. Insulation also protects from excess condensation, which can cause property damage. The outdoor line's insulation must also be protected from ultraviolet radiation, which can break down many common insulating foams over time. Most quality control programs take a zero or near-zero tolerance approach and reference the manufacturer's guidelines to insulate the refrigerant lines all the way to the unit connections with no gaps. However, in direct discussions, manufacturers and technology experts generally acknowledge that small gaps in insulation will have negligible efficiency impacts.

A few manufacturers state that for some of their central system heat pump products, the *liquid line* does not need to be insulated because the metering device that controls this line is housed in the indoor unit rather than the outdoor unit. This small variance in manufacturer guidance, differing even among product lines by the same manufacturer, can confuse a market and incentive programs that rely on universal guidance.

Changing energy and mechanical code requirements for line set insulation also impacts the market. International Code Council codes have required R-6 insulation for multiple code cycles and certain states which is greater than many manufacturer installation requirements. Some jurisdictions, such as the city of Seattle, are now beginning to require R-6 insulation or higher, leading to market confusion and reduced product availability as this level is not yet the standard for manufacturers and suppliers (SDCI Community Engagement, 2021).

[10] https://cleanheat.ny.gov/ .

Unit Clearances

		Practice

Manufacturers specify clearances relative to neighboring objects for both indoor and outdoor units. Outdoor clearances are designed to ensure sufficient airflow through and around the unit. Indoor clearances are specified for three purposes: sufficient airflow through the unit, appropriate mixing of supply air coming out of the unit, and to protect internal temperature sensors from an inaccurate reading caused by conditioned air bounce-back from an adjacent surface.

In all cases, the clearances given are the most conservative values that fully ensure system performance. In practice, they are demarcations of one end of a gray area in which infracting a small amount has no discernible impact on performance. Given the practical limitations of unit placement, many installers find themselves forced to compromise on one or more unit clearance dimensions (i.e., top, side, back, bottom, front). Direct information is lacking on which clearance specifications matter most, to what degree, to what sensitivity, and whether interactive impacts exist when compromising on more than one at a time.

Snow Protection

		Practice

A heat pump's outdoor units are designed to be durable enough to withstand and operate through the spectrum of winter weather conditions. However, their resilience has limits, particularly when the fan's operation is impacted by snow or ice buildup. Vertically-aligned fans are at much less risk of failure than horizontally-aligned ones; that said, all units must be protected from snow buildup on the ground, as well as from excess snow dropping from above. To protect from ground-snow buildup, ensuring the unit is on a ground bracket or wall-mount higher than the average maximum snow depth for that location is typically sufficient. However, compounding effects such as micro-climates, snow-eddies, and roof-dump can be problematic for an otherwise safe-seeming height. If the snow builds up below the unit and buries it or blocks airflow through it, the unit will perform poorly or possibly break. Protecting from excess snow from above is also important; however, natural snowfall is not a problem. The issue arises when snow slides from a roof fall directly onto the unit. Roof slide can create high snow piles that bury the unit, fall into the top of an uncovered horizontally-aligned fan, or knock over a ground-mounted unit if the angles and force of the snowslide align.

Historically, heat pumps have not been used as a primary heating source through the winter; therefore, the norms around a heat pump's outdoor unit location often do not take snow into account. Contractors need knowledge and support in addressing snow considerations and the options to prevent snow-related problems. The industry would benefit from the better study of the frequency and causes of snow-related product failure and effective prevention.

Duct Insulation and Sealing

		Practice

Similar to duct-related issues at the design stage, duct-related installation issues are connected to the HVAC contractor's perceived value of prioritizing quality air sealing, insulation, and duct layout. Duct installation issues are common to all HVAC applications and are not unique to heat pumps. To many contractors, the benefits of proper duct installation are overridden by the labor costs involved and use of increased sizing to overcome any comfort impacts from duct losses. Deficiencies are not often noticed by homeowners nor always associated with a failure on the HVAC contractor's part. The typical HVAC business model values the speed of installation above most other factors; however, poor duct insulation and air sealing lead to an incredible amount of energy waste over the unit's lifetime. These issues can also impact homeowner comfort as heated or cooled air does not get to its intended destination. Proper diagnostics for testing the air sealing of a duct system require specialized equipment plus additional labor. For those reasons, testing duct air sealing is rarely performed without a requirement by energy code or a utility incentive program. In the Northwest, this is further complicated by the Regional Technical Forum's proposal to deactivate single family duct sealing as a unit energy saving (deemed savings) measure. This is primarily due to inconsistent training and installation practices, quality assurance programs without stringent penalties for failure, and a lack of quantifiable savings evaluations (Bopp, 2021).

Information is also inconsistent on the necessity and value of insulating and air sealing ducts in an indirectly-conditioned space such as a basement. On one hand, the energy losses leak into the thermal envelope and can even add value by providing enough basement heat to ensure pipes do not freeze in particularly poorly insulated homes. On the other hand, the energy does not reach its designated location, thus impacting comfort and efficiency. Further confusing this issue are energy code interpretations and language choices surrounding ducts inside building thermal envelopes. Washington, Oregon, and International Energy Conservation Code codes all allow ducts located inside the building thermal envelope (but not necessarily in conditioned space) to have R-8 or less insulation installed.

3.2.2 Controls Setup

General Controls

Knowledge		

VSHPs are sold with their own proprietary control systems, and they often leverage built-in machine learning algorithms to optimize performance over time. These control setups are more sophisticated than basic thermostats and are complicated, diverse, and not transparent. Factory default modes are not optimized for energy performance, yet they are most likely to be used in-field during the initial install. Even if the installation appropriately applied an improved operating mode, the likelihood that an eventual power outage would cause the system to revert to factory defaults after reboot is high (PG&E, 2018).

The specifics of these controls and their algorithms are often proprietary and not known to the homeowner. They will use discrete indoor temperature data relative to a thermostat setpoint for an on/off determination, and some combination of outdoor temperature, supply temperature, and rate of indoor temperature change to determine the operating modes to use at any given time. Different equipment may also provide different locations for measuring the indoor temperature, with ductless heat pumps defaulting to the temperature at the indoor head and short-run ducted mini-split heat pumps often defaulting to the incoming air temperature at the return. Remote wall-mounted controls may be controls only or full thermostats, depending on brand and initial setup. This level of sophistication necessitates a home hoping to leverage a third-party smart thermostat, such as the Nest or ecobee, to ensure that its heat pump is configured to work appropriately with that specific brand of smart thermostat. In some cases, the machine-learning algorithms within the third-party device conflict with the heat pump's programming, leading to suboptimal energy and comfort outcomes. Clarifying the impact of this control overlap challenge would be valuable; however, the relationships between third-party products and various heat pump manufacturers are evolving rapidly, so it would be difficult for research on this topic to stay relevant.

VSHP operating modes can also cause confusion and efficiency losses. Many VSHP control systems have multiple modes with insufficient documentation on how each control option impacts efficiency performance. Most systems will have some version of an efficiency mode versus a comfort mode. Data is insufficient to support which modes for which systems impact efficiency performance and to what magnitude. Some heat pump controls may revert to factory default settings (including the operating mode selection) after a power outage, which constitutes another concern.

Finally, subject matter experts (SME) are in general agreement that the use of deep daily setbacks with VSHPs should not be encouraged. Due to their ability to modulate performance, a heat pump may enter a high-energy catch-up mode (or even revert to using electric resistance strip heat if integrated into the system) when the setback switches to a higher-temperature occupied setting. SMEs agree that the extra energy used during this high-energy mode outweighs the energy savings accumulated by the setback. However, minimal data are available to clarify the exact relationship and conditions under which setbacks have this overall energy loss effect. Shallow setbacks of 2°F to 4°F may be consistently beneficial; deeper setbacks that time-step the catch-up slowly, for example 2°F maximum each hour, may let the heat pump bring the zone back up to full temperature more steadily without triggering the more energy-wasteful high-compression modes. Some manufacturers' products use occupancy sensors to control the heat pump and apply shallow setbacks automatically based on occupancy. Adding a thermostat-driven setback in addition to the systems automation can lead to deeper setbacks than intended. Finally, some manufacturers have acknowledged this issue and have started creating operation modes that meter the catch-up mode appropriately over a longer catch-up period and therefore *do* capture savings from a deep setback. Most utility heat pump programs and energy efficiency guidance currently advocate for no daily setback or shallow daily setbacks only but do so without the benefit of underlying data.

Integrated Controls

Knowledge		

One of the most challenging aspects of current heat pump adoption in existing homes is effectively managing multiple heating systems at the same time for optimal comfort and economic impact. The term "integrated controls" used by several utility programs to recognize thermostats give primacy to the heat pump system until the point it is no longer effective at providing full home comfort, or no longer economically appropriate for providing comfort relative to a backup; the crossover point for both cases occurs at colder temperatures. However, the wide array of home arrangements between heat pumps and backup or supplemental heating sources each has its own nuances. The following are examples of integrated control home arrangements and their energy efficiency implications:

- A ductless heat pump serves the center of a home. Still, the perimeter of the home is not receiving sufficient heating for comfort, and no clear method of initiating the backup/supplemental heat that serves that perimeter controlled by a thermostat at the center of the house. This can result in decreased comfort or engaging the backup/supplemental heat to such an extent that the heat pump is underutilized.
- The natural gas backup heat comes on to serve spaces where the heat pump is not maintaining comfort but covering the entirety of the heating load itself, preventing the heat pump from operating at all. This potentially includes not letting the heat pump take over heating when outdoor conditions become mild again.
- During the switchover from heat pump to natural gas systems, a slow-acting natural gas heating distribution system (such as radiant floors) leading to a sizeable comfort gap as the heat pump stops operating, but the natural gas heat is not yet providing comfort.
- Lab results at the Pacific Northwest National Laboratory showed that use of separate thermostats that are co-located can still result in one system taking most or all of the load by the system thermostat calls for heat first. This can occur when the thermostats are set to the temperature.
- A heat pump serving the top floor of a home, but the bottom floor's natural gas system leaks enough heat upstairs to prevent the heat pump from remaining the primary heat source.

Considerable recent research and program evaluations address the challenges of integrated controls. New methods and concepts to improve integrated control norms are being actively tested in the market. Much of the recent literature does not draw concrete conclusions or integrated control guidance; instead, the best guidance is highly customized to the specific application and often relies on a high degree of end-consumer capability and understanding. It is critical for utilities that make savings claims based on heat pump adoption in homes that retain a natural gas system to understand the conditions under which a heat pump system does not fulfill its estimated run hours and seasonal heating load fulfillment. Multiple measurement and verification projects and program evaluations to add to this knowledge base are currently underway.

Literature Review Connections

The Minnesota Commerce Department released a study report in 2017 entitled *Cold Climate Air Source Heat Pump,* which discussed the issue of integrating heat pumps, particularly ccASHPs, with backup heating systems. As discussed above, the proper integration between a heat pump and the home's backup heating system dramatically impacts a system's performance. The report notes that in Minnesota, ducted systems typically use a natural gas-fired furnace as a backup, while homes with ductless systems typically rely on electric resistance baseboards for backup heating. The report mentioned two primary issues when integrating a ducted ccASHP with an existing furnace: 1) the furnace and heat pump need the capability to communicate with one another, and 2) a multi-stage fan is needed to achieve the full benefit of the ccASHP. The report notes that these issues can be alleviated if the furnace and ccASHP are the same brands, which ensures that the heat pump and furnace can communicate, since integrated controls are required for the switchover setpoint and the furnace fan speed (Schoenbauer, 2017, p. 24). Variable speed ccASHPs need fans in the air handler unit to be variable speed to guarantee ideal system performance; however, most 80% AFUE and condensing furnaces have only a single-stage fan. This is a continued gap in the market since only recently installed, higher-end furnaces have the controls and fan characteristics needed for full integration (Schoenbauer, 2017, p. 24).

Defrost Controls

Knowledge	Resources	

The installer has some selection options for setting defrost controls specific to the homeowner's stated preferences, the home, and climate. The manufacturer determines the slate of options for a given heat pump and varies considerably by product and application type. The long-term impacts on the efficiency of various defrost setups or poor control decisions are unclear. The manufacturers themselves, occasionally routed through an HVAC distributor, provide guidance and training on defrost controls to the contractor. The driving factors in advising on one control scheme versus another may not be based on energy use or efficiency at all. Due to the lack of commonly defined defrost control options, most utility program implementers do not have a way of providing manufacturer or contractor guidance to address energy efficiency impacts of inappropriate defrost settings.

Literature Review Connections

The earlier-mentioned *Cold Climate Air Source Heat Pump* report discusses the defrost performance of ccASHPs, with a particular emphasis on its importance in the heating performance of the system (Schoenbauer, 2017). To supplement the lack of understanding surrounding defrost controls discussed above, the study mentioned that room for improvement exists regarding defrost run time, and how this would result in an annual reduction in backup energy use, costs, and overall site energy consumption (Schoenbauer, 2017, p. 41).

Lockout Controls

Knowledge		

Two lockout setpoints can have substantial impacts on overall efficiency performance.

First is the **compressor lockout** which is the cold-temperature setting below which the compressor is disabled and the system relies 100% supplemental heating to meet the load. Compressor lockout is appropriate for one- or two-stage heat pumps, but not nearly as much so for VSHPs. With VSHPs can operate a much lower temperatures and should be allowed to contribute heat as low as it can maintain reasonable delivered air temperature. Anecdotally, compressor lockouts have been used to curtail VSHP use well above the temperature at which an economic switchover is appropriate. Most VSHP manufacturers advise not setting a compressor lockout at all, as the heat pump can provide a portion of the heating load, complementing the heating provided by the natural gas system. Better data or calculators to accurately pinpoint appropriate economic switchover temperatures would be valuable to the market.

Second is the **supplemental heat lockout**, which is a cold temperature setting above which supplemental heat is disabled. This prevents unnecessary use of supplemental backup heat (typically electric resistance strips in the air handler) to meet the load when the heat pump capacity has sufficient capacity. The supplemental heat lockout temperature can be set far lower for VSHPs than conventional ASHPs. Setting the lockout control too high can significantly diminish the annual energy savings of well-designed systems. The knowledge gap that exists today is being able to identify those products which can automatically set supplemental lockout at the lowest temperature possible. Finding products can do this would remove the contractor burden correctly setting up supplemental heat lockout and increase annual energy savings. To address this gap will likely require, lab and field testing and collaboration with manufacturers.

Literature Review Connections

The Michigan Electric Cooperative Association further commented on the importance of correctly configuring lockout controls in its 2019 article *Dual Fuel Air-Source Heat Pump Monitoring Report* (Margolies, 2019). The article mentioned that if a heat pump is sized to meet a large portion of a home's heating demand, the operating hours may still be limited by a configured lockout temperature above the site's cost-equivalent lockout temperature. Similarly, the study noted that lowering the switchover, or lockout, temperature could increase ccASHP usage in the market. It suggests the need for a modeling tool that better accounts for different factors that influence system performance, focusing not only on configuring the lockout temperature but also onold-temperature efficiency and sizing (Schoenbauer, 2017, p. 40).

3.2.3 Commissioning

Residential commissioning is typically an informal process conducted by the installer. They ensure the heat pump runs and provides heating and cooling with the proper airflow and power use when called for. Commissioning can also include refrigerant confirmation—that the unit is properly charged and not leaking. Some utility programs encourage or require the use of commissioning checklists to fulfill these needs. While some energy codes require third-party verification of these needs (particularly California's Title 24[11]), the Residential Energy Services Network (RESNET) Home Energy Rating System (HERS) Index process is moving in the direction giving lower (improved) HERS scores for homes that undergo third-party commissioning verification with Standard 310 for grading HVAC installations.

Many of the formal and informal commissioning tests in use for power usage and airflow are adapted from air conditioning and gas furnace testing. They are built for fixed air-speed fans working at a maximum and fixed capacity; however, VSHPs modulate their capacity and fan speeds, making the applicability of such commissioning protocols a challenge. Specifics of these challenges are discussed below.

Operating Power Expectations

Knowledge	Resources	

With a variable speed compressor and variable speed fans, a VSHP's operating power will change based on the situation. The industry lacks data and testing protocols to diagnose a VSHP's power draw consistently and to confirm whether it is within an acceptable range. What range of operating power should a technician expect? And how can one diagnose a system drawing more power than expected for a specific current situation, even if that power draw may be within the reasonable range in other cases? In addition, when a power draw issue is present, many technicians are not trained to diagnose or repair the underlying cause if it is electrical in nature.

Airflow Testing

	Resources	Practice

VSHPs leverage dynamic changes in coil temperature and airflow to deliver modulating capacity to the home. Many static airflow testing methods cannot capture this variability, thus adding a risk of misdiagnosis. A commissioning technician may not recognize a problematic pressure

[11] https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards

drop in the duct system and instead incorrectly presume that the fan speed is in a low-speed operating mode. The frequency and impact of airflow commissioning challenges with VSHPs have not yet been studied.

Airflow issues can also occur with ductless systems when they are not installed with indoor unit top clearances as per manufacturer instructions. No consistent and accurate testing methods to confirm airflow needs are met with such a ductless system are currently available.

Refrigerant Charge, Charge Testing, and Leakage Detection

Knowledge		

Proper refrigerant charge is critical to meet the efficiency and capacity expectations of an installed VSHP. The challenges for heat pumps and VSHPs are similar but not identical to those for split air conditioning (AC) systems. While many studies have quantified the impacts of improper refrigerant charge for split AC systems, few studies are specific to VSHPs, particularly to VSHPs in heating mode. Manufacturer product literature commonly states that VSHPs have more flexible refrigerant charge levels than conventional AC or single speed heat pumps. More data on the impacts of improper charge in both heating and cooling modes across multiple VSHP product types.

Multiple methods are available to confirm proper refrigerant charge in the field. The options and specific choice of testing method depend on the outdoor air temperature, the type of metering device, whether the heat pump is in heating or cooling mode, and the method used to charge the system itself. Three basic methods exist, and the most accurate employs refrigerant gauges to measure the pressure and temperature of the refrigerant in specific locations and conditions. Since all VSHPs use thermostatic expansion valve metering controlled by an electromagnetic piston, the subcooling method is applied. The subcooling method measures the refrigerant temperature as it exits the condenser to confirm it is in the appropriate range. Gauged testing is the most appropriate method for new installs in which the technician is initially charging the system. While gauge testing an existing system or a new system after the charging gauges have been removed is viable, it has the downside of potentially losing refrigerant in the process, risking contamination of the refrigerant with moisture and air, or leaving a leak after the test.

Non-invasive, gauge-less (and less accurate) methods to test refrigerant charge also exist. These methods are viable only within a specific narrow band of outdoor conditions. They also typically give the technician only an indication of whether they should connect gauges for a full subcooling test or whether they should instead search for other causes of performance issues. These methods are more difficult for VSHPs given their variable operation nature and the lack of standardized refrigerant test modes.

Finally, the weigh-in method can also confirm the proper refrigerant charge. This method is necessary if charging the system during outdoor air temperatures below a certain point—typically, the threshold is in the 70°F to 55°F range. Each manufacturer has its own guidance, at which point weigh-in is necessary. With weigh-in, refrigerant is added based on its weight using a calibrated scale. The proper amount is detailed on manufacturer-supplied tables specific to the system's line length. Some procedures allow third-party observation of the technician's weigh-in process to count as refrigerant charge verification. The need to use the weigh-in charging method can also be triggered when line lengths are above a certain threshold.

The HVAC market's ability to consistently install VSHPs with proper refrigerant charge across system types, navigating the decision tree of outdoor conditions, line lengths, and system setups, is under-researched. Research in California on split AC systems showed that contractors consistently failed to charge systems properly. This led to the creation of a universal third-party refrigerant charge verification system for code compliance. Additional studies, specific to VSHPs, coupled with quantified knowledge of the capacity and efficiency impacts of improper charges in VSHPs, could help support improved best practices, code standards, and utility program requirements.

On a related note, a system that is properly charged at installation but has a refrigerant leak will quickly degrade in performance and risk premature compressor failure. Two methods exist to detect refrigerant leaks: a refrigerant detection wand and a soap solution brushed onto line connections. Most HVAC contractors skip refrigerant leak detection steps at commissioning due to the added labor time and cost. Some may check certain easily accessible connections, but not all connections. Better research on the frequency of leaks and which locations and connection types most commonly leak would help contractors know which leaks to target and utility programs to understand where to focus quality control.

3.3 Operations and Maintenance

A VSHP, properly matched to a home and installed, may still result in suboptimal energy use. If the homeowner does not have the right expectations and overrides system settings, or if routine service and maintenance are skipped, the long-term energy-saving intentions of a home's new heat pump will fail to accrue. While not designed to represent all VSHPs, NEEA's *Maximizing Mini-Split Performance* report provided recommendations for how ductless heat pump installations could better deliver their originally-estimated savings based on field studies and product research (Trager, 2021). These "enhanced measures" include a section on owner operations, maintenance, and even education and expectations (as discussed in the next section of this report).

3.3.1 Operator Education and Expectations

Operation Expectations

	Resources	

Heat pumps operate differently than natural gas heating systems in ways that may raise concerns for homeowners and tenants. If these users are not adequately informed on what to expect, they may act on those concerns, disabling the heat pump or changing settings to achieve what they perceive to be an improvement. Customer education on heat pump expectations is a necessary component of a heat pump incentive program, and it is also valuable to contractors who can reduce call-backs and unnecessary service calls.

TRC and technical experts who supported this gap analysis identified the following operating norms that contractors should make known to all heat pump customers.

Long and continuous run times: Ideally, VSHPs run continuously at higher efficiency rather than cycling between on and off or running at high power settings to recover from deep setback conditions. Low power operation of VSHPs is generally 25% more efficient than full power operation. VSHPs (when properly sized and set up) provide just the right amount of heat needed to keep the space warm and modulate how much heat they are putting into the room to do so. Natural gas or single-speed heat pump systems, by contrast, will run intermittently—turning on and then off frequently at one heat output setting regardless of the home's load at the time. For fossile fuel systems, run times typically last less than 20 minutes. A homeowner used to intermittent natural gas systems may falsely diagnose continuous runs as being wasteful or a sign that the heat pump is overworked and cannot keep up with the heating need.

Lower supply temperatures that may *feel* cold: VSHPs provide warm supply air to the room at temperatures just above the room temperature, in the 80°F to 100°F range. Natural gas furnaces provide hot air at around 120°F to 130°F. People have become accustomed to expecting the feel of hot air from their heating registers. When they experience the warm air from heat pumps, they often believe it is a sign that the heat pump is not working properly. Further, 80°F air moving across a person's skin feels colder than 80°F due to convective cooling from the air movement, even though it adds heat to the room. This leads to a common misconception that heat pumps blow cold air. Unlike common practice with ducted forced air from natural gas, the best VSHP duct designs and ductless head placements do not throw air toward commonly-occupied spaces such as a couch or an entryway; they instead diffusely blow air into the room, allowing the heated air to mix steadily into the room and providing continuously comfortable indoor air temperatures throughout the conditioned space.

Keeping registers and grilles open and unobstructed: For a ducted VSHP system, a homeowner may attempt to customize their comfort, perhaps in reaction to a false perception of blown cold air as described above, by closing or blocking duct registers and grilles. Doing so can unbalance a carefully planned ducted airflow, impacting efficiency and the ability of the heat pump to meet the home's heating load.

Door undercuts and closed doors: Ductless VSHP systems typically do not have heat pump heads in each room. Such systems rely on natural air and heat transfer within the house to spread heating to unserved rooms. Homeowners need to know which rooms do not have their own direct supply; doors to those rooms should be left open whenever possible. When not, larger-than-standard door undercuts may be used to allow more air to flow under the door. Alternatively, transfer grilles can be installed in walls or the door header to allow more airflow between rooms.

Slow catch-up: VSHPs operate most efficiently when providing steady, consistent heat. When they are tasked with bringing a particularly cold room up to temperature, this occurs much more slowly than with natural gas heating systems. Heat pump operators must be made aware of this difference and be coached to be more patient when expecting rooms to heat up and to plan accordingly if they need to heat a room or zone that had been allowed to cool off significantly.

Use of deep thermostat setbacks: When VSHPs are bringing a cold room up to temperature, they will employ high compressor and fan speeds to produce maximum capacity heating to minimize the slow catch-up time. This is the heat pump's least efficient operating mode. The energy savings accrued by having a temperature setback are often eliminated when the heat pump uses a high compression mode for catch-up. Users must be trained on setback expectations to either not use daily setbacks, use only shallow setbacks (1°F or 2°F), or use a programmable thermostat to trigger a step-function recovery from a deeper setback in stages (1°F to 2°F per hour). For vacations and similar multi-day periods of non-occupancy, a deep setback should be applied; however, users should expect a slow recovery, and perhaps find a way to start the heating catch-up process using remote thermostat controls via common mobile phone thermostat apps, rather than waiting until they are back in the building.

Defrost cycles and cold air: Most heat pumps use a reverse-cycle defrost method in the winter to remove frost buildup on the outdoor coils. When the system enters this mode, it is effectively cooling the indoor air to bring heat to the outdoor units. Customers should be made aware of the defrost cycle, when it is likely to occur, how long it should last, and the fact that during defrost, the indoor unit might produce cold air for a short period of time.

Literature Review Connections

NEEA's *Maximizing Mini-Split Performance* report identified the following practical recommendations (Trager, 2021):

- Ensure homeowners are educated that heat pumps are not just air conditioners and can provide heat for much of the year.
- Homeowners should understand controls and how to set them. For simplified controls, *set it and forget it* can work well and should require the homeowner to set the device for heating and cooling manually. In addition, understanding low setbacks for the new heat pump and appropriate thermostat settings/controls for backup heat is critical.
- Compressors and heads must be installed in correct locations, and outdoor compressors must be kept free of debris and blockages/obstructions.

Maintenance Expectations

Knowledge	Resources	

The maintenance needs of VSHPS are also a little different than those for natural gas systems and traditional split ACs. Informed operators should conduct their own maintenance for certain situations and use contractor service agreements for others. Knowledge of the following maintenance needs is necessary for VSHP operators:

Keep outdoor units clear of snow and debris: Outdoor units require unobstructed airflow to operate properly. Winter snowfall, autumn leaves, and unkempt shrubs can block airflow. Ideally, the outdoor unit is placed above the snow line, away from shrubs, and in a location where leaves do not naturally accumulate. However, occasions may still arise when a homeowner should clear the outdoor unit of blockages.

Filter cleaning and replacement: Each heat pump comes with a manufacturer-recommended filter cleaning and replacement schedule. For ductless heat pumps, monthly cleaning is typically recommended. Cleaning is a simple process of sliding out the air filter and wiping, rinsing or vacuuming off accumulated dust or dirt. For ducted systems, the recommendation is to replace the air filter located in the duct's air handler every six months. Cleaning and replacement schedules vary by usage frequency. Obstructed filters will hurt efficiency and the unit's ability to supply sufficient heating and cooling.

Routine service check-ups: Most manufacturers encourage annual or biannual maintenance from a professional. The inspection includes checking ducts, blowers, and filters for damage or obstructions; confirming adequate airflow; checking for refrigerant leaks and repairing them; replacing lost refrigerant; inspecting electric terminals, cleaning or tightening connections, and applying non-conductive coatings; lubricating motors and inspecting belts for tightness and wear; verifying sensors are working properly; confirming condensate draining is unobstructed; cleaning the outdoor unit of leaves, pine needles, and other dirt; and cleaning dirty indoor and outdoor coils.

Literature Review Connections

The DOE further stresses the importance of proper heat pump maintenance for system longevity and ensure that the system is performing at the appropriate efficiency level (United States Department of Energy (DOE), n.d.). According to the DOE, the energy consumption of a well-maintained system versus a neglected system can range from 10% to 25% more energy use in the neglected system. The DOE also mentions a customer and contractor knowledge gap regarding continuous indoor fan operation, which can degrade heat pump performance unless the system is a high-efficiency, variable speed fan motor—something that may not be well-known, particularly by customers.

Integration with Backup or Supplemental Heat

Knowledge	Resources	Practice

Ensuring that homeowners and tenants understand their backup or supplemental heating system's intentions, methods, and expectations is critical. An operator can easily override some commonly integrated control setups, particularly the *droop* method, which relies on a small difference in heating setpoints between the heat pump and the natural gas backup system or zonal electric heating system. An integrated control system that employs a switchover temperature below which the heat pump turns off and backup or supplemental heat source turns on, can be problematic if the system uses a slow-acting distribution method such as radiant floors or baseboard heaters. A homeowner might engage the less efficient supplement heating rather than waiting for the slow response time to catch up.

Further, operators whose integrated control system relies on separate thermostats for each heating system should be aware of their thermostat locations and how that impacts them being triggered to make a heating call.

Literature Review Connections

NEEA found in a survey of consumers in the Northwest that consumer interest in the early replacement of heating systems is low (Van de Grift, 2015). Most consumers intend to purchase only when their current system breaks down. On the other hand, installing ductless heat pumps in homes with an oil or propane boiler will often bring air conditioning to a home, which is attractive to some homeowners. A customer survey on ductless heat pump installations in Massachusetts indicated that the majority of ductless heat pump installations were undertaken to improve comfort, particularly for cooling, and not to save energy (Vitoff, 2014). Most of these installations supplemented, rather than replaced, existing heating systems. Thus, adding cooling to homes lacking it can be an important segment for the market penetration of heat pumps.

Lack of Informational Feedback Loops

	Resources	

VSHPs, due to their modulation in reaction to variable indoor and outdoor conditions, have an impressive ability to keep occupants from noticing when some aspect of the system is not working properly. Blocked filters, minor refrigerant losses, obstructed outdoor units, and other issues may lead to lost efficiency and suboptimal comfort—but the VSHP may keep operating well enough to escape notice. Few informational feedback loops exist to indicate something is wrong. Quality routine maintenance from a service professional should catch such issues. Still, homeowners do not often follow the maintenance recommendations for their systems. Maintenance technicians may operate too quickly to catch errors if they are not prompted to look deeply into a customer's satisfaction issues. The market would benefit from research that evaluates the performance of older heat pump systems that have experienced various maintenance schedules to quantify the frequency and impacts of gaps in standard maintenance. Such data would spur improved best practices and provide customers with data to help convince them to follow manufacturer guidance on routine maintenance, both for measures within their own control and those requiring the use of professional services.

3.3.2 Maintenance Technician

Refrigerant Charge Verification

Knowledge		

Section 3.2.3: Commissioning discusses refrigerant charge and charge verification challenges at installation. Routine maintenance also commonly checks and confirms refrigerant charge and tests for refrigerant leaks. Similar issues present themselves at these periods of maintenance, as well as at installation.

During maintenance, the process of attaching gauges may contaminate the system or create a leak (at the service valve). The use of non-invasive (gauge-less) methods can give service technicians a relatively accurate indication of the refrigerant charge that can be confirmed with a (gauged) subcooling test. However, such non-invasive tests are only possible in a narrow band of conditions. If maintenance is performed when these ambient conditions are not met, the technician is faced with skipping refrigerant level diagnostics altogether or risking unnecessary contamination by hooking up a gauge. Systems with onboard diagnostics or aftermarket diagnostics integrated controls provide technicians a better sense of when more invasive verification is necessary.

Electrical Issue Diagnostics

Knowledge	Resources	

VSHPs are more complicated electronically than natural gas furnaces or boilers. They are also typically more complex than even standard split air conditioning or heat pump systems. Companies that pivot from traditional natural gas heating systems to VSHPs often do not have either the tools or the knowledge to identify, diagnose, or repair electrical issues appropriately. Electrical issue diagnostic failures cost every party with lost efficiency and lost labor, as the technician struggles to discover root causes they are not trained to identify.

4 Gap Analysis

This chapter presents recommendations to address 26 identified best-practice gaps. Each gap's description and recommendation are accompanied by a short narrative describing nuances of the gap or recommendation, as well as specific literature or resources that directly relate to the gap, when available. Gaps are not listed in any particular order. Detailed explanations of each gap are provided in chapter 3.

Table 5: Gap Recommendations

Type	Name
Knowledge better technical understanding and research is needed	Heat Distribution Design
	Integrated Controls
	Daily Setback Data
	VSHP System Design in Homes with Existing Heat
	Improper Refrigerant Charge
	Defrost Information
	Duct Losses with Variable Speed Fan
Resource Better tools and resources are needed	Heat Distribution Design
	VSHP System Design in Homes with Existing Heat
	Breaker Upgrades
	Consumer Expectations
	Airflow/Power Testing
	Defrost Information
	Efficiency Ratings
Practice improved contractor standards of practice are needed	Load Calculations
	Sizing for Heat
	Lockout Control
	Heat Distribution
	VSHP System Design in Homes with Existing Heat
	Airflow/Power Testing
	Sales Based on HSPF and SEER
	Duct Design
	Hearts and Minds
	Refrigerant Line Connections
	Snow Protection
	Installation Quality

4.1 Knowledge Gaps: Recommendations for Future Work

Energy use and energy efficiency research is needed for utilities and consumers to make accurate and informed choices for heat pumps. Research is conducted, encouraged, and sponsored by organizations such as ACEEE, regional energy efficiency organizations, state and federal agencies, and utilities. Some research comes in the form of efficiency program evaluations, which are commissioned to confirm that energy savings claimed by utility programs to meet regulatory requirements are accurate. Due to these driving forces, most of the energy efficiency research conducted to date on residential heating and cooling has been specific to the most common space conditioning technologies—natural gas furnaces, boilers, and split air conditioning. VSHPs have not had enough market share for long enough to warrant the same level of attention. This has led to gaps in practical knowledge on VSHP operation and optimizing for energy efficiency.

Knowledge Gap 1: Heat Distribution Design Impacts

Best Practices Gap	Description	Recommendations
Heat Distribution Design Impacts	Lack of knowledge on the situations in which an individual room can maintain year-round comfort without its own heat source. For multi-split systems, lack of knowledge on the relationship between number of connected indoor heads and efficiency.	Conduct studies to assess comfort in indirectly-heated residential rooms. Study the relationship between the number of connected indoor units and energy use.

Using ductless VSHPs for whole-house applications becomes prohibitively expensive when a heat pump head is placed in every bedroom of the home. Placing even with the lowest-capacity single head in every bedroom commonly results in oversizing because room loads are generally less than a single head. No other heating technology has the same dynamic. Based on anecdotes from installers who specialize in this approach, all rooms in a home can be kept comfortable, even in cold climates, without installing a head in each room—but it takes planning: consideration of room-by-room heat loss and internal thermal transfer between rooms.

To understand more about the knowledge gap surrounding heat distribution design impacts refer to Appendix B (Ueno, 2014).

Knowledge Gap 2: Integrated Controls

Best Practices Gap	Description	Recommendation
Integrated Controls	Sufficient information is lacking regarding which integrated control methods successfully prioritize the heat pump and under which conditions they may fail.	Conduct research studies on various integrated control setups. Develop methods of testing to identify which systems deliver desired outcomes

Multiple studies related to integrated controls are ongoing. These studies are testing control methods and technologies recently introduced into the market. The Mass Saves program introduced an integrated control specification in 2019; Consolidated Edison (ConEd) in New York started using the same definition for an elevated incentive offering in September 2021. The number of control options continues to expand, including control concepts highly focused on specific heating system arrangements. New control strategies need to be tested and analyzed as they begin to be used.

To understand more about the current knowledge gap surrounding integrated controls refer to Appendix B (Schoenbauer, 2017).

Knowledge Gap 3: Daily Setback Data

Best Practices Gap	Description	Recommendation
Daily Setback Data	Lack of knowledge on which daily setback methods and home conditions lead to higher energy use.	Conduct research to quantify annual VSHP energy use under various thermostat setback setups.

The conventional wisdom is that deep daily setbacks do not, on net, save energy with VSHPs the way they do with natural gas heating systems. However, TRC could not find underlying research or data to support this wisdom, nor any definition of what constitutes “deep.” Though energy savings could likely accrue through better controls, the industry needs data to confirm which types of controls, settings, and conditions lead to energy savings, and which lead to losses.

The literature reviewed in Appendix B did not specifically mention the knowledge gap about daily setback data despite this gap being highlighted by subject matter experts.

Knowledge Gap 4: VSHP System Design in Homes with Existing Heat

Best Practices Gap	Description	Recommendation
VSHP System Design in Homes with Existing Heat	Retrofit scenarios provide a myriad of challenges that span sizing, system selection, distribution design, controls, and customer expectations.	Continue to expand on research that quantifies energy use and the underlying causes of inefficient energy use in homes with redundant heating systems.

In particularly cold climates, contractors and consumers are reluctant to make homes entirely reliant on VSHPs for year-round heating. However, leaving two heating systems intact introduces significant controls and efficiency challenges. Studies could shed light on the homes, system types, and control methods for the best results for VSHP efficiency and performance.

To understand more about the knowledge gap surrounding VSHP system design in homes with existing heat refer to Appendix B (Van de Grift, 2015; Vitoff, 2014).

Knowledge Gap 5: Improper Refrigerant Charge

Best Practices Gap	Description	Recommendations
Improper Refrigerant Charge	Lack of knowledge re: the frequency of improper refrigerant charge and its impact specific to VSHP operation in heating mode.	Perform post-install quality control inspections that test refrigerant charge and quantify the frequency of improper charge. Conduct research that quantifies the energy use impact of improper charge with VSHPs in heating mode.

The issue of improper refrigerant charge persists in the VSHP market and the overall HVAC market. Contractors are pressed for time and do not always follow best practices in charging or charge verification. VSHPs introduce two countervailing facts that automatically mitigate some of the worst parts of poor refrigerant charge experienced with other heat pumps or air conditioners. First, a VSHP system's ability to modulate performance can cover for a refrigerant charge that is slightly off. Second, for systems designed to stay within the manufacturer's refrigerant line length guidance, maintaining proper refrigerant charge is fairly easy. Concerns of improper refrigerant charge with most VSHPs may be overwrought. The market would benefit from data that evaluates the frequency and magnitude of improper refrigerant charging specific to VSHPs and the correlation of poor charge to the system types and installation conditions, such as line lengths. Additional data capturing the efficiency and comfort penalties of improper charge with VSHPs in the heating season would help the market understand the impacts of an improper charge.

The literature reviewed in Appendix B did not specifically mention the knowledge gap about improper refrigerant charge despite this gap being highlighted by subject matter experts.

Knowledge Gap 6: Defrost Information

Best Practices Gap	Description	Recommendation
Defrost Information	VSHP product manuals do not reveal enough information regarding defrost methods, control options, and their energy impacts.	Conduct research on energy impacts of defrost methods and control options. Develop methods of test to evaluate what systems have good defrost control systems

Currently, VSHP product manuals lack sufficient information regarding defrost methods, control options, and their energy impacts. Given the intended applications of VSHPs in colder climates, this information is pertinent to ensure proper equipment efficacy and maintenance. Data on the energy impacts of defrost methods and control options would help to improve VSHP operations in colder climates.

To understand more about the knowledge gap surrounding defrost information refer to Appendix B (Schoenbauer, 2017).

Knowledge Gap 7: Duct Losses with Variable Speed Fan

Best Practices Gap	Description	Recommendation
Duct Losses with Variable Speed Fan	Lack of knowledge re: how convective and conductive heat loss in ducts impacts energy use with variable speed fans and variable capacity heat output.	Research heat loss in ducts across VSHP operating conditions and determine lower bounds where duct losses outweigh efficiency gains from VSHP modulation.

Heat loss from ducts is inevitable. Variable speed fans and variable supply temperatures inherent with VSHPs will lead to convective and conductive heat loss that differs from the duct heat loss values well-studied in split ACs and fixed-speed heat pumps. Research that focuses on heat loss in ducts across VSHP operating conditions and determining the lower bounds where duct losses outweigh efficiency gains from VSHP modulation would help determine the proper system settings to minimize heat loss and achieve the most efficient heating system possible.

To understand more about the knowledge gap surrounding duct losses with variable speed fans refer to Appendix B (Modera, 1994).

4.2 Resource Gaps: Utility, Trade Organizations, and Manufacturers

Utilities, efficiency agencies, trade organizations, and manufacturers support HVAC contractors by creating and distributing best-practice resources to the market. These come in guides, technical manuals, training, calculators, software, case studies, and checklists. TRC's resource inventory captured the current state of such resources, as described in Section 2.1: Resources Inventory and listed in Appendix A. This section describes specific resource gaps TRC identified in its gap analysis and recommendations for parties to resolve the gap partially. As a shorthand, this chapter refers to these as utility resource gaps.

This section presumes that utilities, efficiency agencies, trade organizations, and manufacturers are intrinsically motivated to create and supply such resources. For manufacturers, the motivation is to increase sales. For trade organizations, it is to fulfill their mission statements and support members in increasing sales. The motivation for utilities and efficiency agencies is to support energy efficiency and/or decarbonization goals in the sector as market transformation or as claimed energy savings. For many utilities, this motivation is not sufficiently met. In such utility-focused cases below, the recommendations will have minimal impact, as those utilities will not be invested in creating quality resources, training contractors, enforcing new program rules, or fulfilling their role of quality control over incentive programs.

Resource Gap 1: Heat Distribution Design

Best Practices Gap	Description	Recommendation
Heat Distribution Design	Most HVAC installers are not practiced in considering, evaluating, and optimizing across heat pump distribution options.	Develop decision trees and application guides contractors can use to evaluate VSHP distribution options for a home based on its layout, the existing heating system, and the customer's intentions.

Heat pump distribution design can be complicated. The contractor must consider the home type, current heating method, and customer's intentions and combine them with knowledge of the various heat pump distribution methods available. This can make heat distribution planning seem customized for every house, adding to installation costs. Most markets have predominant home types and frequently-installed existing heating system types. Utilities would help the market by creating decision trees and application guides that steer contractors toward pre-defined, repeatable solutions.

To understand more about the utility resource gap surrounding heat distribution design impacts refer to Appendix B (Ueno, 2014; NYSERDA, n.d.).

Resource Gap 2: VSHP System Design in Homes with Existing Heat

Best Practices Gap	Description	Recommendation
VSHP System Design in Homes with Existing Heat	Retrofit scenarios in homes with existing heat provide a myriad of challenges that span sizing, system selection, distribution design, controls, and customer expectations.	Improve upon integrated control specifications and program requirements that provide precedence to the heat pump.

This resource gap is an active work in progress. The intention is that heat pumps have precedence over the backup system to provide heating for as much of the home's load as is cost-effective and operationally functional. Overlapping national efforts are underway to improve this topic's best-practice guidance. Such efforts leverage a combination of customer education, integrated controls specification, and heat pump installation requirements that ensure winter operation is viable (such as enforcing snow protection). Some programs (such as NYS Clean Heat in Con Edison territory) have begun incenting homes to actively decommission the existing heating system to remove the conflict entirely. Program guidance will vary based on the climate, the overlap of heating system zones, the backup heating system type, the customer's intentions, and more; no universal guidance can capture all scenarios. This resource gap will be mitigated through better program understanding of integrated control options and then enforcing appropriate program rules and requirements. Since research and understanding are actively changing, any program guidance and rules should be evaluated for efficacy and re-assessed annually.

To understand more about the utility resource gap surrounding VSHP system design in homes with existing heat refer to Appendix B (Van de Grift, 2015; Vitoff, 2014; NMR Group Inc., DNV GL Inc., 2020).

Resource Gap 3: Breaker Upgrades

Best Practices Gap	Description	Recommendations
Breaker Upgrades	Utility programs do not understand or consider the impact of adding breakers or upgrading electrical panels.	Provide training or resources to participating contractors to better understand when electrical upgrades are required. Provide additional incentives to offset added costs of breaker/panel upgrades when necessary. Provide incentives for panel-management products that remove the need for a service upgrade.

Heat pump incentive programs consistently ignore electric system upgrade needs. Only a small percentage of HVAC contractors have the knowledge to consistently and appropriately plan for and manage electric system upgrades. Generally, electrical upgrades are necessary less frequently than most contractors assume, and erring on the side of utmost caution is easy to do. Detailed guides created with input from electricians and knowledgeable heat pump contractors would benefit the market. Further, providing increased incentives to offset a portion of the added costs for necessary electrical system upgrades would support customer equity in program design.

The literature reviewed in Appendix B did not specifically mention the utility resource gap regarding breaker upgrades despite this gap being highlighted by subject matter experts.

Resource Gap 4: Consumer Expectations

Best Practices Gap	Description	Recommendation
Consumer Expectations	Consumers have inaccurate expectations of how their heat pumps should operate, leading them not to use them, or to request unnecessary service calls.	Create consumer education materials that contractors and/or programs give to customers to reduce misperceptions.

Consumers unhappy with their heat pump's performance not only reduce heat pump use in their own houses; they can also cost contractors with unnecessary call-backs and hurt adoption rates by complaining to neighbors and friends. Often, the root cause isn't poor heat pump performance; it's poor consumer awareness of operating expectations. Consumer education will help reduce these adverse effects. Repetition and multiple sources help people learn, so having the same message come both from the utility program and the contractor would be beneficial.

To understand more about the utility resource gap surrounding consumer expectations refer to Appendix B (Nadel, 2018; Pickard, 2020).

Resource Gap 5: Airflow/Power Testing

Best Practices Gap	Description	Recommendation
Airflow/Power Testing	Industry standard airflow and operating power test methods do not properly apply to VSHPs that respond dynamically to conditions.	Develop new testing protocols that measure airflow and power draw for VSHPs and allow the technician to diagnose issues accurately.

Field testing and product commissioning procedures take substantial time and investment to develop, vet and approve. This recommendation to develop new testing protocols to measure airflow and power draw for VSHPs represents a considerable investment and effort, probably best undertaken by a partnership of institutional entities.

The literature reviewed in Appendix B did not specifically mention the utility resource gap regarding airflow/power testing despite this gap being highlighted by subject matter experts.

Resource Gap 6: Defrost Information

Best Practices Gap	Description	Recommendation
Defrost Information	VSHP product manuals do not reveal enough information regarding defrost methods, control options, and their energy impacts.	Encourage manufacturers to disclose each product's defrost method and any available data on energy use in product manuals and technical guides.

As knowledge advances to correlate defrost methods and controls to energy use, utilities should create best-practice guides or program guidance that point to specific methods and controls as either preferred (through higher incentives), required, or excluded. Savings claim calculations like those put forward by the northwest's Regional Technical Forum or used in state technical resource manuals could be adapted to include differences in defrost methods as an input to the savings claim methodology. In the interim, groups such as the Advanced Heat Pump Coalition could lobby manufacturers to indicate their system's defrost methods and controls more prominently in technical data sheets and installation manuals.

To understand more about the utility resource gap surrounding defrost information refer to Appendix B (Schoenbauer, 2017).

Resource Gap 7: Efficiency Ratings

Best Practices Gap	Description	Recommendation
Efficiency Ratings	The standard efficiency ratings, HSPF and SEER, are not indicative of efficiency performance in the field for VSHPs.	Continue to develop, test, then promote the use of dynamic voluntary efficiency rating structures such as CSA-EXP-07.

This recommendation is a long-term project that needs buy-in from a broad group of utility and efficiency organization programs and perhaps also from energy codes as a performance credit. Manufacturers will not incur the expense of voluntary testing to fulfill the needs of only a small region. Widespread support of improved ratings is perhaps one of the most market transformational actions that can be taken as it will shift product capabilities, consumer confidence, and utility forecasting accuracy.

The literature reviewed in Appendix B did not specifically mention the utility resource gap regarding efficiency ratings despite this gap being highlighted by subject matter experts.

4.3 Practice Gaps: HVAC Contractors

HVAC contractors vary widely in terms of their capabilities, awareness, and installation quality. This section speaks broadly of contractor challenges; none of the identified gaps are universal across the market. In any market, some contractors do follow best practices and have developed successful business models that include proper design, installation, and commissioning despite the inherent challenges.

At their core, the challenges below mainly stem from an issue of cost. Doing things right costs money, and in a competitive installers' market, that extra cost will not be easily recouped from higher customer charges. With VSHPs, where the heat pump's modulation can often mask moderately poor performance, the contractor may pay no penalty for suboptimal design or installation. Instead, the negative impacts of those decisions impact the customer, through comfort or energy bills, or the utility through reduced realized savings or claw-back based on evaluation results.

All three of the following conditions must be met to resolve HVAC contractor challenges fully:

1. The contractor must adequately understand the underlying technical issue and believe in its relevance and impact on energy use and customer comfort.

2. The customer, or a utility incentive, must financially compensate the contractor for the time and effort to do the right thing.
3. A utility program or code enforcement agent must verify the work was done correctly with real penalties for work that does not comply with requirements.

This chapter's recommendations are written from the perspective of a utility program manager or energy efficiency organization that is designing incentive programs or participating network support structures.

Contractor Practice Gaps 1: Load Calculations

Best Practices Gap	Description	Recommendation
Load Calculations	Contractors do not perform accurate load calculations when they would be impactful.	Develop guidance on when load calculations (and to what level of detail) are needed and support tools that reduce contractor burden. Support mechanisms to pay contractors to perform load calculations. Support integration of free, easy to use load calculation tools that are integrated with product performance database (e.g. NEEP QPL).

Much of the reluctance to perform full, detailed Manual J load calculations for every house is warranted. Detailed Manual J load calculations are not commonly done by contractors as rules of thumb are sufficient for providing comfort, but are inadequate for optimizing system performance. Current load calculation tools both require more knowledge, time and lack detailed integration with product data that can guide equipment selection. A free and easy to use tool that is associated with product performance database could provide multiple contractor benefits that would increase the probability that a load calculation was done prior to equipment selection.

Many utility incentive programs universally require Manual J load calculations for all projects and then do not (or cursorily) conduct quality control confirmation on the submittals. This creates a sense that programs are excessively burdensome with unnecessary paperwork. It also fosters an environment where program implementers do not have sufficient oversight for the instances that would truly benefit from the Manual J approach. Better would be to require Manual J calculations only in specifically defined scenarios and allow contractors to use alternative methods to determine the home's heating load with other program applications. In this scenario, an incentive structure that helped offset some of the costs of the full Manual J process when required would improve program equity across utility customers.

The literature reviewed in Appendix B did not specifically mention the contractor practice gaps relating to Manual J load calculations despite this gap being highlighted by subject matter experts.

Contractor Practice Gaps 2: Sizing for Heating

Best Practices Gap	Description	Recommendations
Sizing for Heating	Contractors do not understand and/or apply concepts, such as capacity degradation and turn-down, when selecting a product in a heating-dominated climate.	Support uptake of sizing, design, and product selection training specific to VSHPs modulating performance. Incent heat pumps based on capacity at winter design conditions. Steer contractors to leverage the NEEP ccASHP product database, or manufacturers' expanded performance tables, to get a holistic view of heat pump performance across various conditions.

Even experienced contractors can struggle with understanding and applying capacity degradation and turn-down in a heat pump's product selection and sizing determination. Those accustomed to sizing for cooling, or sizing for heating with natural gas systems or single-speed heat pumps, may need repeated reminders and support on best practices for sizing VSHPs for heating applications. A combination of contractor training and program processes that force contractors to look at capacity variation across temperatures will support the market transition to a better understanding and application of these concepts.

The literature reviewed in Appendix B did not specifically mention the contractor practice gaps relating to sizing for heating despite this gap being highlighted by subject matter experts.

Contractor Practice Gaps 3: Lockout Control

Best Practices Gap	Description	Recommendation
Lockout Control	Contractors set controls of supplemental heat (electric resistance or natural gas) to minimize call backs rather than maximizing system efficiency.	Work with manufacturers to incorporate efficient lockout control options as default setup. Provide utilities and training organizations with guidelines and clarity on why new VSHPs do not require as much supplemental heat and how safely avoid callbacks.

Contractors often fail to program the back-up heating system's lock-out controls that give primacy to the heat pump whenever it can meet the home's load. A well designed VSHP system does not need any backup heat when the heat pump can provide 100% of the load. This issue can be reduced in part by improving upon contractor training and awareness. This could give contractors learned faith in the capability of the heat pump to fulfill the load without call backs and a better understanding of the intention of lockout controls and. If better informed more contractors would choose to avoid installing back-up heat entirely, thus also reducing the customer's system cost. In scenarios where backup is appropriate, informed contractors will be more willing and ready to use the right lock-out control. This has been shown in the data of the Performance Tested Comfort Systems program which requires auxiliary heat lockout controls and supports contractor training to understand and fulfill the requirement.

A complimentary market improvement is to have manufacturer's program default control options of their products to be in the appropriate temperature range right out of the box.

The literature reviewed in Appendix B did not specifically mention the utility resource gap regarding lockout controls despite this gap being highlighted by subject matter experts.

Contractor Practice Gaps 4: Heat Distribution Design

Best Practices Gap	Description	Recommendation
Heat Distribution Design	Most HVAC installers are not practiced in considering, evaluating, and optimizing across heat pump distribution options.	Support uptake of training for VSHP heating distribution design options.

Distribution system design for heat pumps is more complicated than it is for natural gas systems, with its additional options and considerations. Utilities, efficiency organizations, manufacturers, and trade organizations can collectively provide contractor training, echoing the same concepts from multiple voices. Some of these training already exist but need more traction and uptake. Methods to support expanded training uptake include the use of participating contractor requirements, program onboarding training, training cost offsets, and training promotions.

To understand more about the contractor practice gap surrounding heat distribution design impacts, as described in **Error! Reference source not found.** above, refer to Appendix B (Ueno, 2014).

Contractor Practice Gaps 5: VSHP System Design in Homes with Existing Heat

Best Practices Gap	Description	Recommendation
VSHP System Design in Homes with Existing Heat	Retrofit scenarios provide a myriad of challenges that span sizing, system selection, distribution design, controls, and customer expectations.	Court and develop all-star contractors with a deep understanding of VSHP systems and their interactions with backup/supplemental heat.

As knowledge and resources on this topic improve (see above sections), utilities can help contractors by relaying best-practice findings to the market through webinars and emails. In the interim, some contractors in most markets have engaged with this issue enough to date to have a good process, approach, and rules of thumb at their disposal to consistently achieve good integrated outcomes. Utility programs should cultivate such companies and individuals, learn from them, and, if viable, promote them with contractor awards and program status elevation.

To understand more about the contractor practice gap surrounding VSHP system design in homes with existing heat refer to Appendix B (Van de Grift, 2015; Vitoff, 2014).

Contractor Practice Gaps 6: Airflow/Power Testing

Best Practices Gap	Description	Recommendation
Airflow/Power Testing	Industry standard airflow and operating power test methods do not properly apply to VSHPs that respond dynamically to their conditions.	Support contractor training on appropriately using and interpreting currently available test methods when applicable.

Most programs do not include commissioning requirements or support. Those that do should first review the applicability of their requirements to VSHPs and ensure they are appropriate to the technology type and not simply a carryover from other HVAC program designs. Such utilities should then provide clear guidance on airflow and power draw test methods and expectations.

The literature reviewed in Appendix B did not specifically mention the contractor practice gaps relating to airflow/power testing despite this gap being highlighted by subject matter experts.

Contractor Practice Gaps 7: Sales Based on HSPF and SEER

Best Practices Gap	Description	Recommendation
Sales Based on HSPF and SEER	Contractors select and sell products centered on their HSPF and SEER rather than actual whole-system performance.	Train (and incent) contractors to conduct proper load calculations, system selection, and distribution design—and to include quality whole-home design as a key sales differentiator.

This best-practice gap is a deeply acculturated sales norm that will be difficult, if not impossible, to stamp out entirely. Utilities can support their participating contractor networks in reducing their reliance on SEER and HSPF ratings by helping them understand the greater extent to which other metrics, particularly maximum and minimum capacity at various temperatures, matter for proper VSHP sizing and selection. This can counter the industry's use of SEER ratings in marketing materials and as a primary basis of pricing. The industry's over-reliance on SEER undermines the use of VSHP sizing principles, climate-specific COP values, and house-specific capacity criteria.

The literature reviewed in Appendix B did not specifically mention the contractor practice gaps relating to sales based on HSPF and SEER despite this gap being highlighted by subject matter experts.

Contractor Practice Gaps 8: Duct Design

Best Practices Gap	Description	Recommendation
Duct Design	Contractors do not properly design or redesign ducts for ducted VSHP installations.	Support mechanisms to pay contractors to follow duct-design best practices, including recognizing homes in which converting to a ductless application may be better.

Utility programs should provide clear guidance on duct requirements when existing ducts are repurposed for use by a new VSHP. Such systems should be treated as a particular circumstance/installation method that deserves higher incentives, informational support, and quality control. The program should emphasize that the contractor needs to examine airflow on *all* repurposed existing ducts and that *most* repurposed ducts will need to be redesigned to fulfill their new purpose. Programs can also point out situations in which the use of ductless heat pumps, or new ducting, may be more appropriate and cost-effective.

The literature reviewed in Appendix B did not specifically mention the contractor practice gaps relating to duct design despite this gap being highlighted by subject matter experts.

Contractor Practice Gaps 9: Hearts and Minds

Best Practices Gap	Description	Recommendations
Hearts and Minds	Contractors do not believe heat pumps are a viable year-round heating technology in cold climates.	Demonstrate case studies of successful year-round comfort from heat pumps. Use peer-to-peer messaging to show HVAC contractors that heat pumps can fulfill year-round heating needs.

Contractors are risk-averse. The costs of unsatisfied customers—through call-backs or word-of-mouth reputation impacts—are substantial. Therefore, it will take persistent messaging from trusted information sources to change *hearts and minds* and give contractors the confidence to use heat pumps as the sole or primary heating technology in cold climates. Interviews with contractors and distributors conducted by TRC for NYSERDA revealed that contractors are unlikely to perceive utility staff or implementation contractors as trustworthy sources of information on the efficacy of heat pumps. Instead, they will turn to their peers and real-world evidence to update their presumptions and expectations.

To understand more about the contractor practice surrounding hearts and minds refer to Appendix B (Nadel, 2018, (Pickard, 2020)).

Contractor Practice Gaps 10: Refrigerant Line Connections

Best Practices Gap	Description	Recommendations
Refrigerant Line Connections	Contractors do not properly flare or braze refrigerant line connections due to lack of knowledge, lack of practice, or lack of quality tools.	Support flare, brazing, and compression fitting training that includes a focus on why refrigerant leakage is so problematic. Buy down the costs of higher-quality flaring and brazing tools for contractors that take training.

Fulfilling goals and expectations for accelerated heat pump adoption will require a significant increase in capable and trained installation technicians. Making refrigerant line connections is the most challenging functional skill for a new installer. The impact of failed refrigerant connections—including leaking high-global-warming-potential chemicals into the atmosphere, poor heat pump performance for both efficiency and comfort, and damage to compressors leading to early breakdown—are all particularly damaging to the objective of heat pump adoption. New installers will need more support in learning and practicing this skill than is currently available. Training from distributors and manufacturers, reminders by utility programs, and cost buy-downs for quality tools will help improve quality during workforce expansion.

The literature reviewed in Appendix B did not specifically mention the contractor practice gaps relating to refrigerant line connections despite this gap being highlighted by subject matter experts.

Contractor Practice Gaps 11: Snow Protection

Best Practices Gap	Description	Recommendation
Snow Protection	Contractors do not ensure outdoor units are protected from snow.	Enforce outdoor-unit snow-protection requirements in incentive programs and/or energy codes, considering snow accumulation below the unit and snowslide from a roof eave above the unit.

Heat pumps must have free airflow through the outdoor unit to operate. Excess snow and ice can block airflow or damage fans. Installers accustomed to placing outdoor units for air conditioners or heat pumps intended principally for cooling purposes often fail to consider snow protection. The NYS Clean Heat incentive program demonstrates that[12] program requirements and quality control regarding snow protection can successfully change market norms.

The literature reviewed in Appendix B did not specifically mention the contractor practice gaps relating to snow protection despite this gap being highlighted by subject matter experts.

[12] https://cleanheat.ny.gov/

Contractor Practice Gaps 12: Installation Quality

Best Practices Gap	Description	Recommendation
Installation Quality	Contractors cut corners during installation on items such as refrigerant line insulation/UV protection, unit clearances, vibration dampers, and unit leveling.	Determine which installation failures have actual impacts on efficiency, comfort, or customer acceptance and conduct rigorous training and quality control inspections to enforce them.

In 2021, the NYS Clean Heat's quality control program[13] found 694 non-conformances in 360 installations out of 766 inspections. 28% of projects did not install refrigerant line insulation and UV protection to program requirements. 7% of projects failed to install as per manufacturer outdoor and/or indoor unit clearance requirements. By separating major and minor defect categories, the program can use the quality control process to teach installation best practices to participating contractors without overly penalizing installation defects that have a lower impact. The program has successfully trained participants, as shown by persistent improvement in installation quality with contractors that initially received failing quality control grades.

The literature reviewed in Appendix B did not specifically mention the contractor practice gaps relating to installation quality despite this gap being highlighted by subject matter experts.

[13] https://saveenergy.ny.gov/NYScleanheat/assets/pdf/NYS-Clean-Heat-Program-Manual.pdf

Bibliography

Amarnath, A., Beaini, S., Hunt, W., Domitrovic, R., Tam, A., & Vaddiraj, A. (2021). *Development and Testing of the Next-Generation Residential Space Conditioning System for California.* EPRI. Palo Alto: California Energy Commission. Retrieved from https://www.energy.ca.gov/sites/default/files/2021-11/CEC-500-2021-049_0.pdf

Bertsch, S. S. (2008). *Two-stage air-source heat pump for residential heating and cooling applications in northern US climates.* International journal of refrigeration, 31(7), 1282-1292.

Bopp, D. (2021, December 7). *Single Family Duct Sealing*. Retrieved from NW Council: https://nwcouncil.app.box.com/v/20211207SFDuctSealingPres

Margolies, J. G. (2019). *Dual Fuel AirSource Heat Pump.* Michigan Electric Cooperative Association (MECA). https://slipstreaminc.org/sites/default/files/documents/research/dual-fuel-air-source-heat-pump-pilot.pdf

Modera, J. (1994). *Field Measurement of the Interactions Between Heat Pumps and Attic Duct Systems in Residential Buildings.* Retrieved from https://www.osti.gov/servlets/purl/34373

Nadel, S. (2018). *Energy savings, Consumer economics, and greenhouse gas emissions reductions from replacing oil and propane furnaces, boilers, and water heaters with air-source heat pumps.* Washington, DC: American Council for an Energy-Efficient Economy.

NMR Group Inc., DNV GL Inc. (2020). *Evidence for Market Effects from Support for Ductless Mini-split Heat Pump Integrated Controls.*

NYSERDA. (n.d.). *Heat Pump Planner*. Retrieved from NYSERDA: https://www.nyserda.ny.gov/All-Programs/Heat%20Pump%20Program/Heat%20Pump%20Planner

PG&E. (2018). *Central Valley Research Homes: Evaluation of Ducted and Ductless Configurations of Variable Capacity Heat Pumps.*

Pickard, N. H. (2020, April 14). *Understanding Market Barriers and Opportunities for Cold-Climate Air Source Heat Pumps in Residential Households*. Retrieved from Minnesota Department of Commerce, Division of Energy Resources: https://mn.gov/commerce-stat/pdfs/2020_cadmus_ccashp-market.pdf

Schoenbauer, B. K. (2017). *Cold Climate Air Source Heat Pump.* Washington, D.C.: ACEEE.

SDCI Community Engagement. (2021, July 13). *Heat Pump Refrigerant Line Insulation Requirements Under Seattle Energy Code*. Retrieved from Building Connections: https://buildingconnections.seattle.gov/2021/07/13/heat-pump-refrigerant-line-insulation-requirements-under-seattle-energy-code/

Shen, B. B. (2017). *Finalize field testing of cold climate heat pump (CCHP) based on tandem vapor injection compressors.* Oak Ridge, TN: Oak Ridge National Lab.(ORNL).

Trade Ally Network Northwest. (2021, July 21). *Webinar: Cold Climate Heat Pumps.* Retrieved from Trade Ally Network Northwest: https://www.tradeallynetworknw.com/resources/webinar-cold-climate-heat-pumps/

Trager, S. G. (2021). *Maximizing Mini Split Performance: a Meta,Market, and Measure Study.* Northwest Energy Efficiency Alliance.

U.S. Department of Energy (DOE). (2021, December 8). *Energy Conservation Program: Energy Conservation Standards for Residential.* Retrieved from Department of Energy (DOE): https://www.energy.gov/sites/prod/files/2016/12/f34/CAC_HP_DFR_NOPR.pdf

U.S. Department of Energy. (2016, January 19). *Appliance Standards and Rulemaking Federal Advisory Committee*. Retrieved from Appliance Standards: https://appliance-standards.org/sites/default/files/CAC_Term_Sheet_Draft_1-19-16_Final.pdf

Ueno, K. &. (2014). *Long-Term Monitoring of Mini-Split Ductless Heat Pumps in the Northeast.* Westford, MA: Building Science Corporation.

United States Department of Energy (DOE). (n.d.). *Heat Pump Systems*. Retrieved from Energy.gov: https://www.energy.gov/energysaver/heat-pump-systems

Van de Grift, S. ,. (2015). *Consumer Messaging for Ductless Heat Pumps and Heat Pump Water Heaters.* Northwest Energy Efficiency Alliance .

Vitoff, D. S. (2014). *Ductless Mini-Split Heat Pump Customer Survey Results.*

Appendix A – Resources Inventory

See associated spreadsheet with the inventory of resources

Appendix B – Literature Review

See associated spreadsheet with an inventory of literature reviewed