Connected Commissioning: Enhancing HVAC Performance Through Improved Installation Quality

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ABSTRACT

Residential HVAC systems are widely affected by installation faults, with research showing that 70–90% of systems in U.S. homes exhibit at least one performance-compromising issue. These faults result in 20.7 TWh of excess energy consumption annually, unnecessarily costing bill-payers $2.5 billion in utility expenses and reducing equipment reliability. Connected commissioning offers an innovative technological solution by using onboard sensors coupled with manufacturer-developed software to verify optimal system performance, detect faults during installation, and enhance HVAC functionality.

Connected-commissioning-capable HVAC systems ensure that key performance metrics—such as refrigerant charge, indoor airflow, and control settings—are optimized during installation. Beyond confirming proper system operation, connected commissioning capabilities deliver significant business value to installation technicians (contractors) by reducing costly callbacks, improving equipment reliability, and fostering trust with customers through transparent, data-driven reports.

This new category of HVAC products is being discussed through strong collaboration with private industry (including most major U.S. HVAC original equipment manufacturers), researchers, efficiency program implementers, and utilities. This industry-led process prioritizes metrics that align with utility quality verification programs. Connected-commissioning-capable systems have the potential to improve installation outcomes, support precise measurement and verification, and further reduce costs for American consumers.

Background

The affordability of energy and the systems that use it are critical. Projected near-term electric load growth from data centers poses significant stress to the electric infrastructure (LBNL, 2024), leading to larger peaks on utilities, requiring expensive upgrades and increasing energy costs. Heating and cooling are the largest residential energy loads, and improving their performance can considerably reduce energy costs for Americans. Although more efficient equipment can accomplish this, it is also important to ensure that the systems are meeting their potential performance by ensuring that they are installed correctly.

Heating, ventilating, and air-conditioning (HVAC) equipment installation is a complicated process requiring highly skilled technicians, particularly when working on highly efficient, modern equipment. Load calculations, equipment selection, ducting, working with refrigerants and line sets that contain them, condensate management, and electric capacity

considerations are all critical parts of an installer's job. These tasks must be performed under real-world and often adverse conditions where components fail and could have been improperly installed in the past. This complexity and time pressure paired with a nationwide shortage of trained technicians (Pann 2023) leads to suboptimal installations in most cases—and thus artificially high energy bills for the resident. Literature reviews have shown that 70–90% of residential HVAC systems in the United States have at least one performance-compromising fault (DOE 2018). Nationally, these faults result in 20.7 TWh of excess energy consumption annually, unnecessarily costing bill-payers $2.5 billion in utility expenses and reducing equipment reliability (Winkler et al. 2020). In a baseline field study of residential HVAC equipment in the Northwest, Bonneville Power Administration (BPA) found that many of the tested systems would not have met operational best practices for airflow (33%) and refrigerant charge (28%) (BPA 2019). In addition, important energy-related control settings, such as auxiliary heat lockout (57%) and compressor lockout (28%), would not meet BPA's quality installation program requirements, undermining the efficiency of the equipment.

One way to improve the installation quality of HVAC equipment is through commissioning—a systematic quality assurance process that methodically verifies and documents that all aspects of an HVAC system installation are within manufacturer tolerances and are operating as intended at the completion of the installation. This process is becoming increasingly common in the commercial sector, but it remains rare in the residential space due to a variety of factors, including a lack of incentive for installers, increased time on-site, and insufficient training on commissioning. In the residential space, typically little verification of optimal installation is completed other than the installer checking that the system is supplying cold or hot air. Meanwhile, best-practice commissioning typically includes a check on the indoor airflow, refrigerant charge, and controls for the system. New technologies have made the process significantly easier for installation technicians (contractors) to implement. For instance, wireless probes that communicate directly with an app containing manufacturer information can reduce the time it takes to commission and reduce installer error rates in the process (Allen-Magande 2024); however, even these systems require an installer to have specialty tools, an app subscription, and the knowledge (and desire) to understand the faults identified by the app and, most importantly, the knowledge of how to fix them.

Recently, several air conditioner and heat pump manufacturers began refining their commissioning solutions, which until the early 2020s largely relied on connecting a laptop or a fault code reader to the equipment. The concept of connected commissioning for residential air-conditioning and heat pump systems was introduced in 2019 by the Northwest Energy Efficiency Alliance (NEEA) and was built on the cost savings potential of more intelligent inverter-driven systems (Dymond 2018).

Connected commissioning has the potential to streamline the commissioning process of HVAC systems and reduce the installation technician burden by leveraging embedded sensors, a sophisticated application, specific integrated circuit chips, and a Bluetooth-connected mobile device to assist the installation technician in verifying proper commissioning. Collaboration among NEEA, the National Laboratory of the Rockies (NLR), the Pacific Northwest National Laboratory (PNNL), and original equipment manufacturers (OEMs) revealed the potential of a consistent commissioning report generated by these embedded systems. This has resulted in a multiyear, voluntary, and collaborative effort with OEMs to develop a voluntary product definition that enables differentiating equipment that is connected commissioning capable. This technology will help HVAC installation technicians avoid common faults through an automated

commissioning process. In turn, consumers can benefit from higher-quality installations, utility bill savings, and improved comfort, and utilities can reduce the undue burden on the grid from low-quality HVAC installations.

What Is Connected Commissioning?

Connected commissioning refers to an emerging, voluntary capability of residential HVAC equipment that guides an installation technician through the process of confirming proper commissioning and operation. The voluntary process results in a consistent report generated by a mobile application that contains product-specific, OEM-provided performance information. The optional report confirms that the system meets the manufacturer's criteria for proper commissioning and that system efficiency is not compromised due to refrigerant charge, indoor airflow, and/or poor control settings. The report also contains information that can streamline utility programs that verify the equipment, location, installation date, control settings, etc. Figure 1 illustrates the concept of connected commissioning.

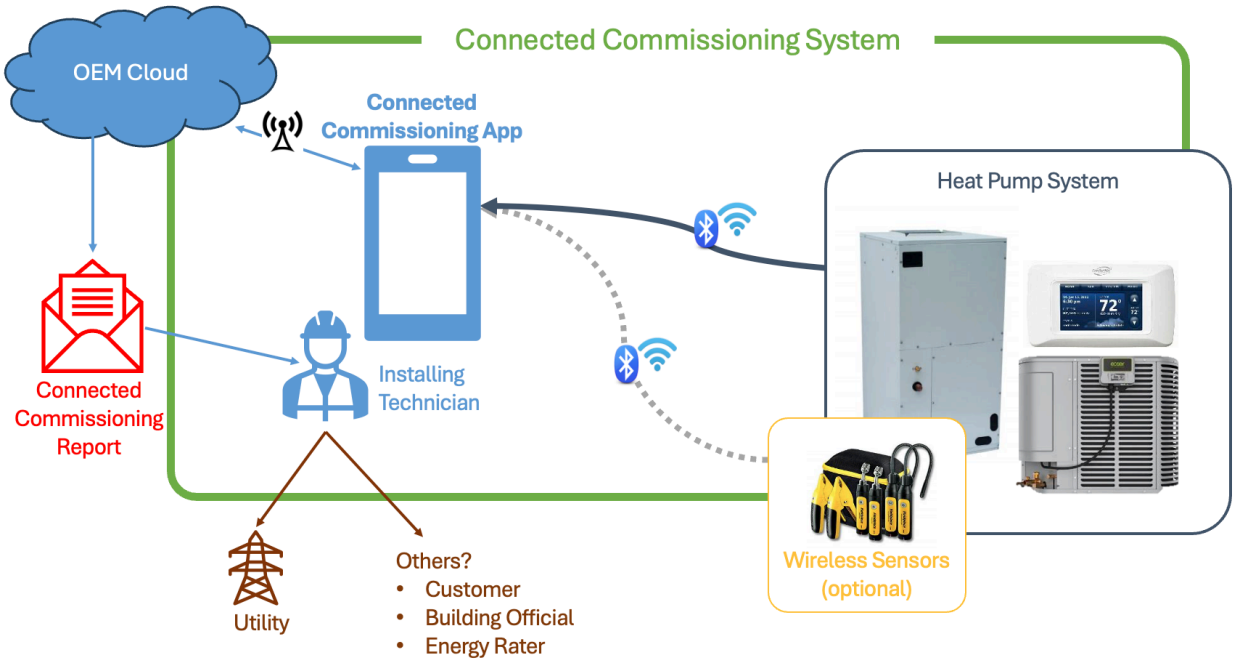

Figure 1. Connected commissioning concept

The key advantage of connected-commissioning-capable equipment is that it is tailored to the manufacturer's unique product design and installation requirements. This is especially valuable in variable-speed systems, which require multidimensional interpolation of operating conditions and parameters, and which currently require searching for specific hardware manuals or databases. However, because of the incremental cost of the embedded sensor and the need for more sophisticated onboard microprocessors, such systems are only now beginning to show up on variable-speed equipment. The ability of the hardware to connect with the manufacturer's cloud database can simplify the installation technician's workflow for commissioning variable-

speed systems. In addition, such systems can identify which components are connected and their impacts on manufacturer commissioning requirements.

It is expected that most connected commissioning solutions will be available first for variable-speed systems that already incorporate the sensors needed for equipment control and monitoring. For variable systems that do not already incorporate the necessary sensors, hardware costs will increase but could be offset by the (1) reduced time needed to commission the equipment on-site (lower labor costs) and (2) economics of scale as voluntary connected commissioning usage increases. Utilities have also expressed interest in providing incentives. All these factors provide the opportunity for connected commissioning to reduce incremental first costs while facilitating large energy bill savings over the lifetime of the equipment. The development costs of the manufacturer's cloud, app, and data security needs remain a disadvantage of connected commissioning; however, these challenges could be overcome by the benefits, particularly as development costs are amortized over more units.

Value Proposition of Voluntary Connected-Commissioning-Capable Equipment

To ascertain the value of voluntary connected-commissioning-capable equipment and its potential benefits to utility HVAC programs, NEEA interviewed 18 utilities and efficiency program implementers. Generally, the interviewees felt that connected commissioning would be valuable to their programs. They expressed that the potential value could include a reduction in the participation burden for the contractor, especially in midstream utility programs[1] Aligning participation processes with voluntary connected commissioning reports could allow programs to operate more efficiently and reduce administrative costs. Data consistency and increased trust in commissioning data could provide greater opportunity to analyze installation data for workforce development and training opportunities. Reducing the administrative burden required for participation in midstream programs could reduce barriers for participation.

The likelihood of success for connected commissioning is not driven by utility programs alone. It could be initiated by the interest of utility programs, but ultimately its market success will be driven by the value proposition for the installation technician and their acceptance of the technology. In addition, several major OEMs see connected commissioning as consistent with their internal plans to provide their installation technicians with clear commissioning guidance to ensure that their systems perform well.

Table 1 provides key value propositions for market actors that can leverage the benefits of voluntary connected-commissioning-capable equipment. Many of these will likely take years to fully manifest in the market as the potential benefits of having a consistent verification report become more widely available and as HVAC contractors and utilities determine how they want to incorporate voluntary connected-commissioning-capable equipment into their business models.

[1] Midstream utility programs are energy efficiency initiatives where incentives are provided directly to installation technicians rather than the end-use customer.

Table 1. Value Proposition of Voluntary Connected-Commissioning-Capable Equipment

Market Actor	Value Proposition
Consumers: homeowners, occupants	- Increases the likelihood of high-quality equipment installation, leveraging a clear, easy-to-understand explanation of the system's correct installation. - Decreases the likelihood of callbacks, improving customer satisfaction. - Lowers energy bills over the lifetime of the equipment due to the minimized risk of energy-wasting installation faults - Increases home comfort due to optimally operating systems.
OEMs	- Enables product differentiation in the marketplace, providing consumers with visibility into voluntary connected-commissioning-capable equipment - Facilitates digital registration of installed systems. Many OEMs use registration as the criteria for extended warranties (e.g., from 10 years to 12 years on a compressor). A connected commissioning report could reduce risks of future warranty claims. - Reduces service callbacks and equipment complaints and improves brand reputation through properly installed systems - Provides ongoing digital data that could be used for future customer engagement, service contracts, and product development if the system remains connected via the home's Wi-Fi - Reduces likelihood of equipment returns.
Utilities and programs	- Streamlines program administration. Connected commissioning reports provide concise information that is required for program application and proper commissioning verification. Midstream incentives are paid quickly upon receipt of the report. - Increases efficiency realization rates of programs because of the improved quality of the installations and the improved verification of program control and sizing requirements - Reduces strain on the electric grid due to improperly installed equipment - Facilitates easy customer messaging through clear product differentiation, e.g., "Be sure to get a connected commissioning report to verify that the system was set up correctly."
HVAC installation technician	- Increases company owner visibility into installation technician performance in the field - Reduces callbacks and equipment complaints - Allows service calls to be made with detail on how the system was operating when it was first commissioned - Facilitates faster training of new hires on how to install and commission a system with the aid of a guided app.

Industry-Driven Collaboration on Voluntary Connected Commissioning

Connected commissioning technology offers potential benefits across the full residential HVAC value chain, including OEMs, distributors, dealers, installers, utilities, and homeowners/occupants. The technology could mitigate installation fault-related energy inefficiency issues that have burdened the HVAC industry for decades. Manufacturers are aware of the industry-wide installation shortcomings, and innovative OEMs have started developing systems that resemble connected commissioning capability. Yet, the successful development of a voluntary connected commissioning product offering that provides value for all parties requires coordination across all residential HVAC stakeholders. Unsurprisingly, OEMs are not usually forthcoming with competitors about the products they are currently building, or plan to build, which introduces challenges for the industry to align on a new, voluntary product offering. In addition, OEMs are not typically privy to the needs of utility and energy efficiency HVAC programs, which can help drive demand for their energy-efficient products.

To build alignment among OEMs and to include the perspective of energy efficiency programs, a voluntary technical working group (TWG) consisting of OEMs and other stakeholders was convened. The main goal of the TWG was to develop a voluntary definition for connected-commissioning-capable residential HVAC equipment that manufacturers could choose to use. The connected commissioning definition establishes a voluntary commissioning report template. NEEA and TRC facilitated the TWG with support from NLR and PNNL as well as active representation from roughly nine major OEMs and seven other key industry stakeholders. Starting in late 2025, meetings were held biweekly with focused subgroup meetings assembled as necessary to reach voluntary consensus on topics that required more detailed discussion (e.g., indoor airflow, refrigerant charge, and controls).

As a result of the TWG meetings, a definition for this voluntary product offering was developed and sent to the participating OEMs for comment in early 2026. This definition represents consensus among OEMs and market actors who are interested in the option of developing connected-commissioning-capable residential HVAC equipment or including the equipment in their utility HVAC programs.

The option to create a connected commissioning report is a primary feature of connected-commissioning-capable equipment and has been designed to be concise, containing only the necessary information to verify proper commissioning with additional data that utilities need for program implementation (e.g., installation location, commissioning date, and equipment efficiency ratings). The equipment must meet four criteria to pass the voluntary commissioning process: (1) The manufacturer connected commissioning protocol is established. (2) At the time of commissioning, ambient operating conditions are suitable. (3) The refrigerant charge is adequate. (4) The indoor airflow rate is adequate. External static pressure (ESP) is also recorded, but because poor (high) ESP is often a symptom of the duct system and not the equipment, only warnings are provided. Figure 2 shows a mock-up of the optional connected commissioning report. The report format could vary by manufacturer, but it would include all the information shown here.

Connected Commissioning Report	Pass, Fail of X (True or False value)

System Information	
Location of Installation	GPS Coordinates
Commissioning Date	Month / Day / Year
AHRI Certification #	Of Matched Pair
Indoor Unit	Make and Model
Outdoor Unit	Make and Model
Thermostat Model	Make and Model
Efficiency Ratings	HSPF2: SEER2: EER2: 5F Capacity Ratio:

Connected Commissioning Protocol Established	True or False

Suitable Conditions	True or False
Outdoor Temperature	°F
Indoor Temperature	°F

Refrigerant Charge Adequacy	True or False
Liquid Line Temperature	°F
Degrees of Subcooling	°F
Target Subcooling	°F

Airflow Adequacy	True or False
Fan Power	W
Airflow	CFM

Controller Information	
Auxiliary Heat Lockout	N/A or Off or °F
Compressor Lockout	N/A or Off or °F
Setback Recovery Mode	N/A or Off or On
WiFi Connection	Connected or Not Connected
AHRI 1380 Capable	True or False

External Static Pressure	OK or Energy Warning or OEM Warning
External Static Pressure	in wc

Figure 2. Mock-up of the connected commissioning report (reference only)

Methodology for Voluntary Connected-Commissioning-Capable Equipment

Laboratory certification of connected-commissioning-capable equipment is critical to ensure that the equipment follows the guidelines outlined in the definition. This will help facilitate utility and efficiency program rebates. The overall goals of the certification methodology are to establish a consistent process for program administrators to confirm the capabilities of connected commissioning solutions; to define the operating conditions, procedures, and tolerances to evaluate connected commissioning equipment in the laboratory; and to verify the accuracy of the data in the connected commissioning report.

The methodology is written for both OEM self-certification and third-party test laboratories that use OEM-provided equipment information and data to support the certification process. As described in the connected commissioning definition section, pass/fail tolerances are determined by the OEM; thus, a third-party certification process requires equipment-specific information to determine whether the pass/fail criteria are accurately reported. The certification methodology attempts to balance rigor with minimizing the overall test burden. This is accomplished by incorporating the certification tests into existing laboratory tests and using visual data confirmation when appropriate. Certification for refrigerant charge adequacy, airflow adequacy, and ESP will use laboratory-based methods; whereas the system and controller information will be visually confirmed by comparing the connected commissioning report to either the equipment controller display or other information that is physically presented directly on the equipment.

Figure 3 shows the methodology to evaluate the connected commissioning charge adequacy. The goal of the charge adequacy certification test is to limit coefficient of performance (COP) degradation to 10% of the baseline value due to an inadequate charge. This is accomplished by establishing a baseline COP followed by an incremental adjustment to the system's refrigerant charge until the connected commissioning report indicates an inadequate charge. COP—as opposed to refrigerant subcooling or superheat—was chosen as the metric to provide OEMs freedom to determine the best algorithm for charge adequacy.

The procedure starts with a refrigerant level that is determined using the OEM's installation instructions. Under these conditions, the connected commissioning report should indicate an adequate charge. If the charge adequacy test indicates a failure, the certification test would fail because the system has been charged using a method that is consistent with ratings tests, which should result in an adequate charge. The A_{Full} test condition (95°F outdoor air dry-bulb, 80°F indoor dry-bulb, 67°F indoor wet-bulb) was selected to minimize the test burden by allowing OEMs to complete the connected commissioning certification tests at preprogrammed chamber operating conditions and in parallel with typical ratings tests. Because the methodology involves incremental adjustments to the refrigerant charge, it makes sense to allow for a one-time larger adjustment at the beginning of the test to shorten the overall testing time. Performance data will be collected and documented each time the refrigerant is adjusted, as will the magnitude of the adjustment.

Refrigerant charge is incrementally adjusted until the connected commissioning charge adequacy fails. At this point, if the COP is within 10% of the baseline value, the certification passed. The test may be repeated if the COP degradation exceeded the 10% threshold before determining whether the certification test failed.

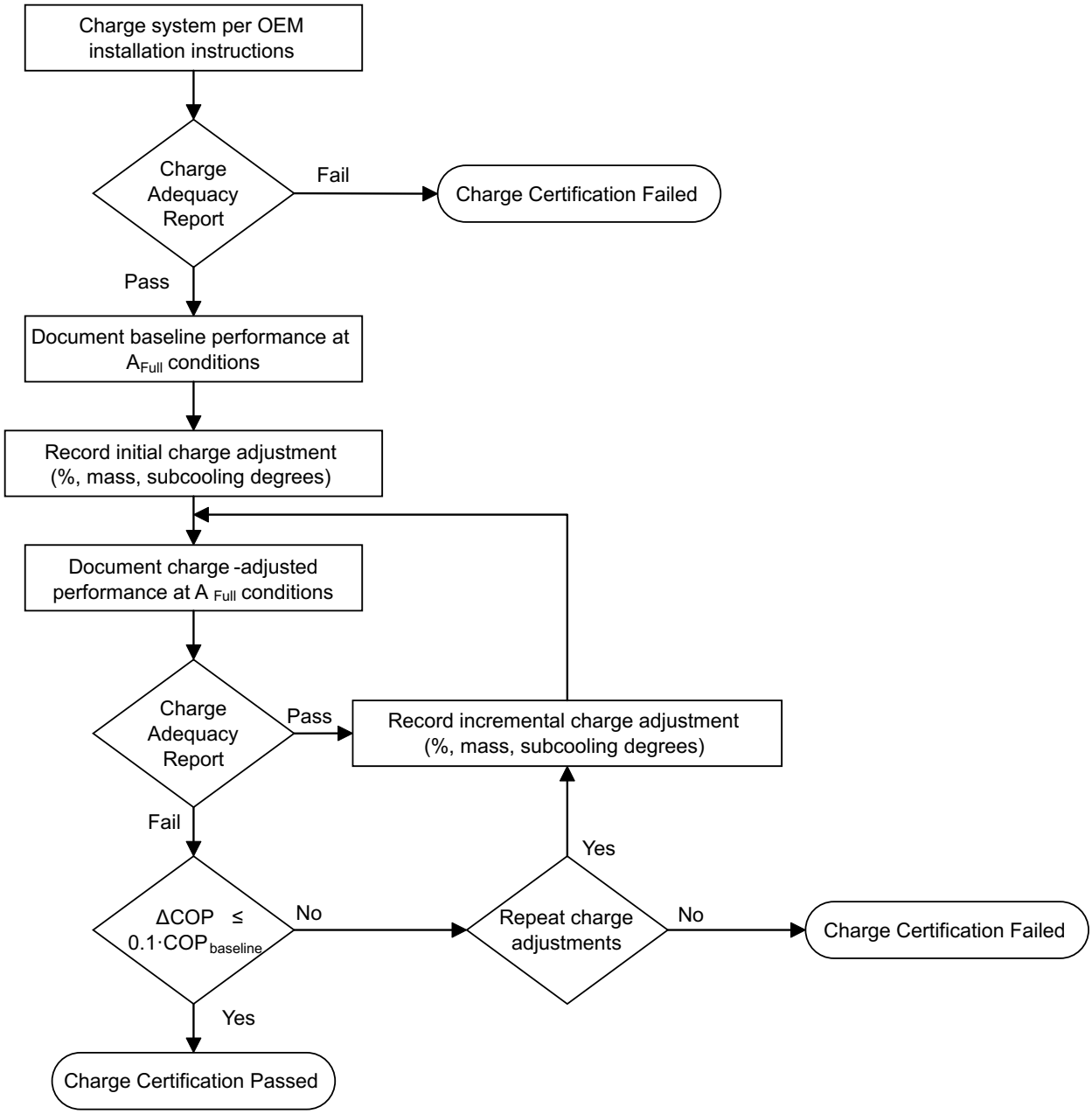

Figure 3. Connected commissioning charge adequacy flowchart

The airflow adequacy certification test consists of a similar iterative procedure, but the test can be performed in blower-only mode, and adequate airflow is determined by the OEM, not the COP impact. It is expected that airflow adequacy and the ESP thresholds will be simultaneously certified. The test starts at a lower-limit ESP (defined by the OEM) and incrementally increases using laboratory equipment, e.g., a code tester, until the airflow is flagged as inadequate and the ESP values are within the expected categories of “Ok,” “Energy Warning,” and “OEM Warning.”

Round-Robin Testing

Although lab testing of connected-commissioning-capable equipment evaluates adherence to the definition, further testing can help determine whether the connected commissioning equipment improves installation outcomes when it is subjected to real-world conditions. Installation technician acceptance of the technology greatly depends on installer user experience and technology integration within typical contractor business models. To better understand workforce impact and acceptance, PNNL is planning round-robin testing in partnership with several HVAC training centers where installers with various levels of experience will be observed while commissioning connected-commissioning-capable equipment. Qualitative evaluation of installer user experience will be collected through observation during commissioning and pre- and post-commissioning surveys. In addition, the voluntary testing will quantify key metrics, such as time spent completing the commissioning tasks.

A consistent, voluntary testing protocol will be established where a proctor will introduce one or a combination of common installation faults to the system, such as refrigerant under-/overcharge and inadequate airflow. The testing will be performed in a training facility and proctored by an HVAC trainer, and the test subjects will be HVAC installers or HVAC installers in training. The voluntary process will require the installers to commission a system that is designed to simulate a real installation. The HVAC equipment will be connected commissioning capable and will provide prompts to guide the technician through the commissioning process.

It is assumed that the equipment being tested meets the connected commissioning definition and has undergone the OEM or third-party laboratory certification. The round-robin field test is not intended to verify that the equipment meets the definition (that is the purpose of the lab certification testing conducted by NLR). The purpose of the field test is to understand how the equipment affects the installer and the installation in an environment that emulates near-real-world installation conditions. The field test is meant to assess the following questions:

- How effectively does the connected commissioning equipment guide the contractor through commissioning?
- Does the connected commissioning equipment catch each artificially induced fault in a field setup?
- Does the connected commissioning equipment effectively communicate the fault?
- Does the connected commissioning equipment effectively guide the contractor toward a solution?
- Does the connected commissioning equipment provide additional actionable recommendations?
- What is the contractor’s overall reaction to the equipment?

Table 2 lists common faults that could be introduced in a test and how they could be induced.

Table 2. Potential Faults and Induction Methods

Fault		Fault Induction Method
1	Ambient temperature too high to perform charge test	Manually apply input or apply a heat source to the temperature sensor.
2	Ambient temperature too low to perform charge test	Manually apply input or apply a cold source to the temperature sensor.
3	Refrigerant charge too low	Undercharge the system before commissioning.
4	Refrigerant charge too high	Overcharge the system before commissioning.
5	Airflow too low	Adjust the fan speed, increase the static, pressure or both (depending on the fan type and control options as well as whether there is a need to isolate variables).
6	Airflow too high	Adjust the fan speed, decrease the static pressure, or both (depending on the fan type and control options as well as whether there is a need to isolate variables).
7	Static pressure too high	Adjust the damper in the return, the supply, or both; change filters; or attempt another obstruction method.
8	Static pressure too low (indicating something might be wrong, e.g., a missing filter)	Adjust the damper in the return, the supply, or both; change filters; or attempt another obstruction method.

Findings from the observational research and survey instruments will reveal connected commissioning equipment sensitivity to installer experience levels and will also provide valuable insights into the installers' perceptions of the technology. Yet, testing in real homes will be necessary to further validate connected commissioning equipment performance and to evaluate the technology's market potential.

Industry-Driven Partnerships

As discussed, version 1.0 of the connected commissioning definition has been drafted through HVAC OEM input during the TWG and subgroup meetings that were facilitated by NEEA and TRC. Utility program implementers and energy efficiency researchers have also provided input through participation in the voluntary Connected Commissioning Advanced Heat Pump Coalition working group and in interviews. Successful technology development and deployment of connected commissioning depend on continued collaboration among utilities, energy efficiency organizations, national laboratories, manufacturers, and the installation workforce. These stakeholders have been engaging in a variety of ways, which are outlined as follows:

HVAC manufacturers. Discussion of the connected commissioning definition has been industry-driven through active, voluntary participation of manufacturer representatives in the TWG. Manufacturers advance the connected commissioning product offering as they design equipment and software that meet the voluntary connected commissioning definition. Several

leading manufacturers have products with all the necessary hardware (e.g., sensors) and that are already cloud-connected but require software updates to align with connected commissioning reports. Most manufacturers that are participating in the TWG will take longer to develop products that align with the connected commissioning definition.

Energy efficiency organizations. NEEA, supported by TRC, has facilitated the manufacturer TWG to align manufacturers on the voluntary connected commissioning definition.

National laboratories. As mentioned, NLR is developing voluntary certification testing methodologies to verify the reporting accuracy of connected commissioning equipment. PNNL's round-robin testing will provide insights into the robustness of the connected commissioning equipment and its ability to support variability in installer experience level. The testing will also provide feedback on the installers' perceptions of the equipment.

Utilities. One motivation for manufacturers to develop this technology is interest from utility programs. Demand generation through utility HVAC programs for this new product class has allowed some manufacturers to justify the cost of development. Utilities have expressed interest in supporting the advancement of this technology by piloting the technology as it emerges and by developing HVAC programs to support it. Utilities with quality installation and tune-up programs are planning to examine introducing voluntary connected commissioning reporting as an alternate method of verifying quality installation.

HVAC trainers. A best practice for workforce development is targeted training on new technologies, such as integrating voluntary connected-commissioning-capable equipment into existing HVAC training curriculum. DOE Energy Skilled plays a pivotal role in aligning training organizations on voluntary curriculum updates, and it has recently released a new Residential HVAC Commissioning recognition category. HVAC trainers have engaged in conversation surrounding the use of connected commissioning technology by voluntarily integrating material on installation and commissioning of connected-commissioning-capable products into their curriculums.

Conclusion

Voluntary connected commissioning is a promising emerging residential HVAC technology that can lower utility bills and save energy by reducing the occurrence of installation-related faults. The technology provides value for stakeholders in the residential HVAC value chain. The development of this connected-commissioning-capable equipment definition has been a multiyear, voluntary collaboration with thoughtful input across many residential HVAC industry stakeholders, including major manufacturers and the TWG. This industry-driven definition can enable OEMs to differentiate equipment in the marketplace, and it can provide consumers visibility into connected-commissioning-capable equipment, assisting with their decisions of which equipment features to purchase.

NLR and PNNL are expecting prototype equipment availability in mid-2026 for lab certification and round-robin testing. This testing will provide valuable insights into the equipment, aiming to meet the voluntary connected commissioning definition, the robustness of the voluntary connected commissioning protocols, and the initial impressions of the technology from HVAC installers. Field validation of connected-commissioning-capable equipment will also be valuable as more connected-commissioning-capable products reach the market and as utilities support the advancement of this technology through pilots and eventually programs that incentivize it.

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