Reimagining Quality Installation in Residential Heat Pump Programs: An Analysis of Energy Savings and Value Propositions

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ABSTRACT

Heat pumps are rapidly gaining traction across the country to reduce energy use, improve access to cooling, and lower utility bills. Past HVAC Quality Installation (QI) programs have struggled with added contractor time and cost required to conduct QI practices. For heat pumps to realize expected savings, quality installation is critical. There is a need to better understand the heat pump QI practice(s) that are most likely to drive energy savings, most feasible for contractors to implement, and most cost-effective for programs to scale. Apex Analytics, in partnership with Tierra Consulting, and Commonwealth Edison (ComEd) defined a heat pump QI framework consisting of five elements (Heat Pump Sizing, Airflow, Refrigerant Charge, Duct Leakage, and Controls) and identified each element's relative importance from an energy savings and program feasibility standpoint. From an implementor's perspective, we outlined what measurements are required across this framework, when they should be taken, and which are most practical to incorporate into heat pump programs. We modeled energy savings potential for heat pump controls – specifically switchover and compressor and auxiliary electric heat lockout temperatures set by installers – as previous QI studies have focused less on the potential of heat pump controls to achieve energy savings. We also interviewed program administrators, implementors, contractors, and heat pump trainers to establish a heat pump QI value proposition for each stakeholder. Overall, these findings expand our understanding of QI for heat pumps and chart a path for utilities and implementors to incorporate the most feasible QI practices into their heat pump programs.

Introduction

Residential heat pumps are a critical component of ComEd's energy efficiency and electrification portfolio, as well as for many utilities across the country. As heating systems continue to be electrified, ensuring these systems are operating as designed is essential for utilities to realize projected savings and customers to realize savings on utility bills. Quality Installation (QI) has long been recognized in the HVAC industry, with industry standards such as ACCA Standard 5 and numerous studies on the energy impacts of rectifying QI issues. Existing evaluations of QI programs have largely focused on air-conditioning systems, and there is limited analysis focusing on QI practices specific to heat pump installations available.

In partnership with Tierra Resource Consultants, Apex Analytics, and ComEd, this study evaluates QI best practices for ducted residential heat pump installations in ComEd's service territory. The research background, our approach, and findings are described below, with a goal of identifying high-impact, feasible heat pump QI approaches to prioritize in utility programs.

Background

Quality Installation Practices for Heat Pumps

Heating, ventilation, and air conditioning (HVAC) systems account for a substantial share of residential energy consumption in the Midwest – approximately 60% of total household energy use (RECS, 2020). Beginning in the 1990s, a growing body of research documented that many HVAC systems were not installed according to manufacturer specifications, prompting studies to examine how QI practice affect system efficiency and energy consumption (Neme et al., 1999). This body of research has tended to focus on the performance of ducted central air conditioners, and to a lesser extent, furnaces and heat pumps. QI practices of focus included sizing, airflow, refrigerant charge, and duct leakage (Neme et al., 1999).

Heat pumps, particularly those in cold climates, have unique considerations for QI. For example, control configurations play an increasingly important role in heat pump performance. In all-electric systems, compressor and auxiliary lockout temperatures determine when inefficient electric resistance heat operates. In dual-fuel systems, switchover temperature determines when the back-up fossil fuel furnace engages. A recent evaluation of a heat pump QI program in the Pacific Northwest saw a high prevalence of sub-optimal auxiliary and compressor lockout settings (SBW Consulting, 2019). This study did not evaluate the energy impacts of these sub-optimal settings. Another field study monitoring 12 variable speed heat pumps found almost half of sites had auxiliary heat energy use exceed 40% of the heat pump (i.e., compressor) energy use, not including use during defrost cycles (Winkler & Ramaraj, 2023). There is a need to evaluate the energy impacts of heat pump controls settings on energy use in colder climates.

In addition, current QI assessments lack a distinction between conventional (i.e., single-stage) systems versus cold climate (i.e., variable speed) systems. A conventional system can only run at one output. In contrast, with a cold climate system, much of the time, the system runs at lower output with lower airflow required most of the time (i.e., part load). During these times of lower output, there may be different implications for airflow and sizing compared to conventional systems. This study expands on earlier work by evaluating the energy implications of various controls settings across different heat pump types and compares these savings opportunities to other practices more traditionally associated with QI (e.g., addressing sizing, airflow, etc.). This study focuses specifically on ducted heat pump applications.

Quality Installation Program Barriers and Opportunities

Despite decades of research, incorporating QI into utility programs remains a challenge. Past QI programs have struggled with the added contractor time and cost required to implement and document QI practices, and uncertainty around savings realization and verification (Hunt et al., 2010). Comprehensive industry standards (e.g., ACCA 5) provide detailed best practices but are often too resource-intensive for early-stage or large-scale programs to fully adopt.

Existing heat pump programs that include QI components have largely focused on sizing, airflow, and refrigerant charge, with less attention to controls. A notable Pacific Northwest program, Performance Tested Comfort Systems, incorporated a set of QI practices (airflow, sizing, refrigerants, duct leakage, and controls), but stopped operating after evaluations found small differences in most installation practices, with the exception of controls (SBW Consulting, 2019). At the same time, emerging "smart" diagnostic tools offer new opportunities to streamline data collection and verification and reduce contractor burden (Valoria et al., 2024).

Program resources are finite. Developing a cost-effective QI program therefore requires prioritizing practices that are practical for installers to implement and that offer meaningful impacts on energy use and claimable savings. This study supports utilities in colder climates seeking to incorporate QI into heat pump programs by identifying the most feasible QI practices and outlining program design approaches that align with varying levels of program readiness.

Research Questions

We aim to answer three research questions as a part of this study:

1. **QI for Heat Pumps Framework:** What are the typical elements of QI for heat pump installations?
2. **Ranking the Importance of each QI Element**: What is the relative importance of each QI element for heat pumps in terms of energy savings potential, prevalence in the ComEd territory, and contractor ease of adoption?
3. **Program Implications:** How can residential heat pump programs more effectively incorporate QI and what are the key considerations, tradeoffs, and opportunities?

Methodology

Literature Review

To develop the definition for heat pump QI in this paper (Research Question 1), the research team reviewed a broad set of resources including academic studies, industry standards, and current heat pump programs to identify QI practices applicable to heat pumps. Individual practices were grouped into categories, and those most consistently cited across sources were incorporated into the proposed framework. Ultimately, five QI practices were selected: heat pump sizing, airflow, refrigerant charge, duct leakage, and controls commissioning.

Energy Modeling

The team identified a further need to model and quantify the energy impact of two QI practices where existing research was lacking: sizing and controls commissioning. The research team developed an Excel-based heat pump performance model to estimate savings for controls and sizing using 15-minute thermal loads derived from EnergyPlus building simulation models (from ResStock End Use Savings Shapes). Models at the 15-minute interval were created for both a conventional heat pump (e.g., minimum efficiency, single-stage) and cold climate heat pump (e.g., high-efficiency, variable speed). For controls commissioning, the energy impacts of varying switchover temperature (hybrid heat pumps) and auxiliary and compressor lockouts (all-electric heat pumps) for both conventional and cold climate heat pumps were modeled. For sizing, the energy impact of reducing the size by 25%[1] for conventional and cold climate heat pumps were modeled at various controls settings to assess the impact on heat pump efficiency and backup strip heat operation. Table 1, Figure 1, and Figure 2 summarize assumptions built into the spreadsheet models. The results informed Research Question 2 to compare energy savings potential across the five QI practices studied.

[1] Sizing modeling was a late addition to this study. As such, only one sizing adjustment was modeled. Future studies should consider examining a wider range of sizing practices at more granular levels.

Table 1. Summary of Energy Modeling Assumptions

Equipment Model Assumption	Approach
Loads and temperatures	Extracted ResStock End Use Load Profiles for buildings with Midway weather. Includes 2,400 single-family homes (average 2,000 sq-ft). Average loads across all sites are shown in Figure 1.
Conventional and cold climate heat pump capacity and efficiency	Based on Carrier Base and High Efficiency Cold Climate Heat Pump Performance Data. Refer to Figure 2 for detailed assumptions on COP.
Thermostat setbacks	Includes an even mix of 0°F, 3°F, 6°F
Heat pump size	Scaled heat pump size to meet load at 20°F, approximately 4.5 tons for single-family cooling.[2]
Backup electric heat sizing	Single-stage. Sized to meet full load of home (no unmet loads).
Droop control operation	Backup heat starts when temp is 2°F below setpoint, runs with heat pump if heat pump not locked out.

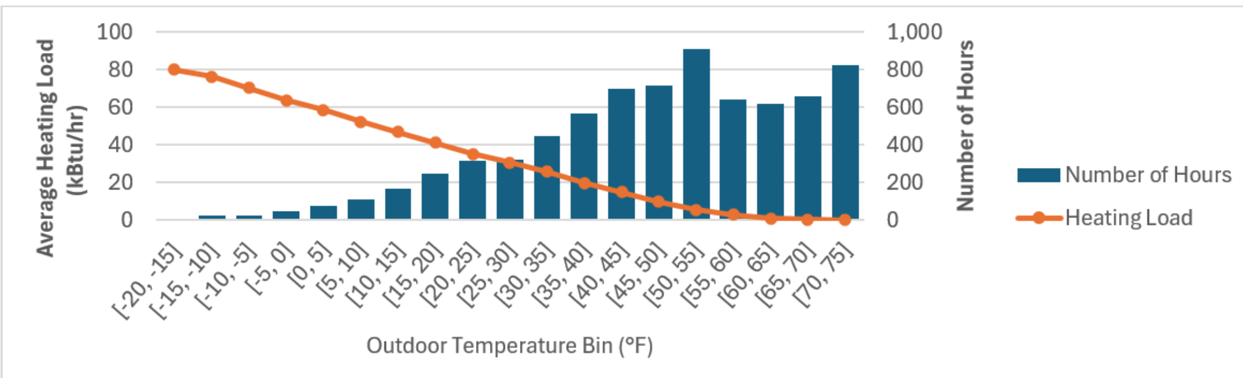

Figure 1. Average heating load (orange) and number of hours (blue) by outdoor temperature bin.

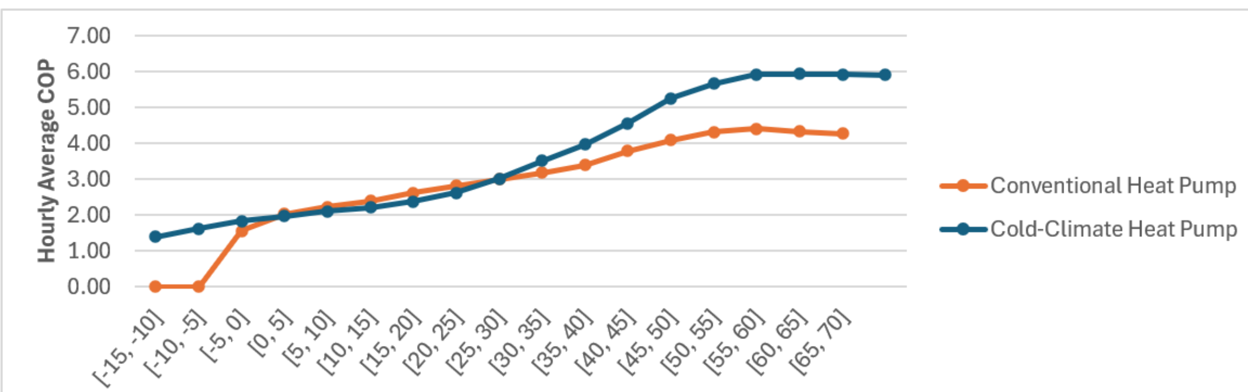

Figure 2. Average COP by outdoor temperature bin for conventional and cold-climate heat pump.

Market Actor Interviews

Market actor interviews informed both Research Question 2 (e.g., contractor ease of adoption by QI practice) and Research Question 3 (e.g., program design recommendations). Market actor groups targeted included subject matter experts (SMEs), program administrators

[2] In this study, the assumed heat pump capacity was scaled up to align with unaltered loads from ResStock. For older homes with poor envelopes, which typically do not have air conditioning, the recommended best practice is to conduct weatherization before installing air conditioning (including a heat pump). If weatherization of older homes had been assumed, this would have resulted in a reduction in heating and cooling loads and lower heat pump size. For newer homes (likely with existing air conditioning), the ratio of heating to cooling load generally aligns with a system with a typically-sized air conditioner providing sufficient heating down to the load around 20°F.

(PAs), and high-volume ComEd contractors and distributors. In all, the research team conducted a total of 14 interviews across all market actors, primarily via Microsoft Teams. Interviews with HVAC Industry SMEs (n=3) helped refine the proposed QI heat pump framework and identify potential PAs we could interview learn more about successful heat pump program designs. The second set of interviews was with Utility PAs and Implementers (n=5) to understand effective (and ineffective) program implementation practices and implications for scalability. The final set of interviews focused on High Volume ComEd Contractors/Installers and Distributors (n=6) to gather insights regarding the prevalence of QI practices, tools and training used to support QI, and to inform contractor effort and willingness to adopt each QI practice.

Results and Discussion

QI for Heat Pumps Framework

The research team reviewed a broad set of resources including academic studies, industry standards, and existing heat pump programs to categorize the most common HVAC QI practices that are applicable to heat pumps. Previous studies have focused on airflow and refrigerant charge (Pigg et al., 2016;Winkler et al., 2020) as well as sizing and duct leakage ((Neme et al., 1999;Domanski et al., 2014). Control commissioning has begun to emerge as a QI consideration for heat pumps (SBW Consulting, 2019; Douglass et al., 2024). ANSI/ACCA 9 QIvp is the predominant industry standard for HVAC QI. These standards focus on system design, distribution (including duct leakage and airflow), refrigerant charge, electrical requirements, combustion venting, and system controls. The team also reviewed commissioning checklists[3] for existing programs and compiled a common list of QI practices. Based on this research, the team identified five elements for heat pump QI in this paper: heat pump sizing, airflow, refrigerant charge, duct leakage, and controls commissioning (Table 2). The remaining analysis and results described in this paper rely on these definitions and framework.

Table 2. Definition of the Five QI Elements for Heat Pumps

QI Element	Key Issue the QI Element Helps Resolve
QI1: Heat Pump Size	The heat pump is sized to meet the building's heating and cooling loads and is not over- or under-sized (within ½ ton).[4]
QI2: Airflow	The maximum airflow at the air handler is within ±15% of the maximum capacity design airflow.
QI3: Refrigerant Charge	The refrigerant charge matches the manufacturer's specifications and leaks have been eliminated/avoided.
QI4: Ductwork Leakage	Duct leakage to the outside is minimized (applicable only to homes with ducts outside the conditioned space).
QI5: Controls Commissioning	The switchover temperature (hybrid systems) or auxiliary and compressor lockouts (all-electric systems) are optimized based on user priorities (i.e., cost, comfort, or environmental impact).

[3] Such as: hvac-incentive-application.pdf and Residential-Heat-Pump-Installation-Checklist.pdf

[4] The authors note in ComEd territory it can be difficult to match the heating load with the cooling load, and sizing the heat pump is a balance between these two, sometimes competing, objectives. In these situations, the advantage of using a variable speed heat pump becomes clearer. Systems that are sized for heating, while providing more efficient heating, may provide lower efficiency cooling and have trouble with moisture control, due to short-cycling. Other installation best practices, including widening the thermostat deadband or adding a minimum cooling runtime, should be explored to deal with cooling oversizing in a system sized for heating.

Ranking the Importance of each QI Element

To address the second research question, each QI element was ranked based on its energy savings potential, prevalence in the ComEd territory, and contractor ease of adoption. The rationale for each ranking is described in the sections below.

Energy savings potential by QI element. We categorized each QI element into one of three broad energy savings tiers for addressing each QI issue: low (0-5%), moderate (5-10%), and high (>10%). Actual energy savings can vary significantly depending on site-specific conditions; our intent is to provide a relative ranking of QI elements in cold climates to support QI program prioritization and design, rather than precise savings estimates. We performed detailed energy modeling for heat pump sizing (QI1) and controls commissioning (QI5).

In terms of heat pump sizing (QI1), conventional wisdom suggests that oversizing, rather than under sizing, is a more common issues in the Midwest (Pigg, 2008), and as a result, most research has focused on the impacts of oversizing. Oversizing conventional heat pumps can lead to short cycling and potential airflow issues. VSHPs, which should operate at part load for much of the time, are less susceptible to short cycling, except during periods of extremely low load. Field studies in Wisconsin (Pigg, 2008) and Florida (Sonne et al., 2006) monitored energy use in homes where an oversized air conditioner was replaced with a properly sized unit and found little to no impact on energy use. Domanski et al. (2014) found that oversizing resulted in an increase of energy use marginally, by 1 – 7%. Less research has examined the energy impacts of undersizing heat pumps in cold climates, and interactions with electric resistance backup heat. Undersizing can lead to increased reliance on electric resistance backup heat and/or extended operation at high part-load ratios, both of which reduce overall system efficiency.

A conventional and cold-climate heat pump were modeled at two different sizes, using a typical set of heating loads for the Chicago area. The heating loads by outdoor temperature are defined in Figure 1. The first system was sized to meet the full heating load at 20ºF, representing typical sizing practices when replacing an existing central AC system.[5] The second system was intentionally undersized by 25%, meaning that it has a capacity that is 25% lower than the capacity required to meet loads at 20ºF. Results are shown in Table 3. The larger system is modeled to use less energy across all scenarios; the reduction in auxiliary heat use associated with the larger system more than offsets any sizing losses from short-cycling of the same system. For conventional heat pumps, savings associated with larger sizing (compared to under-sizing by 25%) range from 0% to 9%. For cold climate heat pumps, potential savings are greater, ranging from 5% to 12%. These results are limited, in that they are focused on one particular point in the sizing continuum, focused on typical sizing in homes in ComEd territory. While these results are indicative of potential savings, a wider range of sizing practices should be modeled in the future, and other researchers should explore sizing with starting and ending ranges that are most appropriate to the question they are studying. One key takeaway from the table is that control settings significantly affect savings, which will be explored in more detail later in the paper. Additionally, cold climate heat pumps are modeled to have greater savings than conventional

[5] While heating design conditions call for a larger system, the existing ducts are not typically large enough to support meeting the full heating load with a heat pump. The limited interviews conducted with trade allies in the region indicated that system sizes were being limited by existing ducts. Newer homes with air conditioning typically have enough duct capacity to meet heating loads at approximately 20ºF. Cold climate heat pumps may have sufficient capacity to extend this to a colder temperature.

systems. Based on these results, we categorize conventional heat pumps in the low savings tier (0-5%) for sizing, and VSHPs in the moderate savings tier (5-10%) for sizing.

Table 3. Energy Savings from sizing to 20ºF versus under-sizing by 25%

Conventional Heat Pump		**Cold-Climate Heat Pump**	
Compressor | Aux Lockouts (ºF)	**Sizing Savings (%)**	**Compressor | Aux Lockouts (ºF)**	**Sizing Savings (%)**
None | 20	5.3%	None | 20	10.7%
None | 25	7.3%	None | 30	11.8%
None | 30	8.4%	None | 40	11.7%
None | 35	8.6%	None | 50	11.7%
25 | 25	0.0%	15 | 20	5.1%
25 | 30	0.8%	15 | 30	6.0%
25 | 35	1.0%	15 | 40	6.0%

In terms of controls commissioning (QI5), few studies have quantified the energy impacts of heat pump controls in colder climates. This research focuses on the switchover temperature controls (applicable to hybrid heat pumps) and auxiliary and compressor lockout controls (applicable to all-electric heat pumps). Ducted heat pumps (both conventional and cold climate) are typically installed with backup heat of some form, either electric resistance or fossil-fuel. The controls determine how and when this backup heat is engaged. Because the heat pump compressor operates much more efficiently than the backup heat, using controls that reduce the operation of backup heat can generate significant energy savings. A contractor configures this setting during installation, typically in a thermostat's "installer" or "hidden" menu.

A brief overview of controls terminology used in this paper and operations is as follows. For any heat pump system, at temperatures above the auxiliary heat lockout temperature, only the heat pump compressor operates and the auxiliary heat cannot turn on. Between the auxiliary heat lockout temperature and the compressor lockout temperature, the system defaults to heat pump compressor operation. Under certain conditions, generally when recovering from a setback or under high loads, the auxiliary heat turns on in addition to (or for hybrid systems, instead of) the heat pump compressor until the setpoint is reached. At temperatures below the compressor lockout (switchover) temperature, only the auxiliary heat operates. In hybrid systems, the heat pump compressor and fossil-fuel furnace do not run simultaneously.

The research team modeled a wide variety of auxiliary heat lockout, compressor lockout, and switchover temperatures for both conventional equipment and variable speed cold climate equipment. Refer to the Methodology section for additional detail. The modeled heat pump consumption for standard efficiency and cold climate heat pumps show modest declines in consumption as the auxiliary lockout is lowered, as shown in Figure 3 (left). Savings relative to no lockout (aux lockout = 70ºF) range from 1-3% for conventional heat pumps and 1-8% for cold climate heat pumps. For conventional heat pumps, savings are calculated for auxiliary lockouts as low as 20ºF, as aux lockout temperatures below 20ºF are not recommended. In contrast to the modest auxiliary lockout savings, compressor lockout has a huge impact on consumption, as shown in Figure 3 (right). It is assumed there is no auxiliary lockout in this plot. Conventional heat pumps likely have higher compressor lockout temperatures compared to cold climate heat pumps. Expected compressor lockout savings relative to 40ºF lockout run from 0-45% for standard heat pumps. Expected compressor lockout savings relative to 20ºF run from 0-24% for cold climate heat pumps. For conventional heat pumps, compressor lockouts lower than 5ºF are generally not recommended.

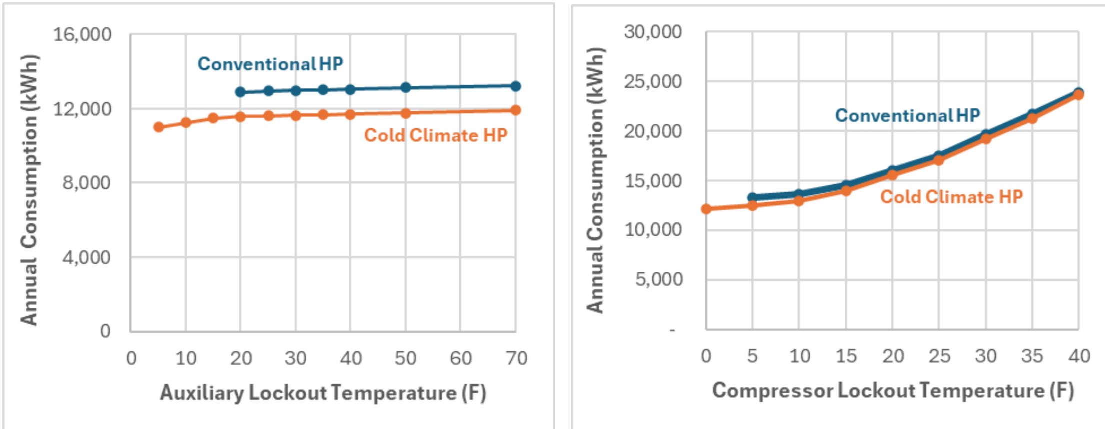

Figure 3. All-Electric HP Annual Heating Energy Consumption across Varying Auxiliary Lockout Temperatures (left) and Compressor Lockout Temperatures (right)

When comparing energy consumption of a cold climate heat pump to a conventional heat pump, the cold climate only generates modest savings if the compressor is locked out at relatively mild conditions. To realize the full savings potential of a cold climate heat pump, the compressor should not be locked out, except for the internal system protection low pressure cutout, which generally corresponds to around -15°F.

For dual-fuels systems, as the switchover temperature drops, heat pump usage goes up, while gas usage drops, as shown in Figure 4. The two gas lines for conventional and cold climate heat pumps are fully overlapping, because gas consumption is a function of switchover temperature, not heat pump type. Because the gas site energy drops more quickly than the electric site energy increases, the resulting overall site energy drops as the switchover temperature drops. Expected site energy savings range from 0-30% for both conventional and cold climate heat pumps.[6]

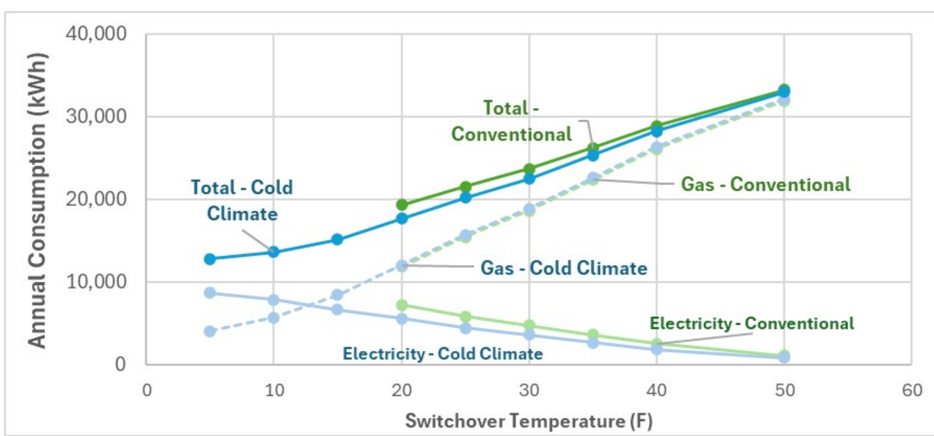

Figure 4. Dual Fuel Heat Pump Annual Heating Energy Consumption across Varying Switchover Temperatures

Important to the expected savings is the typical auxiliary and compressor lockout temperatures. The research team conducted interviews with contractors and distributors participating in the current program. As part of these interviews, the team asked questions about

[6] While it was not a focus of this work, this graphic also shows that heat pumps installed in place of air conditioners will always save energy, as long as they are used for at least some of the heating load.

the control settings that they typically used. Based on these interviews, the team estimated the typical and improved control settings Table 4. While it is possible to implement droop controls in ducted systems, our experience is that this is not at all common. In instances where droop is used instead, then the switchover temperature indicated for the improved case should be used for the aux lockout, with a lower temperature used for the compressor lockout.

Table 4. Typical Heat Pump Settings in the Midwest and Recommended Settings

Heat Pump Type	All-electric Heat Pumps				Hybrid Heat Pumps	
	Compressor Lockout Temperature (ºF)		Auxiliary Lockout Temperature (ºF)		Switchover Temperature (ºF)	
	Typical	Improved	Typical	Improved	Typical	Improved
Conventional	25	None	None	35	35	30
Cold climate	15	None	None	30	35	5

Based on these assumptions for the baseline and efficient cases, the team calculated consumption and savings using the spreadsheet model for each type of all-electric heat pump for each type of control strategy, as shown in Table 5.

Table 5. Expected Savings with Improved Heat Pump Controls

Heat Pump Type	Backup Fuel	Baseline Consumption (kWh)	Expected Savings with Improved Controls (kWh)	Typical % Savings Expected
Conventional	All-Electric	17,503	4,475	26%
Conventional	Hybrid (80 AFUE)	25,637	2,802	11%
Cold-Climate	All-Electric	14,021	2,359	17%
Cold-Climate	Hybrid (96 AFUE)	25,210	12,341	49%

The key takeaway is that control savings vary significantly based on heat pump backup fuel and type, however, in all cases, expected savings are greater than 10%. Therefore, we categorize the controls commissioning element has high potential savings (>10%) and note that initial modeling shows significant opportunity for savings by optimizing controls.

Given the substantial body of existing on the energy impacts of airflow (QI2), refrigerant change (QI3), and ductwork leakage (QI4) issues, we relied on energy savings estimates from existing literature. For airflow (QI2), issues are generally driven by high external static pressures leading to low airflow rates across the evaporator. Modeling by Domanski et al. (2014) found low airflow increased heat pump energy use by 4-12% in Chicago and a Minnesota study found a 7.1% average efficiency improvement after airflow correction across 52 sites (Pigg et al., 2016). Based on these findings, airflow was categorized in the 5–10% savings tier for conventional systems. As a VSHP spends most of the time running at part load (i.e., it has lower airflow and faces lower external static pressure), the system will likely experience smaller airflow efficiency penalties. Because of this, cold-climate heat pumps were placed in the 0–5% savings tier.

In terms of refrigerant charge (QI3), under or overcharging reduces system efficiency. One study found that a 10-30% charge deviation increased energy use by 1-20% (undercharging) and 2-15% (overcharging) (Domanski, 2014). The Minnesota field study observed an average 8.6% EER improvement after correcting charge, though savings were concentrated among a subset of poorly performing systems (Pigg et al., 2016). Accordingly, refrigerant charge was placed in the 5-10% savings tier. In terms of duct leakage (QI4), energy impact depends on duct location, with the greatest penalties occurring when ducts are outside the conditioned space. Domanski et al. (2014) modeled 20-50% attic duct leakage in Chicago and found 13—60% increases in energy use. Earlier field research similarly attributed more than 10% of heating energy use to duct leakage (Jump et al., 1996). Based on this evidence, duct leakage was categorized in the >10% savings tier.

A summary of the ranking of each QI element by its potential for energy savings is provided in Table 6. As described above, addressing duct leakage (QI4) and conducting controls commissioning (QI5) are expected to have the greatest impact on energy use compared to addressing heat pump sizing, airflow, and refrigerant charge. In addition to energy savings potential, other important considerations include how difficult it is for contractors to address each QI element and how prevalent each QI issue is in the field. These factors are discussed in the sections below.

Table 6. Expected Energy Savings Tier by QI Element

QI Element	Energy Savings Tier	Ranking
QI1: Heat Pump Size	<5% (Conv); 5 – 10% (ccHP)	Low (Conv); Medium (ccHP)
QI2: Airflow	<5% (ccHP); 5 – 10% (Conv)	Low (ccHP); Medium (Conv)
QI3: Refrigerant Charge	5 – 10%	Medium
QI4: Ductwork Leakage	>10%	High
QI5: Controls Commissiong	>10%	High

Ease of contractor adoption. Table 7 outlines installer practices and measurements associated with assessing each QI issue. Installer practices are categorized as Standard, Improved, and Comprehensive, with definitions provided in the table footnote. Time estimates assume a practiced installer is doing the work. This table covers time to assess for an issue; the time to address an issue in discussed later. "Improved" measurements are recommended for an early-stage QI program; "Comprehensive" measurements are listed for awareness but may not be cost-effective to incorporate into a program.

Table 7. Standard, Improved, and Comprehensive QI Practices[7]

Element	Standard Practice[8]	Improved Practice[9]	Comprehensive Practice[10]
QI1: Heat Pump Size	Rule-of-thumb sizing/ size to what's there (5 mins)	Manual J and S, with assumptions (1.5 hour)	Manual J and S, with measurements (2.5 hours)[11]
QI2: Airflow	Visual inspect excessive bends and measure ductwork size (15 mins)	Standard + Measure TESP using manometer and airflow using manometer (30 mins)	Improved, but measure airflow with flow plate/hot-wire anemometer (30 mins)
QI3: Refrigerant Charge	Use charge included in unit at shipping (0 mins)	Measure necessary lineset length and weigh in proper charge (30 mins)	Improved + Ensure no leaks via pressure and vacuum tests (1 hour)
QI4: Ductwork Leakage	Visual inspection for obvious leaks around indoor unit (5 mins)	Standard + Visual inspection for obvious leaks in unconditioned spaces (15 mins)	Improved + Measure duct leakage to the outside via duct blaster and blower door (1 hour)
QI5: Controls Commissioning	Use manufacturer defaults, no auxiliary lockout (0 mins)	Confirm switchover temperature (hybrid) or auxiliary and compressor lockouts (all-electric) (10 mins)	NA

[7] Time estimates assume a practiced installer is doing the work.
[8] Represents industry norms and is likely to already be a part of many heat pump programs.
[9] Represents measurements above industry norms, but that can be done relatively quick or with less expensive tools.
[10] Represents the most thorough measurement but also requires the most time and costly tools.
[11] Includes collecting actual data such as building air leakage via blower door testing, instead of assuming.

A key additional layer of information is *when* installers should address each QI element. Some QI elements require actions only during certain stages. For example, required measurements and calculations to properly address Heat Pump Size (QI1) occur during the assessment and pre-installation. Conversely, QI activities for Controls (QI5) occur primarily after installation. Airflow (QI2) and Duct Leakage (QI4) require measurements both before and after the installation.

Table 8 summarizes the final categorization of each QI element by time to diagnose and address each QI element. We categorized each QI element into one of three tiers based on the estimated time for contractors to address each QI element: less than 1 hour, 1 – 2 hours, and more than 2 hours. Steps to resolve each QI issue and time estimates are derived from contractor interviews and professional expertise.

It is important to note for Airflow (QI2), there is a critical go or no-go decision based on the condition of the ductwork. It is expected for a minority of projects the ductwork will be very restrictive or undersized (as determined by visual inspection, simple ductwork measurements, and TESP measurement). These projects would require significant investment to upgrade the ductwork for the heat pump to operate properly. In these situations, it generally costs less to either install a smaller heat pump, sized to the available duct capacity, or consider a ductless heat pump, or both a ducted heat pump sized to existing ducts and additional ductless heads, in order to avoid costly duct upgrades. From a programmatic standpoint, it is important to note that identifying projects with substantial ductwork issues early on (i.e., during the assessment stage) to avoid finding airflow issues post-installation that require expensive upgrades to resolve.

Table 8. Standard, Improved, and Comprehensive QI Practices

QI Element	Contractor Effort to Diagnose Issue	Contractor Effort to Resolve Issue	Total Time to Diagnose and Address Issue
QI1: Heat Pump Size	2 hours (pre-install) 0 hours (post-install)	NA	1 – 2 hours
QI2: Airflow	30 minutes (pre-install) 30 minutes (post-install)	15 minutes[12]	1 – 2 hours
QI3: Refrigerant Charge	5 minutes (pre-install) 1 hour (post-install)	15 – 30 minutes	1 – 2 hours
QI4: Ductwork Leakage	1 hour (pre-install) 1 hour (post-install)	1+ hours	> 2 hours
QI5: Controls commissioning	10 minutes (post-install)	10 minutes	< 1 hour

Prevalence of issue by QI element. We categorized each QI element into one of three tiers based on the estimated prevalence across housing units in ComEd territory: low prevalence (0-20%), moderate prevalence (20-50%), and high prevalence (>50%). These rankings are informed by contractor interviews as well as by published field studies.

Both contractors and previous studies suggested that sizing issues are common. In the Pacific Northwest, only 42% of 92 retrofit heat pumps were found to be correctly sized (within 0.5 ton), with the remainder being undersized (32%) or oversized (26%) (SBW Consulting, 2019). Earlier Midwest research similarly found widespread oversizing of cooling equipment (Pigg, 2008). Contractors interviewed for this study confirmed that retrofit installations often rely

[12] This assumes that sites with significant ductwork issues are identified during the assessment stage, and either don't move forward with the project or major ductwork issues are incorporated into the scope of work and resolved during installation. Therefore, by the time airflow is assessed post-installation, the primary step to resolve issues will be adjusting settings at the control board.

on existing equipment sizing, leading to cooling oversizing and heating undersizing. Based on this, heat pump sizing issues was categorized in the high prevalence (>50%) tier.

Improper airflow has also been frequently documented. The Pacific Northweset study found a third of retrofit heat pumps had airflow outside of acceptable ranges (SBW Consulting, 2019), and a Minnesota field study reported airflow issues in 40% of tested systems (Pigg et al., 2016). Contractors noted that airflow adjustments are part of standard commissioning but are inconsistently verified in practice. Taken together, airflow was categorized in the moderate prevalence (20-50%) tier.

Large meta-analyses and field studies indicate that refrigerant charge problems are widespread. Winkler et al. (2020), synthesizing 11 studies (over 2,600 air conditioners), found roughly half of systems were improperly charged. A Minnesota field study reported similar findings, with 58% of homes either under or overcharged (Pigg et al., 2016). Anecdotally, shortages of refrigerants in 2025 leading to high prices have led to undercharging. Refrigerant charge was placed in the high prevalence (>50%) tier.

Housing stock data for the ComEd region indicate that a substantial share (70%) of single-family homes have ductwork in semi-conditioned and conditioned spaces (ResStock, 2020). Based on this, duct leakage was categorized in the moderate prevalence (20-50%) tier.

Available evidence on heat pump control settings in heating-dominated climates suggest control misconfiguration is common. Studies have commented that most contractor customer callbacks with heat pumps are customers concerned with controls (Tudawe et al., 2022). A Pacific Northwest study found only 27% of non-program participants had acceptable auxiliary lockout settings (SBW Consulting, 2019). Contractors we interviewed noted the vast majority of the time installers are using the control default settings, rather than optimizing settings for the customer. Accordingly, controls were categorized in the high prevalence (>50%) tier. Tier categorization across all QI practices is summarized in Table 9.

Table 9. Prevalence of issue by QI Element

QI Element	Issue Prevalence (% housing units)	Ranking
QI1: Heat Pump Size	>50%	High
QI2: Airflow	20 – 50%	Medium
QI3: Refrigerant Charge	> 50%	High
QI4: Ductwork Leakage	20 – 50%	Medium
QI5: Controls	Likely >50%	High

Final ranking of each QI element. While all five QI elements contribute to optimizing heat pump performance, program resources are finite, making it necessary to prioritize them based on their relative impact and implementation effort. To develop a cost-effective QI program, priority should be given to elements that are practical for installers to address and that offer higher impacts on energy use and claimable savings. Figure 5 presents the final ranking of each QI element based on the three studies criteria: energy savings potential, time required to diagnose and correct the issue, and prevalence in the ComEd region.

As shown in Figure 5 Controls (QI5) issues are estimated to be highly prevalent in ComEd territory, represent the highest opportunity for energy savings compared to other QI elements, and can be addressed in less than one hour. Heat Pump Sizing (QI1) and Refrigerant Charge (QI3) represent the next best opportunities due to their high prevalence, moderate energy savings potential, and moderate effort required for correction. Rectifying ductwork issues (QI4) represents a high energy savings opportunity, but it is only moderately common, and it requires more labor to resolve. Lastly, airflow (QI2) is moderately prevalent and provides moderate energy savings potential, with a corresponding moderate time investment to address.

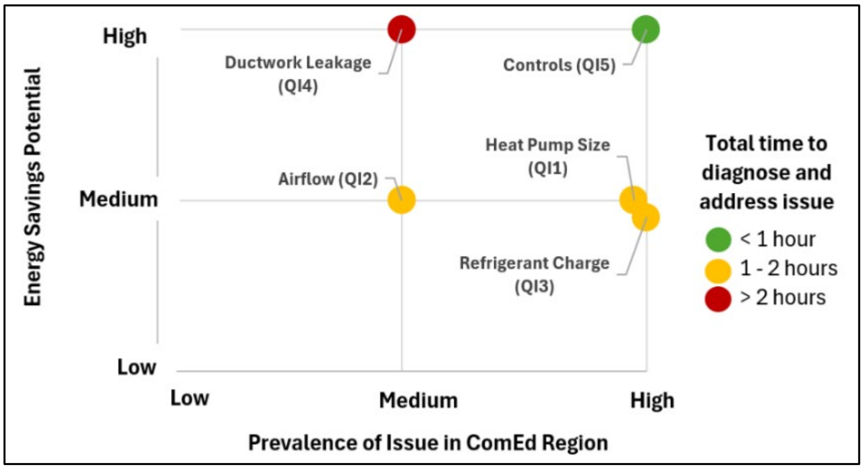

Figure 5. Ranking of each QI element by energy savings potential, prevalence, and total time to diagnose and address issue

Program Design Implications

Designing heat pump programs that incorporate QI requires balancing added contractor effort and program costs with increased claimable savings. We interviewed five program administrators running heat pump programs that incorporate QI. Programs in Table 10 are organized by increasing levels of documentation and QA/QC required. Sizing (QI1) and refrigerant charge (QI3) are the most commonly included QI elements. In contrast, none of the interviewed programs formally include controls (QI5) in their QI scope. This is especially notable as the analysis conducted in this paper indicates that controls commissioning has the best opportunity, with the greatest potential for energy savings[13], while being relatively easy for contractors to address.

Table 10. Summary of Utility Programs Interviewed with Heat Pump Programs Incorporating QI

Entity	QI1	QI2	QI3[14]	QI4[15]	QI5	Contractor Documentation and QA/QC Method
Utility 1			x	x		**Documentation:** Attestation to a checklist. **QA/QC:** 25% random post-install virtual QA.
Utility 2	x					**Documentation:** Participate in higher-tier contractor network. **QA/QC:** 25% random QA for base network; planned "enhanced inspections" for leaders
Utility 3	x	x	x	x		**Documentation:** Submit detailed commissioning form. **QA/QC:** Random post-install inspections (minimum 1 per contractor/ season)
Utility 4	x	x	x			**Documentation:** Submission of detailed test-in/test-out data for 100% of jobs. **QA/QC:** 100% desk audit, 30% random field inspections, with penalties for failure.
Utility 5	x	x	x	x		**Documentation:** Use of Measure Quick for 100% of installs. **QA/QC:** Review of geolocated, timestamped data from Measure Quick; 20% random field inspections.

[13] Of note, utilities 4 and 5 operate in cooling-dominated climates, where controls would yield lower savings.
[14] With the exception of Utility 1, does not include nitrogen and vacuum decay testing.
[15] Utility 1 and 3 only require visual inspection of ducts; only Utility 5 requires measuring duct leakage.

QI programs must balance documentation and verification requirements with time and costs when determining which QI elements, and associated measurements, to include. Multiple factors must be considered including how contractors demonstrate QI was performed and how utilities confirm it was done correctly since these significantly impact program costs, contractor willingness to participate, and savings achieved. Approaches vary widely, with tradeoffs between administrative burden and savings certainty. For example, the main program goal for Utility 1 is expanding residential electrification. Contractors are required to follow a detailed checklist, but only need to attest to completing the form. The program conducts post-install QA/QC on 25% of projects. This low-friction model supports broad contractor participation and limits administrative overhead, but it provides lower certainty that QI practices are consistently executed and makes it more difficult to claim verifiable savings.

At the other end of the spectrum, Utility 4 operates a highly rigorous program aligned with ACCA Standard 9. Contractors must submit comprehensive test-in/test-out data for every installation. This program's core principle is that the incentive is for achieving the federal minimum efficiency through proper installation, not for purchasing higher-efficiency equipment. This approach yields high confidence in claimed savings and strong contractor accountability, but it requires significant contractor effort and program oversight. The administrative burden limits participation and has led, in some cases, to contractors attempting to "game" specific documentation requirements.

Emerging smart commissioning tools aim to reduce these tradeoffs. Utility 5 built its program around third-party software, requiring contractors to use MeasureQuick for all installations. MeasureQuick automates data collection and reporting for some QI elements. The utility gets reliable, verifiable data for its savings claims, while the contractor receives a customer-facing report that serves as a sales tool and differentiator from competitors. Although the program requires detailed data submission, Utility 5 reports the additional incremental contractor time is approximately 15-20 minutes per installation. To support contractor adoption, the utility funded contractor training with the tool and covered first-year software fees.

Programs under Utilities 2 and 3 fall somewhere in the middle in terms of documentation and verification requirements. Utility 2 uses a tiered Heat Pump Installer Network to encourage wider contractor participation, including those just beginning to install heat pumps. Utility 3 is evolving, moving from a less stringent model to one with stronger QI requirements to legitimize savings. Collectively, these examples illustrate a core program design tension: lower-friction models encourage market participation but weaken savings certainty, while highly rigorous models improve defensibility at the cost of contractor burden and administrative complexity. Smart diagnostic tools may offer a pathway to balance both objectives.

Successful QI programs must also be built around a clear value proposition for each stakeholder. Based on our stakeholder interviews, the following themes emerged. For Utilities, value of QI is driven by net program benefits, including verified energy and demand savings, streamlined program administration, reduced customer and contractor costs, and overall market transformation. For Customers, value of QI is driven by a reduced likelihood of callbacks, improved comfort, lowered utility bills, and enhanced system reliability. For Contractors, value is driven by alignment with their business models, such as participating in a preferred installer network for market differentiation from non-QI contractors and access to QI-specific incentives to support the additional effort to enable them to promote the above-mentioned customer value propositions. Well-designed programs address the requisite value propositions for utilities, customers, and contractors.

In summary, utilities are incorporating a range of different QI measurements and using different strategies for contractor documentation and QA/QC. Additional program design considerations such as contractor network structures, incentive design, training approaches, and downstream versus midstream delivery models also shape program outcomes, but these are not explored in detailed in this paper. Future research could further examine these and the long-term persistence of savings, contractor adoption barriers, and customer awareness of QI benefits.

Conclusion

This study focused on Quality Installation for ducted residential heat pumps. Drawing from existing research, industry standards, heat pump programs, and interviews, this study defines heat pump QI as consisting of five core elements: heat pump sizing, airflow, refrigerant charge, duct leakage and controls commissioning. Among these, controls commissioning was identified as an under-addressed opportunity, especially in cold climates where heat pumps rely on backup heating sources. Energy modeling indicated that controls commissioning has the highest relative savings potential compared to the other QI elements, while requiring the least contractor time to implement. Sizing and refrigerant charge represented the next strongest opportunities. Sizing in cold climates creates unique problems. It remains difficult to size a heat pump to work well for heating (i.e., large enough to avoid significant backup heat usage) and work well for cooling (i.e., small enough to avoid short-cycling and poor moisture control). Existing sizing protocols reviewed do not address this problem sufficiently. In theory, variable speed cold climate systems are better equipped to deal with this sizing problem, since they can run at lower speeds and/or lower airflow to reduce output, allowing a large system to perform well during heating season, while avoiding short-cycling and accompanying reduced moisture removal during cooling season. Further work is needed in this area.

Interviews with five utility program administrators revealed that none currently require controls commissioning as part of their heat pump program. QI programs have historically struggled with the added contractor burdens associated with QI measurements and documentation. Interviews with program administrators revealed a wide variety of approaches for documentation and verification rigor, which depend on the program goals and maturity. Overall, incorporating cost-effective QI practices into residential heat pump programs can strengthen savings realization, enhance customer affordability, and support contractor market differentiation. These findings provide a practical roadmap for utilities and implementers seeking to scale the most feasible heat pump QI strategies into their programs.

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Disclosure template

AI-assisted tools used: ChatGPT
Used for: Writing clarity and reducing length.
Extent: Light editing.
Human review: The authors reviewed and verified all content, calculations, and citations.