Increasing Uptake of Residential HVAC Commissioning with Advanced Technologies

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ABSTRACT

Historic funding from the Inflation Reduction Act (IRA) has paved the way for a wave of incentives directed toward efficient heating and cooling systems. Over the next decade, a surge in the installation of high-efficiency heating, ventilation, and air conditioning (HVAC) systems is anticipated. However, a critical challenge remains in ensuring these systems are installed correctly to realize the promised benefits of energy savings, reduced utility bills, enhanced comfort, and system reliability.

Research spanning back to the mid-1990s reveals a staggering statistic: 70-90% of residential air source heat pumps and central air conditioners suffer from energy-wasting faults due to improper installation. The solution lies in commissioning these systems to verify quality installation. Unfortunately, many residential HVAC businesses neglect this crucial step. Reasons vary, from contractors lacking awareness of correct commissioning procedures to concerns about the time investment involved.

Despite these challenges, there is a window of opportunity on a national scale. The confluence of newly available incentives, heightened consumer awareness, and technological advancements, create a unique opportunity to revolutionize HVAC commissioning practices. This paper briefly summarizes the impact of improper installation, overviews quality installation standards, outlines barriers to the broad adoption of residential HVAC commissioning, and describes new technological solutions for streamlined commissioning. Additionally, it highlights current initiatives aimed at increasing the adoption of residential HVAC commissioning and highlights key considerations for the inclusion of quality installation and commissioning to states participating in the IRA's Home Energy Rebates Program.

Introduction

Historic funding from the Inflation Reduction Act (IRA) will make heat pumps more accessible to low- and moderate-income households in the U.S. Although the exact number of heat pumps that will be installed is unknown, the rate of new heat pump installations is expected to greatly increase due to the confluence of incentives, heightened consumer awareness, and subsequent demand. This nationwide deployment of high-efficiency heat pumps in residential buildings will be critical for reaching U.S. decarbonization goals, since these systems can deliver excellent performance and comfort with higher efficiencies than standard models of heating,

ventilation, and cooling (HVAC) systems and in many cases do not require supplemental fossil-fuel heating.

The process of installing HVAC systems, however, does not make for a straightforward path to achieving the IRA's aims of increasing energy efficiency, comfort, and reliability in residential households. HVAC installation is complex and requires a high level of skill and competency. Contractors must be knowledgeable in calculating heating and cooling loads, selecting the right-sized equipment, sizing duct systems, fabricating and installing those ducts, fastening line sets to accommodate pressurized refrigerants, connecting line voltage, and plumbing drains. Further, to achieve the expected performance and efficiency, charge and airflow must be tuned and system controls properly configured. The level of complexity in the installation process coupled with workforce shortages unfortunately means that many HVAC systems end up being installed by those without the necessary expertise or those who feel rushed to complete the job and forgo best practices. This leads to most residential HVAC systems operating below their promised efficiencies. A review of research shows that 70-90% of residential HVAC systems in the U.S. have at least one performance-compromising fault (EERE 2018).

Commissioning has gained traction in the commercial sector and is poised to improve installation quality and in-field performance of residential HVAC systems. Although the adoption of commissioning is limited in the residential sector, advancements in commissioning and diagnostic technologies present a critical market transformation opportunity. This paper briefly reviews the impact of improper HVAC installation, introduces two new technology-assisted commissioning technologies, provides a brief overview of current initiatives aiming to increase the adoption of commissioning, and outlines key considerations on quality assurance for states administering rebate programs.

Impact of Improper HVAC Installation

In simulation and laboratory experiments across five different climate zones in the U.S, Domanski et al. (2014) tested for correlations between a single-speed split heat pump's operating performance and the presence of installation faults and simulated the faults on a slab-on-grade single-family house and a basement single-family house. The authors found common faults of duct leakage, incorrect refrigerant charge, oversizing with nominal ductwork, and low indoor airflow from undersized ductwork are the most likely to impact performance and annual household energy use. Overall, the authors posit that up to 30% of additional energy use can be caused by improper installation.

In another study, Winkler et al. (2020) used a residential building stock simulation tool to model two common installation faults of indoor airflow rate and refrigerant charge levels in residential single-stage air source heat pumps (ASHPs) and central air conditioners (CACs). The study explored installation faults' impacts on annual household energy consumption and resulting utility costs in the U.S. residential stock. The analysis found these two common faults cause approximately 20.7 TWh per year of energy waste in U.S. single-family homes or 9 percent more energy use than if those systems were installed correctly (without installation faults). Additionally, the modeled ASHPs in the simulated building stock disproportionately accounted for the increased energy waste compared to CACs. Only 14% of homes in the study had an ASHP, but those systems accounted for approximately 39% of the total increased energy

use (8.0 TWh/y). This can be attributed to higher hours of operation of ASHPs since they provide both heating and cooling. The study also notes that heating mode operation is more sensitive to faults, and if the indoor airflow rate or refrigerant charge fault decreases heating capacity, the energy use from lower-efficiency electric resistance backup heat will increase. This indicates the additional importance of commissioning and quality installation of heat pumps, especially in colder climates.

While past studies primarily focused on single-stage HVAC systems, a recent 2022 study tested variable-capacity heat pump (VCHP) systems in three laboratory single-family houses in Stockton, CA. Six different ductless and ducted multi-split heat pumps were installed and operated under a range of conditions with varying levels of refrigerant charge (100%, 80%, 65%, and 50% of the manufacturers' recommendations), and alternated in heating and cooling seasons to compare to reference single-speed heat pumps and electric resistance heaters that were also installed in the laboratory homes (Wilcox et al. 2022). The results showed the efficiency and energy losses from low refrigerant charge were more significant to the VCHPs compared to the reference systems when in cooling mode than in heating mode. In cooling mode, the normalized seasonal energy use of the tested undercharged VCHPs increased from 6% up to 59%, when compared to reference single-speed heat pumps. The normalized seasonal efficiencies were also impacted, with losses between 6-37% when refrigerant was undercharged. The authors noted that in one of the VCHPs at 65% or below recommended refrigerant levels, the impacts to efficiency were underestimated due to the system's inability to meet cooling loads. In heating mode, the normalized seasonal energy use for the variable-speed systems were reduced in some systems by 10%, and increased in others up to 26%, when compared to reference electric resistance heaters. Similarly, for normalized seasonal efficiencies in the heating mode, impacts ranged from 12% efficiency gains to 42% losses in these variable-speed systems.

In 2018 the Department of Energy (DOE) completed a comprehensive review of research on residential HVAC installation practices (EERE 2018) and highlighted the importance of proper installation – namely airflow, refrigerant charge, and duct performance. The review included a wide variety of residential HVAC fault research encompassing different system types, climate zones, and housing characteristics. The meta-analysis summarized potential benefits of addressing faults in existing residential systems. For corrections to duct sealing and insulation, studies showed up to 33% improvement in cooling capacity and 16-41% improvement in seasonal system efficiency. When duct sealing and insulation are combined with airflow and refrigerant charge corrections, the review found improvements of 12-47% in energy savings. For corrections to static pressure, capacity, efficiency, refrigerant charge, and thermal expansion valves, the review found up to 24% improvements in air conditioning and heat pump systems. The wide spreads improvements were most likely due to the various climate zones, represented by studies in several western states, one southern state, and one eastern state. Importantly, the review also recommended continued pursuit and support of HVAC quality installation and noted that new approaches may be required.

The literature suggests that faults in residential HVAC systems are not only widespread but costly and compromise system performance. Ultimately these HVAC installation faults impact HVAC contractor businesses' bottom line due to increased callbacks, service warranty claims, and customer dissatisfaction. While the causes can be many (faulty system, homeowner error, etc.), the most common cause is installation error. One solution to combat this deficiency in the residential HVAC industry is to employ system commissioning, which helps to systematically identify and correct faults at the time of installation.

Commissioning in the IRA

Since improper residential HVAC installation is a common occurrence, broad deployment of quality-installed heat pumps through the IRA-funded Home Energy Rebates Program will be a large task. The U.S. Department of Energy State and Community Energy Programs (DOE SCEP) office developed guidance and requirements[1] for application to the Home Energy Rebates Program on consumer protection and quality assurance. Participating states, territories, and Tribes must create Consumer Protection Plans that satisfy the requirements provided in the Required Elements of a Consumer Protection Plan guidance document (SCEP 2024a). These plans are designed to provide a high-quality consumer experience concerning energy, cost, and emissions savings. In addition, DOE SCEP developed an optional Consumer Bill of Rights template (SCEP 2024b) that participating entities can consider incorporating into their rebate programs. This document serves as a consumer education tool that includes information on quality contractors and installation standards, among other pertinent information.

The Home Energy Rebates consumer protection plan requirements include installation quality elements along with other quality assurance elements such as qualified contractor requirements, data review, onsite and virtual home inspections, and consumer feedback. According to the April 2024 version, to satisfy installation element requirements, a state must identify and establish minimum quality installation standards that "ensure proper function of the equipment" and establish processes to enforce those installation standards, allowing states to verify and document that these standards have been met. In addition, the Data Review section requires a state to retain documentation of data points, including:

- Post-installation photos of major upgrades / the equipment included in each qualified electrification project for all homes
- Proof of combustion safety testing on fossil fuel equipment in all homes where fossil fuel systems have been impacted by the installation.
- Proof of commissioning testing on HVAC and heat pump water heater equipment in all homes where HVAC systems are installed.

These are essential elements for rebate programs that center consumer experience and quality assurance. Language in the requirements appears to leave flexibility for states to develop consumer protection programs that work best for their circumstances (i.e., climate zone, consumer demographics, contractor engagement and experience, etc.). Some key questions remain for HVAC-related installation requirements: what "minimum quality installation standards" will states choose to implement in their programs, and what comprises "commissioning testing" on HVAC equipment? The following section provides a primer on quality installation standards and proposes a definition for residential commissioning.

[1] DOE SCEP has released several versions of the guidance. Latest application guidance can be found at: https://www.energy.gov/scep/home-energy-rebates-application-guidance.

What is Commissioning?

Commissioning is a quality control process that involves verifying that a building's systems are functioning properly, meeting design intent, and satisfying owner project requirements. Commissioning boasts many benefits, including energy savings and persistence of those savings, improved thermal comfort, indoor air quality, operation and maintenance, and system function (LANL 2002). It is important to distinguish between equipment start-up that confirms the equipment is running, and commissioning which includes measuring key system performance characteristics and verifying efficient operation. The distinction between start-up and commissioning is commonly understood among those who work on commercial HVAC systems. However, many HVAC professionals who work solely on residential systems have little exposure to commissioning to optimize system performance.

For commercial HVAC systems, commissioning has become a fairly common practice involving verifying that the system meets design specifications, verifying proper operation of control sequences, and compiling documentation of test results, equipment literature, and record drawings. This process also includes Testing, Adjusting, and Balancing (TAB), where various system components are tested, adjusted, and balanced to pass performance criteria (e.g., measured airflow is within design tolerances). Requirements for system commissioning were first introduced in the 2012 International Energy Conservation Code (IECC) (ICC 2021) and have also become criteria for green building certification programs such as LEED[2].

For residential HVAC systems, commissioning is virtually non-existent. It is common that only equipment start-up is performed, and only basic system operation is verified (i.e., the system delivers heating and/or cooling, but installed system capacity and actual operating efficiency are not tested). A typical installation process rarely includes performance-related verifications or optimization of airflow, refrigerant charge, and control settings. Furthermore, refrigerant system integrity and equipment longevity-related tasks such as nitrogen pressure tests, vacuum decay tests, and refrigerant leak testing are rarely completed. Failure to complete these tests increase the risk of refrigerant leakage and introduction of non-condensable gases into the system – both of which can compromise system efficiency and longevity. Although the model residential energy code includes provisions for duct leakage testing (ICC 2021) it does not require the other performance or longevity-related tests mentioned above.

The industry has developed several guidelines and standards that define residential HVAC system commissioning as described below. Although these standards exist, there is a great need to increase their adoption along with other best practices. Table 1 compares the intended applications, building sector, and audiences for each standard.

- **ACCA[3] 5 QI-2015** - First introduced in 2007 the ACCA HVAC Quality Installation Specification (ACCA 2015) establishes minimum criteria for proper installation of HVAC systems and applies to unitary air conditioning and heat pump systems, furnaces, and boilers in both residential and commercial buildings. The specification is split into sections that verify aspects of design, equipment installation, distribution, system documentation and owner education.

[2] Leadership in Energy and Environmental Design
[3] Air Conditioning Contractors of America

- **ACCA QIvP-2016** - The Quality Installation Verification Protocols (QIvP) (ACCA 2016) complement the guidelines outlined in ACCA 5 QI. ACCA QIvP provides evaluation protocols in two levels of system verification: Level 1 Installation Checklist Verification and Level 2 Field Verification. This standard also provides program administrators with minimum requirements for programmatic policies and procedures.
- **RESNET[4]/ACCA 310-2020** - The Standard for Grading the Installation of HVAC Systems (RESNET/ACCA 2020) establishes procedures, tolerances, and documentation practices associated with evaluation and grading an HVAC system's design and installation. It consists of five evaluation tasks: 1) design review, 2) total duct leakage, 3) blower fan airflow, 4) blower fan watt draw, and 5) refrigerant charge. This standard is intended to support energy rating and labeling and intended to be used by energy raters, energy auditors, or HVAC Contractors.
- **ASHRAE[5] Standard 221-2020** - The Test Method to Field-Measure and Score the Cooling and Heating Performance of an Installed Unitary HVAC System (ASHRAE 2020) provides a field evaluation and test method to measure and score the performance of an installed unitary HVAC system. The score is based on delivered cooling or heating capacity or cooling efficiency.

Table 1. Comparison of Industry Quality Installation Standards

Standard	Equipment Types	Sector(s)	Target Audiences
ACCA 5 QI	Unitary air conditioners, air-source/water-source heat pumps, geothermal heat pumps Furnaces and Boilers (gas-fired, oil-fired, electric, other)	Commercial Residential	HVAC Contractors Equipment Manufacturers HVAC Trainers Utilities Building owners/operators Certification Bodies
ACCA 9 QIvP		Commercial Residential	Program Administrators HVAC Contractors Third-Party Verifiers
RESNET / ACCA 310	Unitary air conditioner, air-source heat pump up to 65 kBtu/h Furnace up to 125 kBtu/h	Residential	Home Energy Raters Energy Auditors HVAC Contractors
ASHRAE 221	Single-zone unitary split and packaged direct expansion (DX) cooling, air-source heat pump, and combustion furnace HVAC system of any capacity with forced-air distribution systems.	Commercial Residential	HVAC Contractors Technicians Design Engineers Balancing and Energy M&V Professionals Manufacturers Facility Personnel Commissioning Agents

Key industry stakeholders and subject matter experts have devoted extensive effort to developing these standards, which have seen some adoption by contractors, programs, and

[4] Residential Energy Services Network, Inc.
[5] American Society of Heating, Refrigerating, and Air-Conditioning Engineers

energy raters. In addition, several utility programs have utilized ACCA's quality installation specification and verification protocols, including the ENERGY STAR Verified Installation (ESVI) program. However, these standards and programs have faced challenges with contractor engagement and limited adoption.

ACCA QI5 and the verification protocols are comprehensive and encompass all core areas that characterize a quality installation, including design (e.g., load calculation, equipment sizing, and selection), distribution (e.g., duct leakage, airflow balancing), equipment installation (e.g., verification of airflow and refrigerant charge), and system documentation and owner education. HVAC business owners can get overwhelmed by the amount of documentation and resulting change in processes involved in implementing the above standards. In addition, several people within an HVAC business may be involved in the design and installation of an HVAC system. The ACCA QI standards divide responsibilities for documentation between the HVAC designer and the HVAC Installer or Start-up Technician.

Although pre-installation procedures (i.e., proper design, sizing, and equipment selection) are important and should be verified, this paper focuses on commissioning procedures conducted during or after installation, barriers to industry adoption, and advancements in technologies that can help installers and technicians. Along with visual inspections, the commissioning testing scope of an installer or start-up technician should at minimum include verification of refrigerant charge for all systems, verification of proper airflow and measurement of total external static pressure for ducted systems, and verification that controls have been properly configured. In addition, refrigerant pipe integrity and dehydration should be tested during installation through a pressure test and vacuum decay test. Additional verification procedures include measurement of installed system heating and cooling capacity along with duct leakage testing.

Barriers to Industry Adoption of Commissioning

In the residential sector, HVAC contractors are entrusted with multiple responsibilities including marketing/sales, accounting, inventory control, fleet maintenance, customer service, and other business operations. The additional time and skill to perform proper load calculation, sizing, system selection, installation, start-up, and commissioning are a burden few professionals are willing to bear. As indicated by Butzbaugh, et al., "a considerable number of HVAC contractors either do not know about [diagnosing HVAC faults] or do not trust the [fault diagnostic] technology" (p.27, 2020). As a result, many contractors forgo the use of ACCA and ASHRAE standards and instead rely on rules-of-thumb. This section highlights key barriers to industry adoption of commissioning, namely lack of training, lack of contractor engagement in utility QI programs, lack of consumer demand, and lack of contractor awareness on value proposition attributed to commissioning.

Lack of Training on Commissioning Processes

Residential HVAC contractors are not trained on a standardized commissioning process. Variations of technologies commonly found in residential applications require different commissioning processes, approaches, and technologies. For example, a comprehensive process for commissioning a ducted ASHP would evaluate total external static pressure, airflow, refrigerant charge, blower fan power draw, and duct leakage, whereas the process for a ductless

ASHP might only include verification of proper refrigerant charge. The process for commissioning a cold climate heat pump with electric resistance should include verifying proper configuration of controls such that the system doesn't call for supplemental heating until the outdoor temperature dips below the balance point. Unlike a single-stage heat pump, the complexity and proprietary controls of a variable-speed heat pump requires the manufacturer to provide a "test mode" that locks the system into an appropriate fan speed and compressor capacity setting so a technician can test refrigerant charge, airflow, external static pressure, and blower fan power draw. These are only a few examples demonstrating the complexity and varied nature of training on commissioning processes.

Additionally, contractors face significant challenges due to an industry-wide labor shortage. Training contractors on commissioning takes time and money, as does integrating standardized processes into installation workflows and business practices. As contractors interviewed for a recently funded Building America paper indicate, "Like most techs, [we] hate change that takes more time. The most common complaint [about commissioning systems] is that [new users] think it takes too long. However, once they start using [commissioning tools] on a regular basis it really doesn't take much longer and provides clarity into system performance they were not seeing before" (EERE, n.d.).

Lack of Contractor Engagement in Utility Programs

Utility programs have attempted to upskill HVAC contractors in their service areas by providing limited training on quality installation and commissioning and providing incentives for quality installations. Verified quality installation (VQI) programs help realize energy savings through quality installation of higher-efficiency HVAC equipment. There have been successful implementations of VQI programs; however, they have not been widely adopted among utility programs. According to the Consortium for Energy Efficiency in 2022, only 4% of members administered quality installation programs for new residential HVAC systems. This is a small minority compared to the 52% of members with a ducted ASHP measure, and 43% of members with a ductless ASHP measure (CEE 2023). Utility program administrators are aware of the prevalence of equipment faults due to improper installation and the resulting energy savings left on the table, but the majority have chosen not to implement VQI programs.

A major challenge for these programs has been a lack of contractor engagement and buy-in. Evaluation studies of these programs suggest that contractors are reluctant to fill out checklists and documentation, and frequently do so by inserting values that meet the requirements rather than taking measurements and making system adjustments, sometimes referred to as "pencil whipping" or "rebate gaming." In the review of residential HVAC installation practices (EERE 2018) DOE concluded that new approaches may be required to broaden adoption of quality installation. The report recommends additional support to engage the market for technology solutions, including advanced equipment, controls, and automated verification tools. Other key recommendations include promoting technologies and processes that reduce deployment and implementation costs, and developing quality control protocols to detect and minimize the opportunity for data input gaming.

Lack of Consumer Awareness and Demand

Homeowners lack visibility and understanding of the performance impacts of common faults on the operation and maintenance of their HVAC systems. This results in a lack of demand

from homeowners for commissioning and retro-commissioning services. With most HVAC systems operating with one or more performance faults, homeowners experience increased energy expenses and system inefficiencies due to inadequate HVAC installation and commissioning. These increased energy expenses are largely invisible to homeowners since utility energy use data does not independently track HVAC energy use. Additionally, many homeowners do not know their systems are operating improperly. According to a California study designed to understand the customer decision-making for HVAC VQI services, most homeowners assume their system is properly installed if it turns on, looks acceptable, or they believe the contractor is competent (Steiner 2015). The emergence of reporting tools and monitoring devices is arming homeowners with greater insight into the operations and maintenance of their HVAC systems. Providing value-added services, such as commissioning and retro-commissioning, combined with diagnostic reporting and data helps HVAC technicians and installers build customer confidence in recommendations.

Contractors Unaware of Value Proposition

HVAC businesses are driven by a need to make as many transactions as quickly as possible to serve more calls per day. Owners, technicians, and installers all want to avoid receiving callbacks. Callbacks are return service calls to correct work on an already completed job. Callbacks can occur because of failures in manufacturing parts[6], but more often occur because of technician and communication errors. Table 2 (Orr 2021) summarizes typical reasons for callbacks into these three categories, the latter two categories can be mitigated through proper commissioning.

Table 2. Reasons for Callbacks

Category of Callback	Reason for Callback
Manufacturer/ Warranty Issue	• Leaky coils • Capacitor failure
Technician Error	• "Tunnel vision," leading to incorrect diagnosis • System setup incorrectly • Not testing the whole system before leaving • Condensate drain issues • Not putting the disconnect back in • Improper low-voltage or thermostat wiring • Dirty coils • Improper refrigerant charge
Communication Error	• Poor listening/understanding of homeowner concerns • Not clearly communicating with customers on which services were provided (or not)

Callbacks are expensive, no charge, no profit service visits. According to a session presented at the 2024 HVACR Symposium[7], the callback cost for HVAC businesses ranges from

[6] The industry standard manufactured parts failure is typically 2 to 2.5% (Grandy 2024).

[7] The 5th Annual HVAC/R Symposium is hosted by HVAC School, a popular resource among the residential HVAC community. For more information: https://hvacrschool.com/events/5th-annual-hvac-r-training-symposium/

$400 to $1,200 or higher. Industry leaders and experts advise companies to address callbacks by instituting standardized procedures for tasks (e.g., sales, pre/during/post service calls, installs), employing performance commissioning procedures for new installs, conducting full diagnosis reviews for service calls, documenting findings and customer decisions, and offering training for all departments (e.g., sales, call center, service, etc.) (HVAC Pro Blog 2023). Contractors not addressing the costly impact of callbacks is directly related to the industry's lag in adopting commissioning. According to a DOE Building America (BA) funded project[8], 83% of application users reported fewer callbacks since adopting it; however, interviews with business owners indicated they are not tracking this data. This poor line of sight to understanding the impacts of one of the HVAC industry's key performance indicators impedes the adoption of commissioning services (EERE, n.d.)

New Technology Can Help: Technology-Assisted Commissioning

New technology can reduce barriers to market adoption of residential HVAC system commissioning. New solutions can improve the value proposition to consumers, contractors, manufacturers, and energy efficiency organizations. Automated fault detection and diagnostics (AFDD) technologies are available on the market that monitor ongoing operation of residential HVAC systems to verify that equipment are operating within key parameter thresholds or system performance estimates – but these are currently only available in premium HVAC equipment (Winkler et al. 2022). However, this paper is focused on technology designed to identify faults and commission new systems at the point of installation. The new technology-assisted commissioning solutions that will be discussed are smart diagnostic and commissioning tools and connected commissioning systems.

Smart Diagnostic and Commissioning Tools

Third-party probes that wirelessly connect to a smartphone application that enables streamlined data collection, calculations, fault detection, and reporting are collectively known as "smart tools." Probes are temporarily placed during time of installation to measure refrigerant-side, air-side, and electrical characteristics of a system. Smart tools replace test instruments commonly used by HVAC technicians and are slowly gaining traction in the industry. Traditionally, an HVAC technician's test instruments included an analog refrigerant manifold to measure refrigerant-side pressures and saturation temperatures, thermistors to take refrigerant line temperatures and to calculate refrigerant superheat/subcooling, a multimeter for electrical readings, and sometimes a manometer to measure total external static pressure. Smartphone-connected versions of all these test instruments now exist. Smart tools help a technician perform standard calculations and utilize parameter thresholds and FDD algorithms to detect faults and suggest corrective actions to the technician. Some smart diagnostic tools may use a combination of measurements to estimate system performance (e.g., energy efficiency ratio, capacity, etc.). An example deployment of these test instruments during commissioning is shown in Figure 1. Several smart diagnostic tool platforms include commissioning workflows for a variety of

[8] This BA project was funded to investigate the efficacy of one smart diagnostic application and to better understand business impacts of implementing this application.

residential HVAC equipment that help standardize and streamline the commissioning process. Features including geolocation, timestamping, direct system measurements, and automatic report generation make smart diagnostic tools an ideal option for utility programs that would like to verify that a system was commissioned without errant reporting. Several utilities such as MassSave and Entergy have adopted these tools into their VQI and tune-up programs (Butzbaugh et al. 2022).

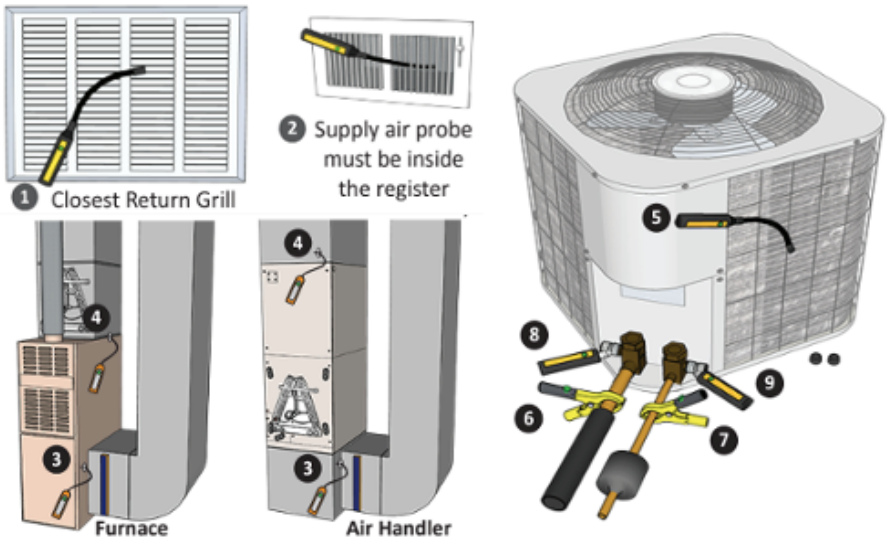

Figure 1. Illustrated example of temporary probe deployment on a residential HVAC system, courtesy of measureQuick. These probes connect to smartphone commissioning application.

One challenge to broader adoption of smart diagnostic tools for commissioning is that HVAC business owners have a poor understanding of their value proposition. Taking more time per service or installation call to ensure thorough investigation with smart diagnostic tools can be counter intuitive for contractors seeking to complete more jobs per day. According to the DOE BA study, 64% of application users indicated more time is spent on site, because their use of smart diagnostic tools and software enables technicians to find more faults to repair. “[We] address more issues so we conduct less calls daily at a higher value for our customers and our company.” In examining the revenue impacts, the BA study found those using smart diagnostic tools reported an increase in revenue per ticket/visit in the range of 20 to 80% for service call revenues and a range of 30 to 40% for new installation sales. The study found that 79% of application users indicate that data-driven diagnostic and commissioning reports help build customer confidence in their recommendations. More specifically, contractors interviewed for the BA project indicate customer confidence grows with commissioning reports (EERE, n.d):

- “[It] has increased the trust by showing actual data on how their system is operating.”
- “Customers see value in information. In fact, some of our Google reviews mention "the electronic report" the customer received and how thorough we are”.
- “[Commissioning reports] greatly increases customer confidence.”
- “Most customers really like the ability to have verification. That they don't have to just take someone's word about how the system is performing or what the issue is. Being able

to back up conversation with verifiable data is something this industry should have done long ago. [..it opens the door for these conversations and accountability."

Connected Commissioning (CCX) Systems

The second type of advanced technologies are "connected commissioning" systems. These are HVAC systems that have onboard sensors and micro-processing capabilities that provide data via Bluetooth, Zigbee or Wi-Fi to the contractor through a manufacturer-provided tool or through an app on a cellular phone or tablet device. These solutions are still emerging and not widely commercially available compared to smart diagnostic tools. Many manufacturers have begun refining their own approaches to adopt a more cloud-driven set of commissioning resources. Some manufacturers are focused on solutions which provide ongoing continuously connected diagnostic and fault detection services while others are proceeding with a simple approach that verifies initial operating conditions, gauging airflow, charge, control settings, etc. but does not rely on a cellular or onsite Wi-Fi connection. A key distinction of these connected commissioning systems is that they are tailored to the specific manufacturer's needs with an app interface designed to help the contractor through the process of commissioning of their products. Figure 2 below provides an illustration of a connected commissioning system that includes the option of wireless commissioning tools to support the data gathering.

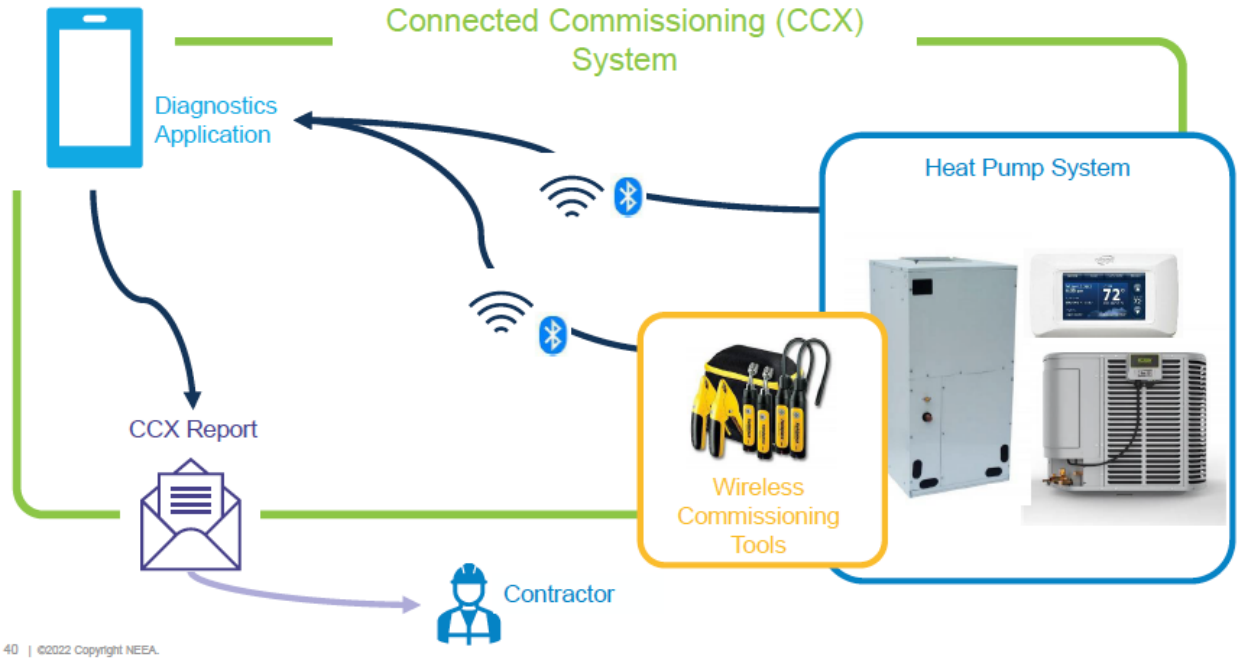

Figure 2. Connected commissioning concept diagram, courtesy of NEEA.

Both smart diagnostic tools and connected commissioning approaches have their own advantages and disadvantages. They are not mutually exclusive and in many cases a solution can be a combination of both. Smart diagnostic tools advantages are that they do not tie a contractor to a singular equipment manufacturer and the cost of these tools can be spread across multiple installations. As a consequence, the quality of the sensors and tools can be of higher quality and

accuracy and can be used for more than just commissioning purposes. A disadvantage of smart diagnostic tools is that they are not as well suited for commissioning of variable-speed heat pumps and require contractor intervention to input the specific product information and operational parameters. The current products on the market are well suited for single-speed heat pumps and AC units where testing and verification of performance can be done without detailed knowledge of the equipment's unique operating parameters, speeds and modes that are typical of variable speed systems.

Connected commissioning solutions' key advantage is that it is tailored to the manufacturer's unique product properties. This is especially valuable in variable speed systems which require multidimensional interpolation of operating conditions and parameters that require looking up specific hardware specifications or databases. Given the incremental cost of the embedded sensor and need for more sophisticated onboard microprocessors, such systems are only currently beginning to show up on variable-speed equipment. The ability of the hardware to connect with the manufacturer's cloud database can simplify the contractor workload for commissioning variable speed systems. In addition, such systems can identify what components are connected and their impact on system commissioning requirements. The disadvantage of connected commissioning systems is the need for additional hardware costs and the development costs of the manufacturer's cloud, app, and data security needs.

Current Initiatives

The **Smart Tools for Efficient HVAC Performance (STEP) Campaign**[9], managed by PNNL for DOE, aims to increase adoption of smart tools that help contractors commission residential HVAC systems. The STEP Campaign's key functions include raising awareness of smart tools and the need for residential HVAC commissioning, developing resources to build the body-of-knowledge on smart tools, providing technical support, and recognizing innovators and early-adopters. Key stakeholders include residential HVAC contractors, training providers, utilities and energy efficiency organizations.

ACCA offers **Quality Installation (QI) certificates**[10], powered by measureQuick®: Verified Equipment Operation and Verified System Performance. There are only a few HVAC professionals who are able to install systems that earn an ACCA QI certificate. Most heating and cooling companies do not invest in the tools or training to deliver systems that perform as the manufacturer intended. ACCA's QI certificates are badges of distinction showing a contractor has delivered on their promise of exceptional HVAC installation, commissioning, and system performance. ACCA's QI Certificates offer consumers third-party verification of quality work.

The **PNNL Quality Install Tool**[11] is an open-source web app funded by DOE that facilitates quality installation processes for central ducted split heat pump and ductless heat pump systems, along with other energy efficient upgrades and installations. This tool simplifies, standardizes, and expedites quality installation documentation through photo-driven workflows. The QI Tool is intended to be used by the installer to document key steps, best practices, and

[9] https://rescampaigns.pnnl.gov/campaign/step
[10] https://www.acca.org/qa/prove-it
[11] https://www.pnnl.gov/projects/quality-install-tool

essential measurements at the time of installation. The tool automatically generates formatted PDF reports that can be directly shared with the customer, for company records, attached/uploaded to rebate submission portals, and reviewed by independent third parties such as utility or program implementers. This QI tool is not a smart diagnostic tool but still holds great potential to simplify and improve utility QIV programs. It does not directly connect with test instruments and does not include automatic calculations for refrigerant charge or system performance; however, it does include timestamping and geo-location for required photos.

The **Connected Commissioning Technical Workgroup**, currently led by NEEA, this is a collaboration between residential heat pump manufacturers, national laboratory staff, and heat pump subject matter experts to develop a specification for connected commissioning. This workgroup seeks to define a standard commissioning report and the methodology that will be used to verify a manufacturer's methodology and results are sufficiently accurate and reproducible. Ultimately this collaborative seeks to develop a product certification which can be used by manufacturers to improve the value proposition for customers and contractors and justification for utilities to provide incentives.

Conclusion

Commissioning is key to ensuring the promised benefits of heat pumps. Standards for quality installation have been around for some time, and utility programs have also attempted to address proper system installation and commissioning to benefit their customers and to ensure realization of energy savings. However, industry uptake by residential HVAC contractors has been limited due to the additional time and skills required to perform system commissioning in an already time- and workforce-constrained environment. As a result, many systems are not installed to operate as efficiently and reliably as they should.

With new technological solutions on the market, new initiatives aimed at commissioning and quality installation standards are pushing to re-energize interest among contractors. Smart diagnostic/commissioning tools and connected commissioning systems both help to make the commissioning process more efficient and accurate for trained professionals. Educational programs and tools are also being offered to increase awareness and upskilling opportunities for seasoned and apprenticing technicians.

State energy offices appear to have flexibility in how they administer their Home Energy Rebate programs and the broad language used in the program requirements document leaves the concepts of "quality installation" and "commissioning" up for interpretation. The authors recommend that program administrators strongly consider:

- adopting established quality installation and commissioning standards, as summarized in this paper,
- taking advantage of technology-assisted commissioning products already in the market (e.g., smart diagnostic tools) to implement verified quality installation and commissioning protocols into their consumer protection plans,
- utilizing available workforce funds to train contractors on technology-assisted commissioning,
- including connected commissioning and OEM-embedded commissioning products (when they come to market) into future program plans.

At this moment in time, the industry has an unprecedented opportunity: funding is available for heat pumps, funding is available for training, and the IRA has the attention of consumers. If coordinated well, this is an opportunity to transform the state of residential HVAC quality by arming installers with new technology that embeds commissioning workflows into their standard practices which could have transformative benefits that far outlive IRA funding.

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