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Automated Fault Detection & Diagnostics: Residential Market Analysis

September 2020

Joshua Butzbaugh
Abraham Tidwell
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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Executive Summary

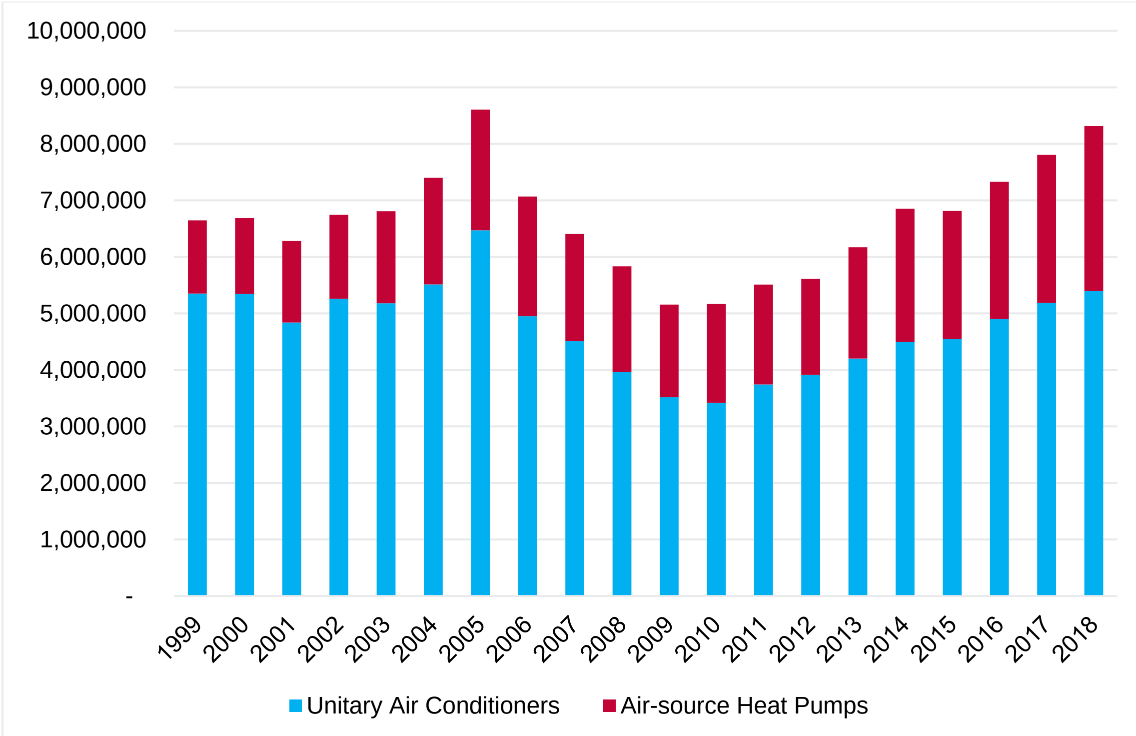
Heating, ventilation, and air conditioning (HVAC) systems account for a significant amount of energy consumption in U.S. residences. In total, 44% of residential energy use is attributed to space heating and cooling (EIA 2020). Poorly installed or maintained HVAC systems can lead to equipment operational issues, called faults, which can cause increased energy use and repair/maintenance costs, as well as lead to occupant comfort issues. Automated fault detection and diagnostics (AFDD) systems monitor data points in HVAC equipment (e.g., flows, temperatures, pressures, control signals) in real-time and apply a set of rules to identify equipment operational issues and their underlying causes (FacilitiesNet 2013). AFDD embedded into HVAC equipment can identify and communicate system faults digitally to building owners or maintenance personnel, notifying these stakeholders of issues with HVAC operation. There are also smart diagnostic tools, which can monitor HVAC equipment over a finite timeframe using a combination of smart gauges, sensors, and a mobile app to diagnose performance issues to ensure quality installation and tune-ups.

Collectively, central air conditioners (CACs) and air-source heat pumps (ASHPs) are installed in more than 70 million homes in the United States (EIA 2018). Multiple studies have shown that AFDD enables the repair and resolution of performance issues caused by inadequately installed or maintained HVAC equipment (Mowris, Blankenship, and Jones 2004; Downey and Proctor 2002; Turner, Staino, and Basu 2017). Improper HVAC installation is common in the residential sector. Many faults, and the resulting poor HVAC performance, are attributed to inadequate installation. A recent meta-analysis by the U.S. Department of Energy (DOE) found that poor HVAC installation results in at least one fault in 70–90% of homes, and when duct leakage is considered, this number increases to 90–100% (DOE 2018). Improper installation leads to increased energy use and higher HVAC repair costs over the lifetime of the equipment. For CACs and ASHPs, poor installation may increase energy use by 9% over an ideal installation with no faults, costing homeowners an extra $2.5 billion annually in utility bills (Winkler et al. 2020).

Field studies have demonstrated that common faults, namely inadequate refrigerant charge and insufficient evaporator airflow, were present in 50–72% of CACs and ASHPs inspected at varying stages in their lifecycle (Mowris, Blankenship, and Jones 2004; Roth, Westphalen, and Broderick 2006). Fixing these two faults alone has the potential to decrease residential cooling energy loads by 5–10% when considering the total CAC and ASHP stock. Technology solutions, such as embedded AFDD in CAC and ASHPs or smart diagnostic tools used during installation, can detect and diagnose HVAC system faults and facilitate quality equipment installation, preventing energy waste.

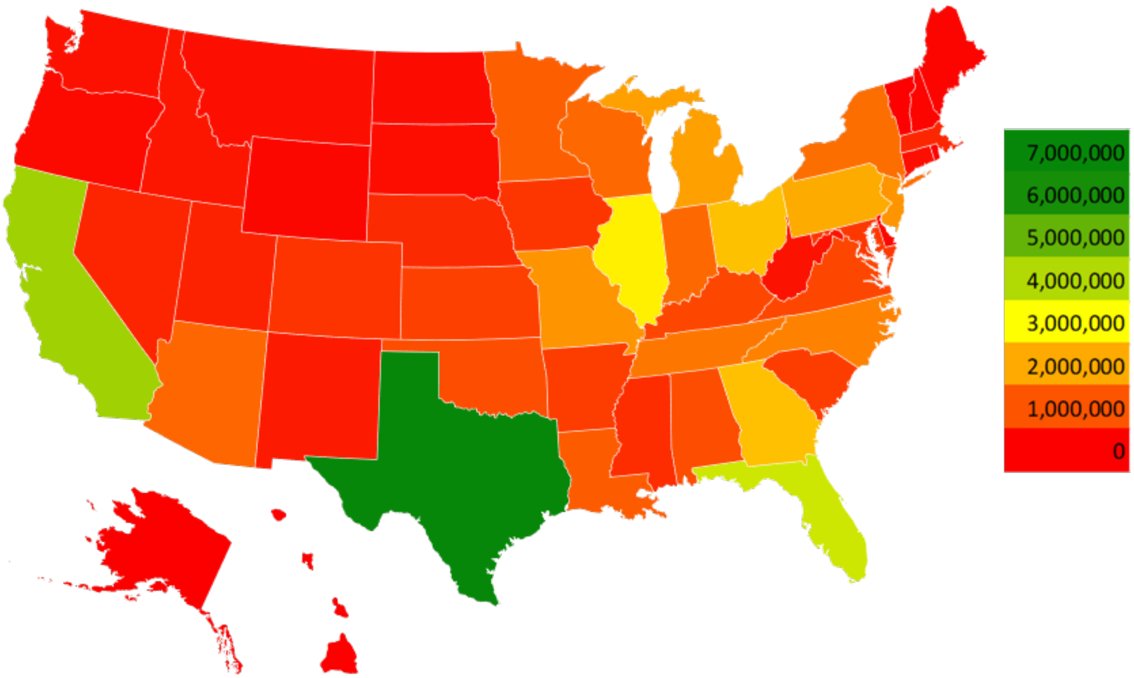
S.1 Market Overview

Over the past 20 years, shipments of CACs and ASHPs have increased from approximately 6.6 million total shipments in 1999 to 8.3 million total shipments in 2018. This trend was driven by ASHPs, which had an annual growth rate of 4.2%, more than doubling their 1999 shipments by 2020. CAC shipments have been relatively flat over the past 20 years with fluctuations following a similar path with the economy. The 20-year trend for CAC and ASHP shipments is provided in Summary Figure 1.



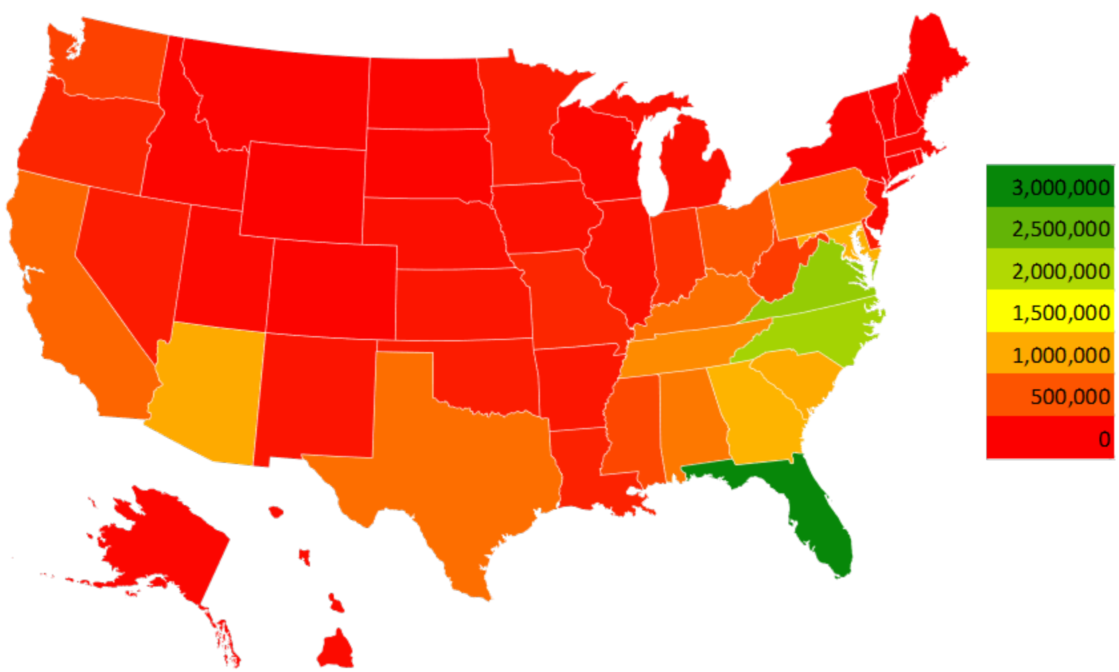
Summary Figure 1. U.S. shipments of CACs and ASHPs, 1999–2018

The trend in CAC and ASHP shipments is reflected in the installed base. According to data from the Energy Information Administration (EIA) 2009 and 2015 Residential Energy Consumption Surveys (RECS), the installed base of CACs fell from 54.9 million in 2009 to 51.4 million in 2015. Conversely, the installed base of ASHPs increased from 13.3 million to 19.3 million from 2009 to 2015 (EIA 2013, 2018). Using RECS and Census data, the states estimated to have the largest number of CAC installations are Texas, California, Florida, Illinois, Ohio, Georgia, Pennsylvania, Michigan, Missouri, and New Jersey (top 10, in order) (Census 2018). A heat map of CAC installations in the U.S. is depicted in Summary Figure 2. For this report, market opportunity is defined in terms of energy efficiency potential. Based on that definition, states offering the greatest market opportunity for both CACs with embedded AFDD and quality CAC installations using smart diagnostic tools are represented by the colors green, yellow, and orange, whereas states depicted in the color red offer a limited market opportunity.



Summary Figure 2. Heat map of CAC installations in the U.S.

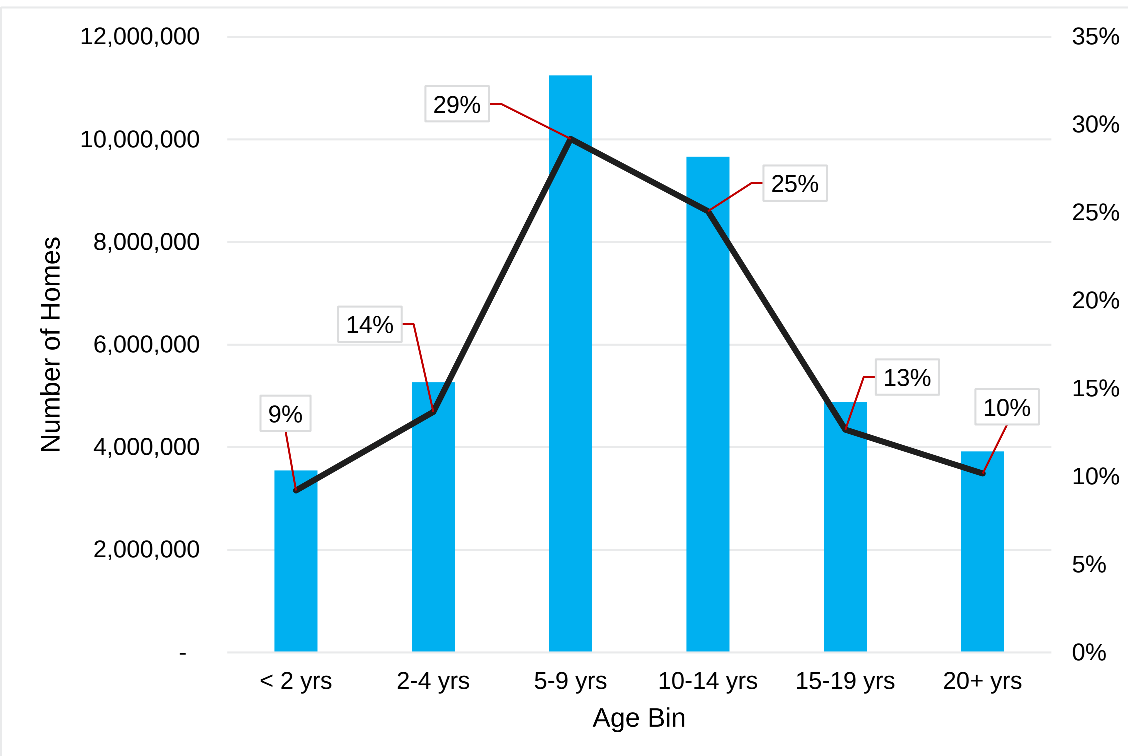
Using RECS and Census data, the states estimated to have the largest number of ASHP installations are Florida, Virginia, North Carolina, Georgia, Maryland, South Carolina, Arizona, Tennessee, Pennsylvania, and Alabama (top 10, in order). A heat map of ASHP installations in the U.S. is provided in Summary Figure 3. The states offering the greatest market opportunity for both ASHPs with embedded AFDD and quality ASHP installations using smart diagnostic tools are represented by the colors green, yellow, and orange, whereas states represented in red offer a limited market opportunity.



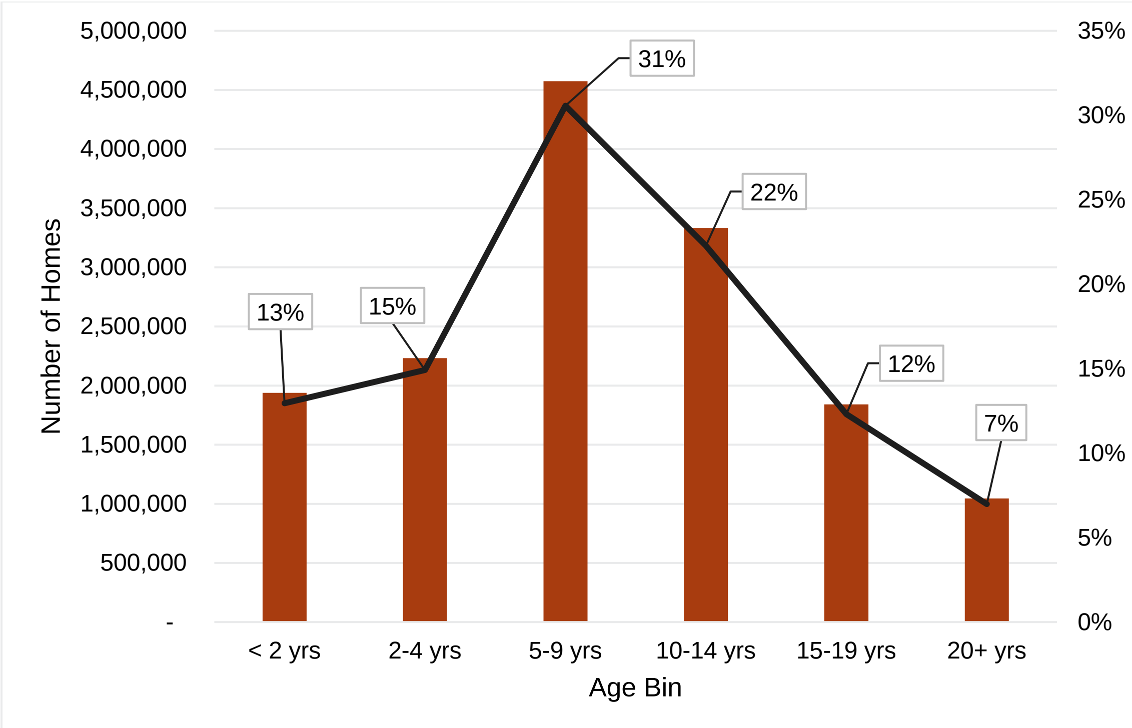
Summary Figure 3. Heat map of ASHP installations in the U.S.

In the residential sector, CAC and ASHP stock penetration is primarily in single-family homes, which comprise 75% of CAC and 78% of ASHP installations (EIA 2018). In addition, single-family homes are 82% owner occupied, meaning the homeowner is responsible for HVAC equipment maintenance, repair, the purchase of replacement equipment, and payment of energy bills. Approximately 79% of single-family homes have wireless internet, which is needed for remote communication of diagnostic and/or fault data to the homeowner, their utility provider, and their HVAC contractor for certain AFDD-enabled HVAC equipment currently on the market (EIA 2018).

As CAC and ASHP equipment ages, it becomes more likely to experience performance degradation and failure, and when equipment fails in the later stages of its lifetime, it's typically more expensive to repair (DOE 2016). Using RECS 2015 data, Summary Figures 4 and 5 illustrate the CAC and ASHP equipment age for U.S. single-family homes, respectively. More than 10% of CAC equipment and 19% of ASHP equipment in single-family homes are nearing end-of-life, presenting an opportunity for replacement and quality installation.



Summary Figure 4. Equipment age for U.S. single-family homes with CACs

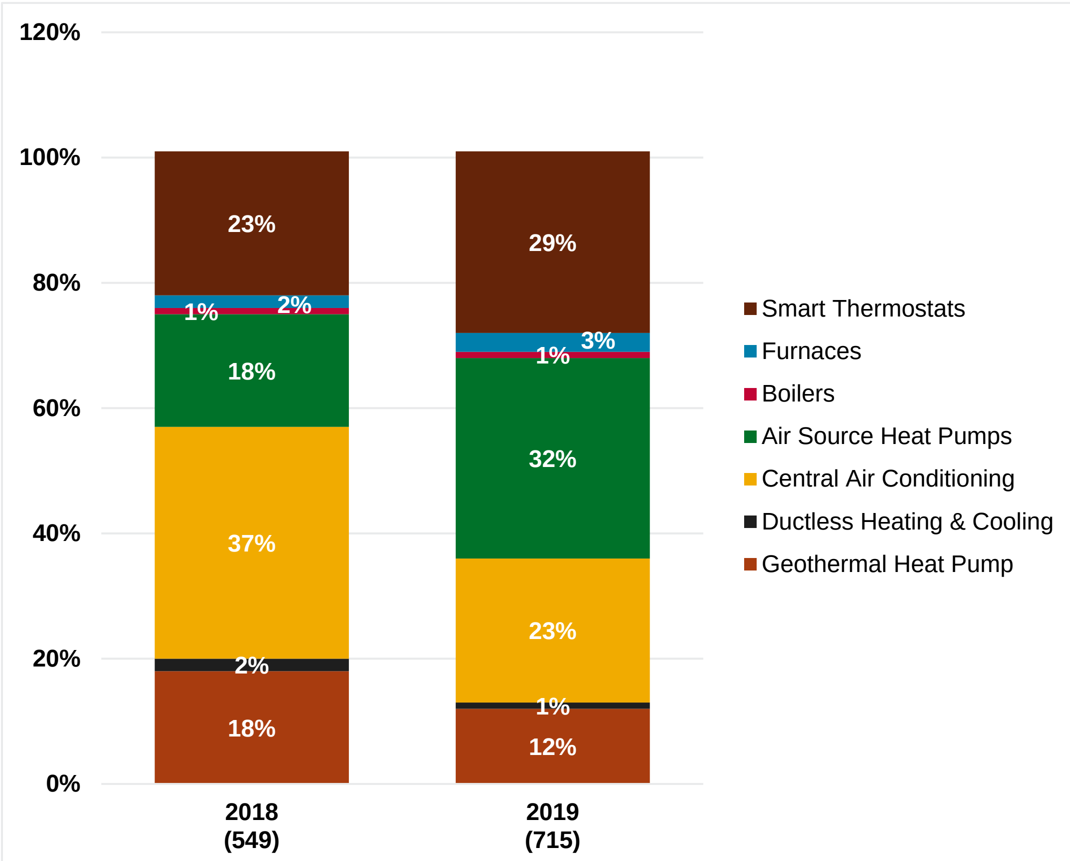


Summary Figure 5. Equipment age for U.S. single-family homes with ASHPs

S.2 Utility, Municipality, and Cooperative ASHP and CAC Incentives

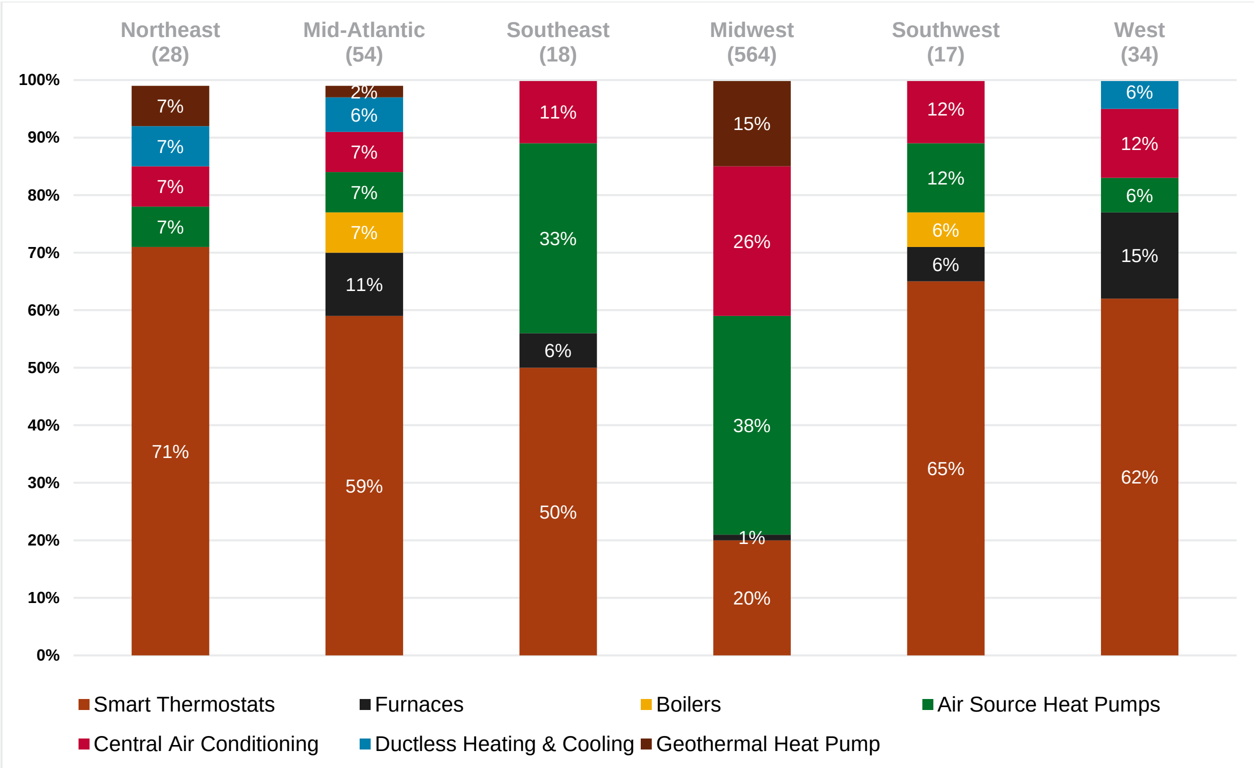
In 2019, ASHP and CAC incentive programs comprised 55% of the total number of existing ENERGY STAR® certified HVAC/smart thermostat incentive programs, with the largest growth in ASHP incentives over the preceding year (EPA 2019). In terms of total programs, ASHP grew from 99 programs in 2018 to 219 in 2019. Conversely, programs for CAC decreased over this window, and those incentivizing smart thermostats increased from 126 to 207. Summary Figure

6 compares the composition between the 549 programs operating in 2018 to the 715 available in 2019 nationally.



Summary Figure 6. ENERGY STAR certified HVAC/smart thermostat incentive programs (EPA 2019)

Midwestern states have the largest number of total incentive programs due to the large number of smaller cooperative and municipal utilities alongside larger investor-owned companies. The majority of nationwide ASHP incentive programs are also in the Midwest, followed by the Southeast. Other regions have fewer ASHP programs and a much larger proportion of smart thermostat incentives, comprising between 59% and 71% of available programs in the region, as indicated in Summary Figure 7.



Summary Figure 7. ENERGY STAR HVAC/smart thermostat incentive programs, by region, 2019 (EPA 2019).

S.3 Market Barriers

Residential CAC/ASHP equipment with embedded AFDD has the potential to improve the quality of equipment installation, provide real-time feedback on the energy efficiency performance of equipment, and reduce time between fault detection and the arrival of trained HVAC service contractor. All these factors in aggregate can improve the overall energy efficiency of homes and human comfort. However, certain barriers currently limit embedded AFDD capability to high-end products. Summary Table 1 lists the pertinent barriers limiting the presence of embedded AFDD equipment in the existing residential market.

Summary Table 1. Technical and market barriers to advancing AFDD in the marketplace

Barrier	Description
Lack of embedded AFDD for energy efficiency performance	Embedded AFDD for the purpose of measuring energy efficiency performance does not exist in current CAC and ASHP models.
Lack of AFDD standards and method of test	Manufacturers have different approaches and implementation strategies for AFDD in residential HVAC.
Product cost	Embedded AFDD for monitoring reliability is currently only available in high-end, variable-speed CAC/ASHPs. This would initially be the same for measuring energy efficiency.

Lack of standardized or industry-accepted communications protocol	In absence of standardized or industry-accepted communications protocols, the indoor unit, outdoor unit, and connected thermostat must be a matched set from the same manufacturer to enable AFDD, meaning third-party smart thermostats are incompatible.
Lack of standardized or industry-accepted fault codes	HVAC equipment fault codes are specific to each manufacturer, which means contractors have to learn a different set of fault codes to service each manufacturer's HVAC equipment.
Lack of knowledge	End-users note a lack of awareness about AFDD, and do not understand the potential benefits. Most are unaware of the possibility their HVAC equipment was improperly installed.
Lack of contractor training	Most HVAC contractors are unfamiliar with using AFDD and smart diagnostic tools to conduct installations or tune-ups. Training is needed so contractors understand how to administer testing and make use of the diagnostic data.
HVAC contractor business model	HVAC equipment manufacturers target HVAC dealers and contractors as their primary customers. Servicing HVAC equipment is not a primary revenue driver for most contractors, and thus is perceived negatively even though it can reduce callbacks.

S.4 Primary Findings

Currently, embedded AFDD only exists in premium variable-speed CAC/ASHP models to ensure equipment reliability, not monitor energy efficiency performance. Premium equipment already possesses the sensors and controls to monitor energy efficiency performance, though R&D still needs to be conducted to leverage measurements for diagnostic outputs. Once embedded AFDD is capable of monitoring energy efficiency, the primary market opportunity and application for this technology is in single-family homes with wireless internet. The states with the most homes fitting this profile are California, Texas, Florida, North Carolina, Virginia, Georgia, Illinois, Ohio, Pennsylvania, Tennessee, and Arizona.

Based on the age distribution of installed equipment, approximately 10% of CACs and 20% of ASHPs in the U.S. will need replacement in the next five years. In the near term, these replacements are an opportunity for using smart diagnostic tools to facilitate quality installation of new equipment, thereby improving energy efficiency performance. Over the long term, the replacement of CAC and ASHP equipment is an opportunity to install new product models with embedded AFDD to ensure quality installation and continual performance monitoring, thus reducing energy waste over the entire lifespan of the equipment.

Utility providers are a major stakeholder for ensuring quality installation, and thus may have interest in offering incentives to HVAC contractors who install equipment properly, either using embedded AFDD or smart diagnostic tools to validate and report the status of equipment. Instant rebates, given directly to contractors, for AFDD-equipped ASHPs, CACs, and/or smart thermostats are a promising way in which this technology could quickly penetrate the market. Another opportunity is to offer training and incentives to contractors who use smart diagnostic tools to perform quality installations. In 2019, the highest percentage of incentives for ENERGY STAR certified CAC and ASHPs were offered in the Midwest, followed by the Southeast, and finally the Southwest. The highest percentage of smart thermostat incentives were offered in the Northeast followed by the Southwest. Utilities located in these regions offer an opportunity to form partnerships to promote equipment with embedded AFDD or quality installation using smart diagnostic tools.

Acknowledgments

The Pacific Northwest National Laboratory (PNNL) worked closely with the National Renewable Energy Laboratory (NREL) and the Oak Ridge National Laboratory (ORNL) to research automated fault detection and diagnostics in the market. The authors acknowledge Jon Winkler at NREL and Jeff Munk at ORNL, who researched capabilities and specifications for embedded AFDD technology. The authors also thank Holly Campbell of PNNL for document production.

The project team gratefully acknowledges the U.S. Department of Energy's Building Technologies Office for funding this project, especially the project managers Marc LaFrance and Jonathan Cohen from the Residential Building Integration program.

Acronyms and Abbreviations

AEP	American Electric Power
AFDD	automated fault detection and diagnostics
AHRI	Air-conditioning, Heating, & Refrigeration Institute
API	application programming interface
ASHP	air-source heat pump
BTO	U.S. Department of Energy Building Technologies Office
CAC	central air conditioner
CBI	U.S. Department of Energy Commercial Buildings Integration Program
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CFM	cubic feet per minute
COP	coefficient of performance
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EER	energy efficiency ratio
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ESCO	energy services companies
EUI	energy use intensity
FDD	fault detection & diagnostics
HUD	U.S. Department of Housing and Urban Development
HVAC	heating, ventilation, and air conditioning
LBNL	Lawrence Berkeley National Laboratory
MYPP	Multi-Year Program Plan
NEEA	Northwest Energy Efficiency Alliance
NEEP	Northeast Energy Efficiency Partnerships
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
ORNL	Oak Ridge National Laboratory
PHA	public housing authorities
PNNL	Pacific Northwest National Laboratory
R&D	research and development
RBI	U.S. Department of Energy Residential Buildings Integration Program
RECS	Residential Energy Consumption Survey
REEO	Regional Energy Efficiency Organization
SEEA	Southeast Energy Efficiency Alliance

SEER	seasonal energy efficiency ratio
SMUD	Sacramento Municipal Utility District
SWEEP	Southwest Energy Efficiency Project

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1.0 Introduction

As stated in the Multi-Year Program Plan (MYPP), the U.S. Department of Energy's (DOE's) Building Technology Office (BTO) has a mission to "develop, demonstrate, and accelerate the adoption of technologies, techniques, tools and services that are affordable and enable high-performing, energy-efficient residential and commercial buildings for both new and existing buildings" (DOE 2016). The primary pathway of technology development and market adoption progresses from the Emerging Technologies (ET) program to either the Commercial Buildings Integration (CBI) or the Residential Buildings Integration (RBI) programs. There are concurrent efforts in both CBI and RBI to promote and complement technology deployment initiatives.

The BTO has sponsored numerous competitions over the past three decades to engage market stakeholders and leverage ongoing research to speed the development and uptake of more energy efficient products (Sandahl et al. 2020). One of the competition types that BTO undertakes is called a Technology Challenge, which encourages industry to fill a market need by developing a high-efficiency new-to-market technology, system, or product. A Technology Challenge aims to encourage the development of advanced residential building technologies that have potential for significant energy savings and net economic benefits, contributing to the BTO's long-term goal of reducing the energy use intensity of buildings by 50% from 2010 levels.

In late 2019, the Pacific Northwest National Laboratory (PNNL) began research in preparation for a BTO Technology Challenge with the goal of identifying and promoting a technological solution to the problem of improper installation of residential central air conditioners (CACs) and air-source heat pumps (ASHPs), which cause energy waste. To that end, the challenge sought to encourage the development of automated fault detection and diagnostics (AFDD) embedded in CACs and ASHPs to monitor and evaluate energy efficiency performance for ensuring quality installation. To do this, AFDD capabilities were identified for CAC and ASHP technology, and then reviewed with market stakeholders to understand how AFDD can add value to their organization operations and/or business models. In addition, the challenge sought to understand the viability of smart diagnostic tools to ensure quality installation, and how to promote the usage of these tools by HVAC service contractors. Utility provider incentives, volume purchases, and procurement guidance were some of the approaches vetted with stakeholders for influencing the market.

The remainder of this report presents background on AFDD, stakeholder engagement efforts, a technology assessment of AFDD and smart diagnostic tools, residential CAC and ASHP market trends, a characterization of the CAC and ASHP installed base, a synopsis of utility provider HVAC programs, and market barriers to AFDD.

2.0 Background

Heating, ventilation, and air conditioning (HVAC) systems account for a significant amount of energy consumption in U.S. residences. In total, 44% of residential energy use is attributed to space heating and cooling (EIA 2020). Underperforming HVAC systems result in increased energy use, repair/maintenance costs, and occupant comfort issues as well as decreased indoor air quality and humidity control. AFDD is a tool that monitors data points in an HVAC system (e.g., flows, temperatures, pressures, control signals) in real time and applies a set of rules to identify equipment operational issues, called faults, and the underlying causes (FacilitiesNet 2013). Once an AFDD system identifies faults, it can communicate the analytical data and/or data interpretation via the internet or other means to equipment owners, HVAC contractors, and manufacturers so they are notified of the issues for repair or resolution.

Multiple studies have shown AFDD could potentially reduce issues caused by underperforming HVAC equipment with active faults (Mowris, Blankenship, and Jones 2004; Downey and Proctor 2002; Turner, Staino, and Basu 2017). A recent study by researchers at the National Renewable Energy Laboratory (NREL) noted two faults in CACs and ASHPs, namely refrigerant charge and airflow rate, lead to 9% of energy waste (Winkler et al. 2020). This should be considered a conservative estimate because it doesn’t account for other fault types (e.g., duct leakage, improper sizing, conduction losses) or maintenance-related airflow rate and refrigerant charge faults, both of which lead to energy waste and could potentially be monitored/captured by AFDD.

AFDD is now included in most commercial building HVAC systems, and research over the years has identified approaches, barriers, and system operations (Kim and Katipamula 2018; Granderson et al. 2017). Figure 1 illustrates the presence of AFDD in HVAC equipment installed in commercial buildings. While large buildings have significant AFDD presence, smaller buildings (less than 10,000 ft^2) still have relatively low levels of AFDD capabilities within existing HVAC equipment options.

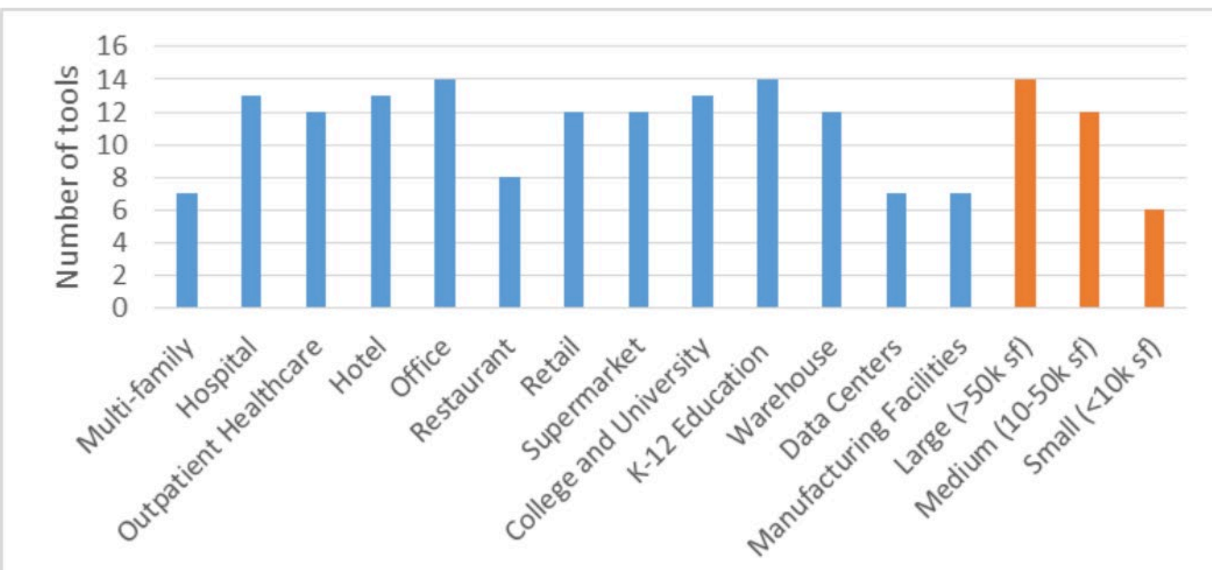

Figure 1. Presence of AFDD in the commercial building marketplace (Granderson et al. 2017).

Collectively, CACs and ASHPs are installed in over 70 million homes throughout the United States (EIA 2018). Field studies have shown that common faults, namely improper refrigerant charge and insufficient evaporator airflow, were present in 50–72% of the CACs and ASHPs inspected (Mowris, Blankenship, and Jones 2004; Roth, Westphalen, and Broderick 2006). Fixing these two faults alone has the potential to decrease residential cooling energy loads by 5–10%. Many equipment faults, indicative of deficient HVAC performance, are due to inadequate installation. A recent meta-analysis by DOE found that inadequate HVAC installation results in at least one fault in 70–90% of homes, and when duct leakage is considered, this increases to 90–100% (DOE 2018).

Unlike commercial buildings, HVAC equipment with embedded AFDD is uncommon in the residential sector. Rogers, Guo, and Rasmussen (2020) attribute this low adoption rate to the higher costs of AFDD-enabled residential HVAC equipment from sensor networks that must connect interior and exterior HVAC equipment to work effectively. AFDD capabilities in residential HVAC vary between manufacturers and can include a variety of communications about errors or maintenance requirements for HVAC equipment. These error "codes" are digital signals that are typically stored in the HVAC unit or its connected thermostat and can be downloaded or transmitted for interpretation by a contractor with a computer or mobile device and the appropriate software or web application. When AFDD is embedded in HVAC equipment, the system is paired with a connected thermostat, which is a required component, along with the indoor and outdoor units. Few HVAC manufacturers have embedded AFDD in their residential equipment, and when present, it exists in only high-end, variable-speed units specifically for the purpose of equipment reliability. Furthermore, the industry has yet to standardize the domain of residential AFDD or identify which types of faults should be consistently reported, how to report them, and which stakeholders are intended to receive what information.

In the residential building sector, BTO's RBI program partners with industry, national laboratories, and applied research organizations to collaborate on residential R&D, designed to bring energy-efficient innovations to the marketplace. The program has invested in research in both new and existing residential construction, including enclosures, HVAC, IAQ, water heating, and appliances. RBI funding is distributed through competitive solicitations open to both the public and private sector.

Faults in residential HVAC equipment can arise from installation-related issues or ongoing operational degradation, impacting energy consumption, thermal comfort, and/or equipment lifespan. The first generation of embedded AFDD designed to measure energy efficiency performance is unlikely to capture all fault type combinations, and therefore, should focus on high-priority faults at impactful levels for equipment energy efficiency. High-priority faults will be determined based on the impact to system performance, sophistication of fault detection, and incremental cost for the embedded capability.

The RBI's Building America program is designed to focus goals and develop solutions to building science problems in the housing industry. One primary focus of Building America R&D is developing solutions to promote high-performance HVAC in new and existing homes, which includes AFDD and quality equipment installation (DOE 2015). An investigation into advanced HVAC controls determined that approaches to standardizing application programming interfaces (APIs) would be necessary to connect sensors and controls produced by different manufacturers (Metzger, Goyal, and Baechler 2017). A synopsis of AFDD-related Building America research is presented in Table 1.

Table 1. U.S. DOE Building America AFDD projects currently funded.

Building America Team	Project Title	Link to project
Fraunhofer USA	Physics-Based Interval Data Models to Automate and Scale Home Energy Performance Evaluations	Link
Southface Energy Institute	Optimizing Residential HVAC Performance Using Quality Installation Verification and Monitoring Tools	Link
The University of Alabama	IoT Based Comfort Control and Fault Diagnostics System for Energy Efficient Homes	Link
University of Oklahoma	Development and Validation of Home Comfort System for Total Performance Deficiency/Fault Detection and Optimal Comfort Control	Link

3.0 Stakeholder Engagement

Stakeholder engagement, on both the supply and demand sides of the market, is a key factor in understanding the market viability of technology. PNNL research focused more on the demand side to gain a sense of how equipment purchasers can influence technology availability in the market. Influencing market actors to adopt business practices, ranging from promotion (e.g., utility providers) to production (e.g., home builders), is an end-user targeted approach with the potential to yield impactful results. Levers for catalyzing change depend on understanding the motivating factors behind how stakeholders choose to prioritize outcomes and a keen recognition these may be complementary yet different for subgroups within a market (de la Rue du Can et al. 2014; Ma, Kuusinen, and Kjærgaard 2019; Rouleau et al. 2016).

The stakeholder engagement effort focused on identifying the motivating factors and perceived barriers for the availability of embedded AFDD in equipment and usage of smart diagnostic tools. Through a targeted strategy, key sub-sector actors were recruited to explore how the parameters of a demand-side strategy could align with their motivations and goals. Other goals of the stakeholder engagement process included, but were not limited to, the following:

- Vet concepts for capabilities, specifications, and test methods with both industry and market stakeholders
- Cultivate stakeholder interest in encouraging manufacturers via market mechanisms to integrate AFDD into residential CAC/ASHP technology or offer aftermarket systems compatible with CAC/ASHP technology
- Collaboratively shape long-term opportunities with risk-tolerant stakeholders across the supply chain to catalyze a transition from the current high-end “early adopter” market to wider and more socioeconomically diverse groups.

In the spring of 2020, the PNNL team worked with key stakeholders to understand the landscape of influencers around AFDD technology. Using this information, PNNL prepared an approach for engaging key stakeholders with the greatest potential to influence manufacturer R&D and product line decisions. These efforts included discussions with utility providers, manufacturers, HVAC installation and maintenance organizations, public housing authorities, Regional Energy Efficiency Organizations (REEOs), retailers of HVAC equipment, and homebuilders. In addition, the team worked with technical and market experts to evaluate stakeholders for potential engagement in future outreach, focusing on those with a high potential to coalesce actionable partnerships leading to the adoption of AFDD technologies. Table 2 provides a synopsis of stakeholders that participated in discussions in 2020.

Table 2. Stakeholders that participated in conversations and planning processes in 2020

Manufacturers	Government	Housing Authorities
Johnson Controls	NYSERDA	Atlanta Housing Authority
Mitsubishi	CEC	Yolo County Housing Authority
Trane	HUD	Chicago Public Housing
Ice Air	EPA/ENERGY STAR	City of Phoenix
	DOD	
Utility Providers	**REEOS/Efficiency Orgs**	**Builders/Retailers/Consultants**
Xcel Energy	SEEA	Frontier Energy
Duke Energy	SWEEP	CLEAResult
SoCal Edison	NEEA	ICF International
Entergy Mississippi	NEEP	Pearl Certification
Arizona Public Service	CEE	Lowe’s
Salt River Project	Mass Save	University of Nebraska
Eversource Energy		Thrive Home Builders
		Pulte Group Homes

Outcomes of the stakeholder outreach efforts helped the research team gain market knowledge of embedded AFDD and smart diagnostic tools with the goal of understanding how to ensure proper HVAC installation and therefore optimized energy efficiency performance.

4.0 Market Analysis

4.1 Technology Assessment

The technology assessment focuses on evaluating embedded AFDD in CAC and ASHP models in the market, as well as aftermarket AFDD products. It also discusses smart diagnostic tools used in the installation or tune-up of CACs and ASHPs.

4.1.1 AFDD-Enabled CAC and ASHP Equipment

AFDD is embedded in certain variable-speed, high-efficiency CAC and ASHP product models for monitoring equipment reliability (e.g., refrigerant charge). There are also third-party, aftermarket products that are designed to attach to equipment and operate through smart thermostats or online applications. HVAC units with embedded AFDD make up a small fraction of the total market and little is known of the accuracy and effectiveness of their capabilities at detecting and diagnosing faults. Embedded AFDD is not readily available in mass market products due to the additional sensors and controls needed to perform diagnostics. Due to cost barriers and manufacturer marketing strategies, it's unclear if embedded AFDD capabilities would trickle down to lower efficiency products because these products do not have a market facilitator such as ENERGY STAR® or the Consortium for Energy Efficiency (CEE). Table 3 outlines the major AFDD-enabled HVAC systems available in the domestic heating and cooling market.

Table 3. U.S. HVAC market AFDD-enabled technologies

Manufacturer – AFDD-Enabled Product	Integrated System?	Shares Maintenance Information with Service Provider?	Hardware Cost	Diagnostic Service Type/Cost?
American Standard – AccuComfort	Yes, with Nexia home automation system	Yes, a specified service provider will have access to the information	Depends on configuration	$9.99/mo. for Nexia plus costs of service provider
Armstrong Air – Comfort Sync	Yes	Yes	Depends on configuration	Responsive to alerts/regularly scheduled maintenance; depends on service provider
Carrier – Infinity Bryant – Evolution	Yes	Yes, including remote software system updates	Depends on configuration	Responsive to alerts/regularly scheduled maintenance; depends on service provider
Coleman – Echelon and Charge View	Yes	No, only with homeowner	Depends on configuration	Regularly scheduled maintenance/emergency calls
Emerson – Sensi Predict	No, compatible with most HVAC	Yes, subscribed service from Emerson sends alerts to service provider and homeowner	~ $280–450	Depends on service provider
Fraser-Johnston – multiple light system	Yes	No, homeowner or service provider must go to the physical unit and look at the light's color	Depends on configuration	Regularly scheduled maintenance/emergency calls
Goodman/Amana – ComfortBridge	Partially – does not require a Goodman/Amana thermostat	Yes, provided service provider has app	Depends on configuration, homeowner's thermostat choice	Depends on service provider
Lennox – iComfort	Yes	Yes, will share alerts with service provider and homeowner	Depends on configuration	Responsive to alerts/regularly scheduled maintenance; depends on service provider
Loxone – Smart HVAC Controls	Unknown	No, only with homeowner	Depends on configuration	Depends on service provider
Luxaire – Acclimate and Charge Smart	Yes	No, only with homeowner	Depends on configuration	Regularly scheduled maintenance/emergency calls

Maytag/Frigidaire/ Broan – iQ Drive	Yes	No, must go to the physical unit and read a two-digit code	Depends on configuration	Regularly scheduled maintenance/emergency calls
Rheem/Ruud – EcoNet	Yes	No, only with homeowner	Depends on configuration	Regularly scheduled maintenance/emergency calls
Trane – ComfortLink II	Yes	Yes, a specified service provider will have access to the information	Depends on configuration	$9.99/mo for Nexia plus costs of service provider
York	Yes	Yes, user can determine what information service providers have access to	Depends on configuration	Responsive to alerts/regularly scheduled maintenance; depends on service provider

AFDD-enabled technologies exist on a spectrum of data communications configurations, ranging from proprietary equipment-to-connected-thermostat systems to third-party sensor networks that attach to existing HVAC systems. The former is common throughout the market in higher end products, with major manufacturers offering diagnostic capabilities through Wi-Fi enabled networks that connect HVAC units of the same line to a “control center” connected thermostat. These systems can only provide diagnostic capabilities for equipment of the specified brand line, and the control center itself must be of the same brand or an approved subsidiary label (such as in the case of Nexia home automation systems with the Trane ComfortLink II-enabled units) (Trane Technologies 2020).

In contrast, the Goodman/Amana ComfortBridge systems only require behind-the-wall technologies of the same product line or compatible two-way communication product lines, enabling the equipment owner to use any number of smart thermostat options from other companies (McIver 2018). Goodman’s model embeds the controller systems within the units, enabling single-stage thermostat usage for the equipment owner. Emerson’s Sensi Predict represents the third-party side of the market, integrating with most HVAC units (except geothermal systems or those with proprietary communicating systems) as an external system with a sensor and diagnostic network.

The AFDD technologies in the market provide varying levels of local and remote access to diagnostic information, enabling equipment owners and service providers to receive notifications and act accordingly. Only three systems—Emerson’s Sensi Predict, Fraser-Johnston’s technologies, and Maytag/Frigidaire/Broan iQ Drive—do not provide access to diagnostic information at the point of the in-home thermostat/control center. Emerson’s diagnostic information for this system is fed directly to Emerson for processing and the distribution of diagnostic alert emails to the homeowner and an HVAC contractor (if specified); both Fraser-Johnston and Maytag/Frigidaire/Broan only allow for the observation of diagnostic alerts at the point of each individual HVAC unit, which can be reviewed by a technician (Fraser-Johnston 2020). Maintenance service providers can have access to real-time diagnostic information from many of the currently available technologies, provided the homeowner specifies a service provider. Of these, only York (Johnson Controls 2017) allows customers to determine which information a specified maintenance provider can access and/or which data they can push (e.g., software updates) to the HVAC equipment.

A review of the listed systems did not yield significant information about the costs of operating AFDD-enabled HVAC units, particularly the expenses incurred by equipment owners to have access to diagnostic information and real-time HVAC service provider responses to alerts. The little information that exists indicates that due to the dominance of proprietary systems, HVAC dealers do not charge homeowners for the access or use of the diagnostic results. Other HVAC manufacturers, such as Emerson and Goodman/Amana, also did not list charges for access.

Of the systems that provide some form of diagnostic information to the user that enables third parties to access diagnostic alerts, all suggested identifying an HVAC contractor to provide maintenance and upkeep response to the HVAC units. The costs of these services are unclear, and no manufacturer suggested specific contractors beyond those certified to maintain their brand's equipment. This information gap represents an important part of the AFDD-enabled technologies market in which, even for the current small group of high-end units sold with these systems, little is clear about how the HVAC service industry fits into the long-term costs of utilizing AFDD technologies.

4.1.2 Smart Diagnostic Tools

Smart HVAC diagnostic tools emerged in the last decade as a response to the need for more accurate and efficient ways to measure key aspects of equipment functionality, such as superheat and subcooling while allowing for remote data collection for longitudinal analysis. Existing "smart" diagnostic tools on the market today utilize a variety of two-way communication enabled devices that monitor temperature, pressure, refrigerant weight, airflow, and other key dimensions of equipment performance. Most utilize some form of either a Wi-Fi or Bluetooth® system for transmitting data between each piece of equipment in the field to a central data logger or mobile device monitoring outputs (either Apple or Android based). Table 4 outlines the current suite of manufacturers and the two-way communications-enabled diagnostic tools they currently offer.

Table 4. Smart control-enabled HVAC diagnostic equipment

	Airflow Sensors	*Clamp Meter*	*Data Logger*	*Hygrometer*	*Manifold*	*Multimeter*	*Pressure Gauges*	*Psychrometer*	*Refrigerant Scale*	*Surface Probes*	*Temperature Sensors*
CPS Link	Green	Grey	Green	Grey	Green	Grey	Green	Grey	Green	Grey	Green
FieldPiece	Grey	Green	Grey	Grey	Green	Grey	Green	Green	Green	Grey	Green
iManifold	Green	Grey	Green	Green	Green	Grey	Green	Grey	Grey	Green	Green
Parker Sporlan	Grey	Green	Grey	Grey	Grey	Grey	Green	Grey	Grey	Grey	Green
Supco-Redfish	Grey	Green	Grey	Grey	Grey	Green	Grey	Grey	Grey	Grey	Grey
Testo	Green	Green	Green	Green	Grey	Grey	Green	Green	Grey	Grey	Green
UEi	Green	Green	Green	Green	Grey	Green	Green	Grey	Green	Grey	Green

Green - Sells Tools with this Feature/Capability | Grey - Does not Sell Tools with this Feature/Capability

The cells highlighted in green indicate the manufacturer provides a communications-enabled diagnostic tool of that variety. In the current market, UEi and iManifold offer the largest number of "smart" sensor and tool options, while it appears Parker Sporlan and Supco-Redfish have chosen to focus on a specific suite of tools.

While each of the tools and sensors listed above will communicate remotely with a diagnostic software application (i.e., a tablet or smartphone app), each system has different capabilities and limitations. Table 5 provides an overview of all existing HVAC diagnostic monitoring and data logging applications that interface with smart equipment.

Table 5. Diagnostic tool mobile applications

Diagnostic Mobile Application	*Single Platform (i.e., only works with branded tech)*	*Uses Realtime Data*	*Calculates Performance (Static or Realtime Tests)*	*Data Logging Capabilities (local or remote)*
CPS Link				
Fieldpiece JobLink				
iManifold App				
MeasureQuick				
RefTech				
SMART Service Tool				
Supco TechLink				
Testo Smart Probes				
UEi Hub				
Green - Feature of App | Grey - Not a Feature of the App				

Most diagnostic applications are designed for use with the manufacturer's specific equipment (e.g., the Testo Smart Probes app only works with Testo equipment). The exceptions are the two tools highlighted in orange: measureQuick and RefTech. These two apps will work with any of the sensors and tools listed in Table 5. The app measureQuick stands out as it is not only a system in its own right, but the digital backbone of the Supco TechLink system, which is a Supco-branded tool developed by measureQuick.

The presence or lack of data logging capabilities is another distinguishing factor between the different applications available; most diagnostic software tools provide real-time data analysis for a variety of tests (e.g., validate airflow, refrigerant charge, and overall system efficiency). However, not all mobile applications allow for the storage and use of data later. Of those that do, all provide some form of hardware for data logging and transmission to either the mobile device or any other device desired (via email).

4.2 Supply Chain for Embedded AFDD in ASHP and CAC Equipment

The supply chain for the CAC and ASHP market is expected to remain the same for equipment with embedded AFDD capability. Equipment manufacturers sell systems primarily to HVAC distributors (i.e., wholesalers), retailers, and dealers, which are considered midstream suppliers of equipment in the supply chain. Midstream suppliers typically either have contractors on staff or sell equipment to contractors, who then sell and install equipment for homeowners. In the new construction market, dealers may sell to a general contractor (i.e., builder) who will work with a contractor to have equipment installed in new homes. Figure 2 outlines the three primary distribution channels for CACs and ASHPs (DOE 2016).

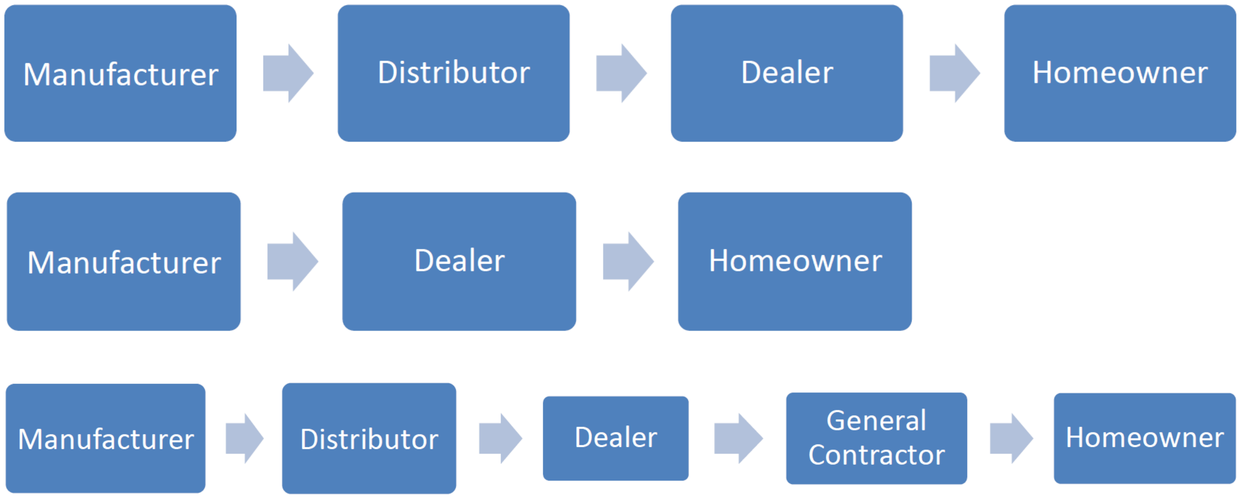

Figure 2. Distribution channels for ASHPs and CACs

Based on the current business model, contractors earn greater profit from HVAC equipment replacement, which is considered the priority. Long-term servicing of equipment is not the focus of contractors. Manufacturers are reluctant to promote or train their certified contractors in AFDD operation, and as a result, a considerable number of HVAC contractors either do not know about AFDD or do not trust the technology. Coupled with certain manufacturers stepping away from embedded AFDD due to a lack of customer engagement, both demand and supply sides of the existing AFDD market are limited due to significant gaps in awareness and knowledge.

While it is not entirely clear what has led to these gaps, current and future initiatives intended to shape the market for AFDD-enabled equipment should involve addressing any underlying assumptions about the benefits/risks of AFDD to each respective group of actors within the larger supply chain.

Figure 3 breaks down the existing HVAC equipment market for CACs and ASHPs by manufacturer. UTC/Carrier, Goodman (Amana line), and American Standard (Trane) represent over 50% of the current market. Each represents a major line or company owned by a global leader in HVAC manufacturing (Carrier-UTC, Goodman-Daikin, Trane-Ingersoll Rand prior to the 2020 spin-off of Trane Technologies) and demonstrates the dominance of a few large players on the current domestic CAC and ASHP technologies landscape (DOE 2016).

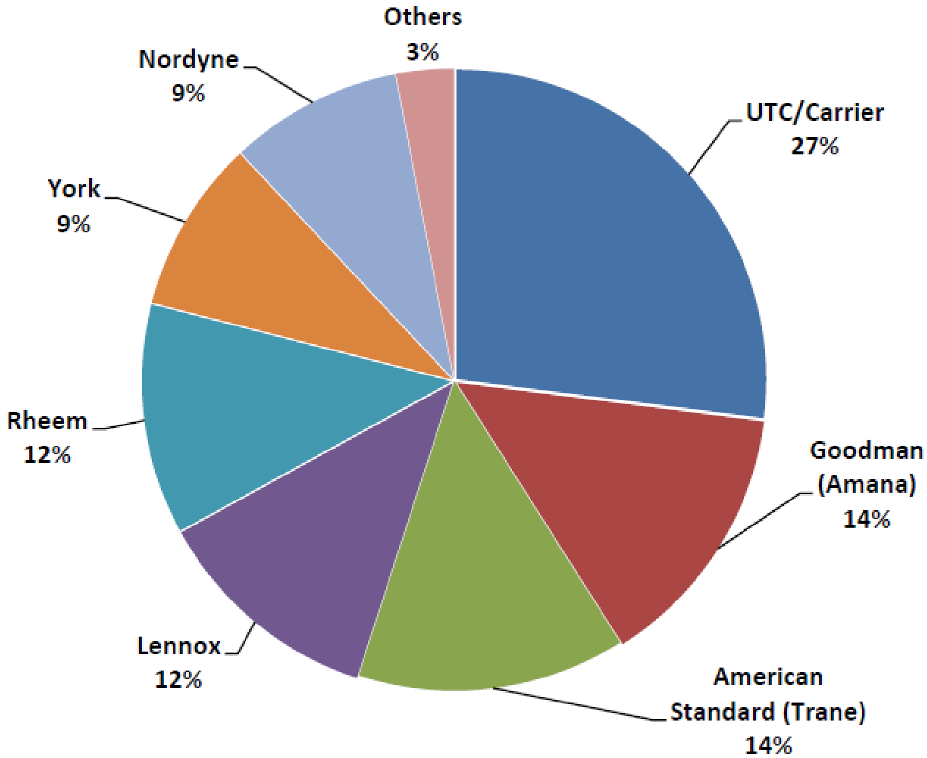

Figure 3. 2008 market share for unitary air conditioners and heat pumps

During meetings with manufacturers, experts from the industry indicated they consider contractors and equipment dealers as their primary customers rather than equipment purchasers. This relationship drives which brands and equipment lines are carried by contractors and dealers, and manufacturers compete directly with each other to recruit dealers to carry their product lines. Manufacturers may provide dealers and contractors with considerable funds and materials to promote co-branding and marketing of equipment and the dealership. These funds may cover TV/radio advertising, promotional items, and other resources deemed impactful for the specific HVAC market.

In addition, manufacturers use contractor training and equipment design as an impediment for dealers to change product lines. Currently, each manufacturer has its own set of fault codes associated with equipment issues and repairs. When industry has shown interest in standardizing HVAC faults, like the OBD II system for motor vehicles, certain manufacturers have viewed standardization as a threat to their competitive advantage among dealers and contractors. If faults were standardized, it would allow dealers to change the brands they carry more easily.

4.3 Market Analysis

The market analysis for embedded AFDD in CACs and ASHPs is composed of market trends, characteristics of the installed base, and new construction trends.

4.3.1 CAC and ASHP Market Trends

Over the past 20 years, shipments of CACs and ASHPs have increased from approximately 6.6 million total shipments in 1999 to 8.3 million total shipments in 2018 (AHRI 2020). This trend was driven by ASHP shipments, which had an annual growth rate of 4.2%, more than doubling their 1999 shipments by 2020. CAC shipments have been relatively flat over the past 20 years, with fluctuations following a similar path as the U.S. economy. The 20-year trend for CAC and ASHP shipments is provided in Figure 4.

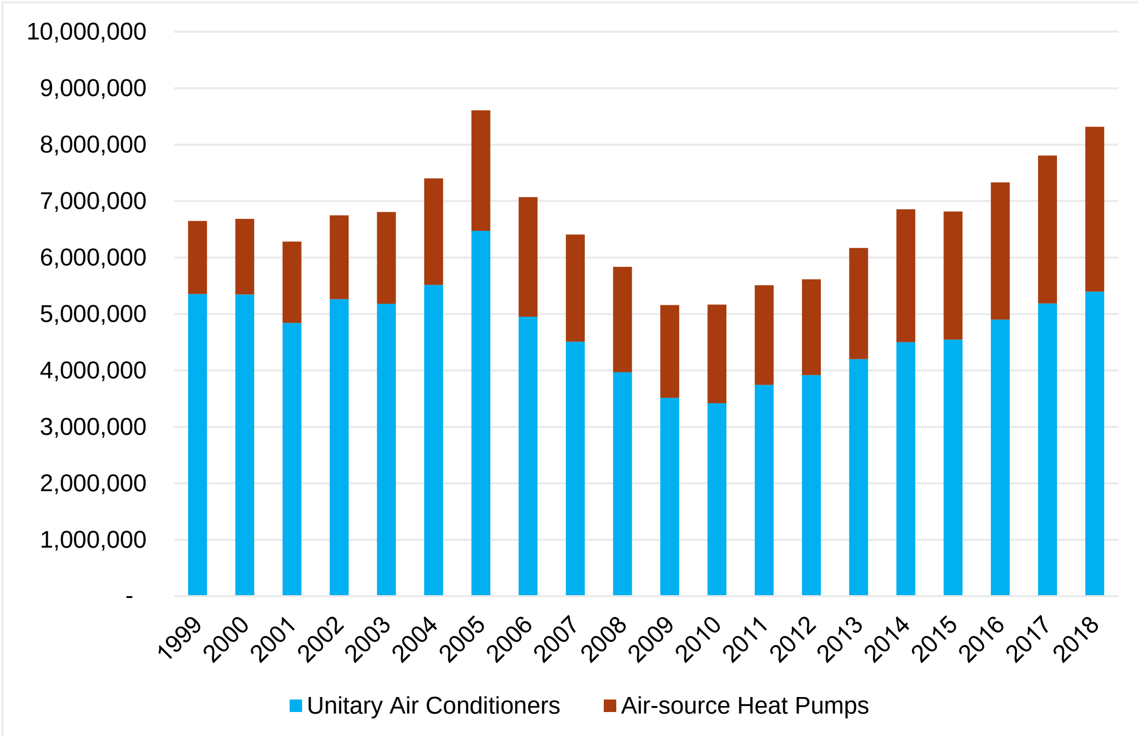

Figure 4. U.S. shipments of CACs and ASHPs, 1999–2018

4.3.2 CAC and ASHP Installed Base Characteristics

The trend in CAC and ASHP shipments is reflected in the installed base. According to data from the Energy Information Administration (EIA) 2009 and 2015 Residential Energy Consumption Surveys (RECS), the installed base of CACs fell from 54.9 million in 2009 to 51.4 million in 2015. Conversely, the installed base of ASHPs increased from 13.3 million to 19.3 million from 2009 to 2015 (EIA 2013, 2018). Using RECS and Census data, the states estimated to have the largest number of CAC installations are Texas, California, Florida, Illinois, Ohio, Georgia, Pennsylvania, Michigan, Missouri, and New Jersey (top 10, in order) (Census 2018). A heat map of CAC installations in the U.S. is depicted in Figure 5. For this report, market opportunity is defined in terms of energy efficiency potential. Based on that definition, states offering the greatest replacement market opportunity for both CACs with embedded AFDD and quality CAC installations using smart diagnostic tools are represented by the colors green, yellow, and orange, whereas states depicted in the color red offer a limited market opportunity.

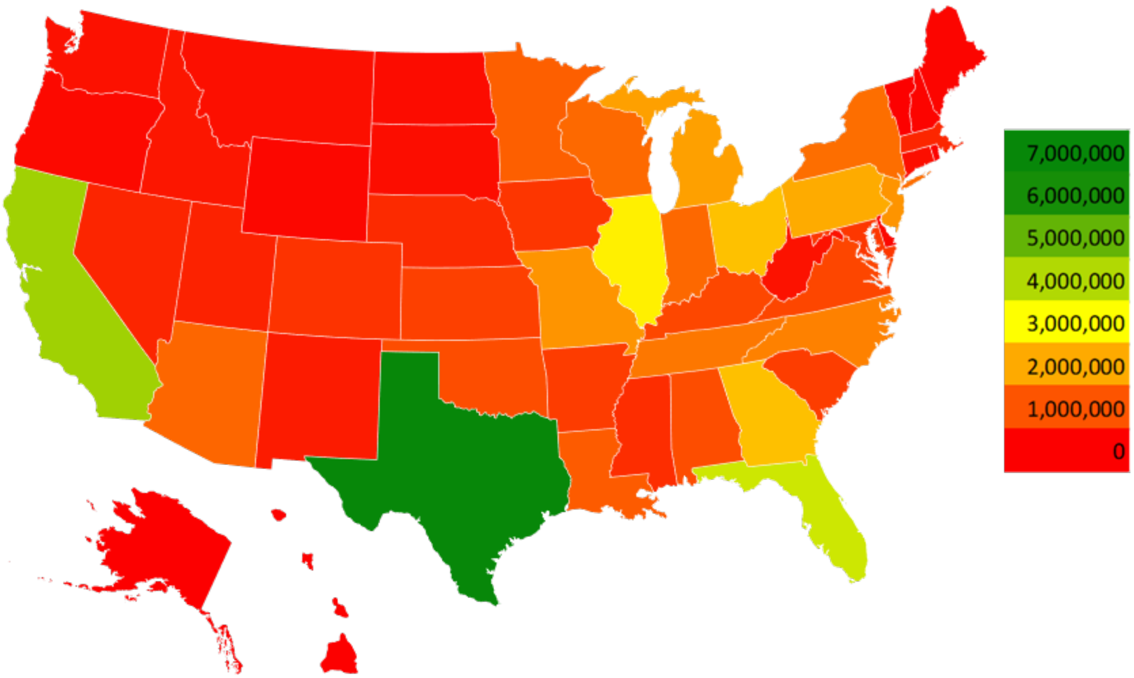

Figure 5. Heat map of CAC installations in the U.S.

Using RECS and Census data, the states estimated to have the largest number of ASHP installations are Florida, Virginia, North Carolina, Georgia, Maryland, South Carolina, Arizona, Tennessee, Pennsylvania, and Alabama (top 10, in order). A heat map of ASHP installations in the U.S. is provided in Figure 6. Using the same definition for market opportunity noted above, the states offering the greatest replacement market opportunity for both ASHPs with embedded AFDD and quality ASHP installations using smart diagnostic tools are represented by the colors green, yellow, and orange, whereas the states represented in red offer a limited market opportunity.

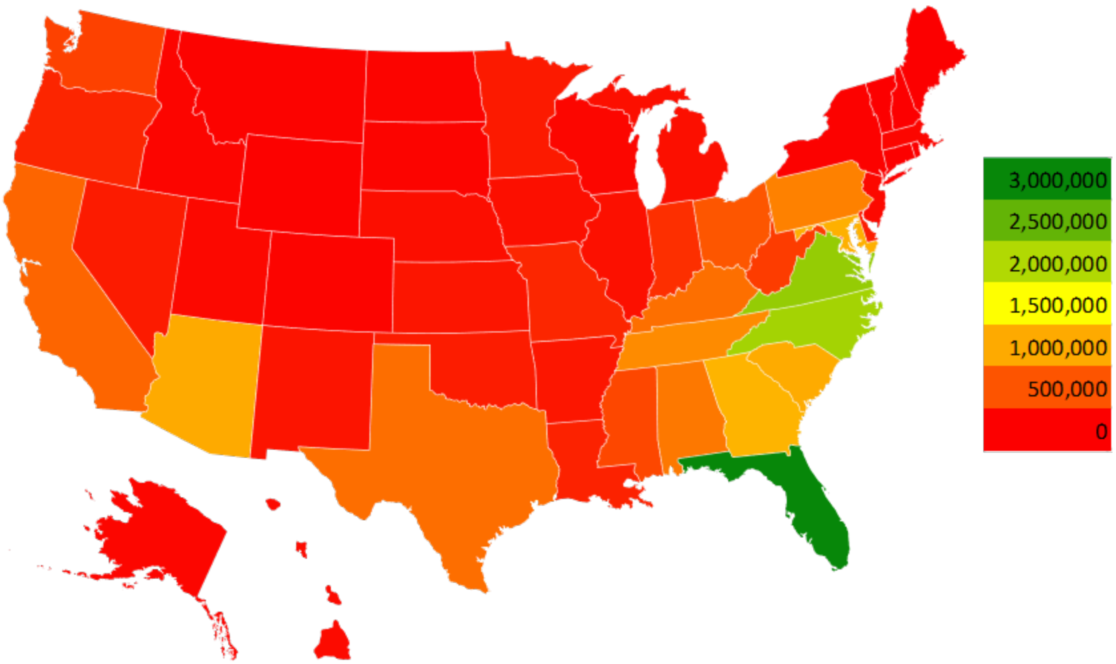

Figure 6. Heat map of ASHP installations in the U.S.

In the residential sector, CAC and ASHP installations are primarily in single-family homes, which comprise 75% of CAC and 78% of ASHP installations (EIA 2018). In addition, single-family homes are 82% owner occupied, meaning the homeowner is responsible for HVAC equipment maintenance, repair, purchase of replacement equipment, and payment of energy bills. Approximately 79% of single-family homes have wireless internet, which is needed for remote communication of diagnostic and/or fault data to the equipment owner, their utility provider, and their HVAC contractor (EIA 2018).

This is in sharp contrast with multifamily homes, which offer a limited opportunity for AFDD-enabled CAC and ASHP equipment in the residential sector. Multifamily homes comprise 21% of CAC and 18% of ASHP installations (EIA 2018). Just 11% of multifamily homes are owner-occupied with the remaining 89% either renting (88%) or occupying the domicile without paying rent (1%). In addition, just 65% of multifamily homes have wireless internet (EIA 2018).

Further analysis of the CAC and ASHP installed base will focus on single-family homes due to the viable opportunity to increase deployment of AFDD-enabled CAC and ASHPs in this segment of the residential sector.

Wireless internet connectivity facilitates several possible communication features for AFDD-enabled equipment. Currently, CAC and ASHP models with embedded AFDD have a matched indoor unit, outdoor unit, and connected thermostat. The fault and diagnostic reporting data are communicated from the indoor and outdoor units, which are wired to the connected thermostat. The connected thermostat communicates with the home's network equipment, which typically transmits the data through the manufacturer/vendor's cloud or proprietary communications network (via an app) to the equipment owner, HVAC contractor, and/or utility provider via a computer or mobile device. Using this capability, utility providers offering incentives for CAC and ASHP models in the replacement market can receive verification of proper equipment installation, along with the equipment manufacturer, HVAC contractor, and equipment owner. This provides assurance to each market actor, and potentially safeguards HVAC contractors from misattribution for equipment failure. For new construction, equipment is typically installed prior to the initiation of wireless service, which means verifying proper installation would have to involve a mobile device and app (e.g., smartphone), or printed report.

Wireless connectivity also enables alerts that call for regular maintenance (e.g., air filter replacement) or the presence of faults derived from inadequate maintenance. This is advantageous for resolving significant equipment operation issues that result in the degradation of the equipment's coefficient of performance (COP). These issues often call for HVAC contractors to service equipment. Alerts are also beneficial for addressing issues that equipment owners can resolve themselves (e.g., clogged air filter).

Using RECS 2009 and 2015 data, Figure 7 depicts the maintenance and wireless internet breakdown of single-family homes with CACs, whereas Figure 8 illustrates this breakdown for ASHPs. Single-family homes with wireless internet that don't perform regular equipment maintenance would benefit from AFDD to prevent equipment failure. In addition, single-family homes with wireless internet that perform regular maintenance may appreciate the assurance and convenience of AFDD continuously monitoring equipment performance.

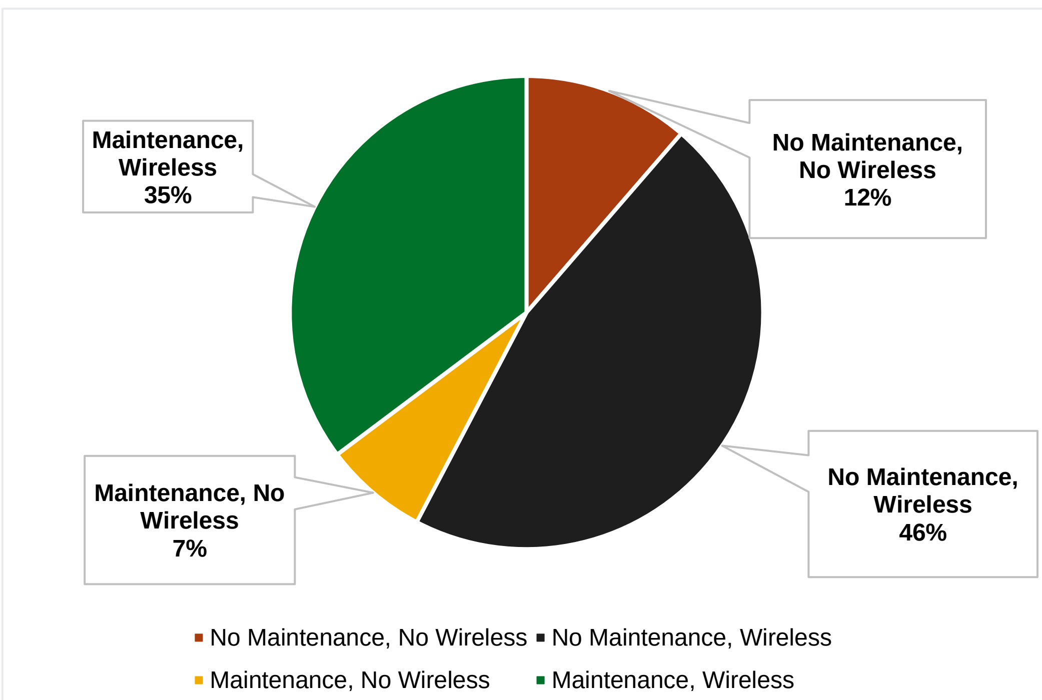

Figure 7. Maintenance and wireless internet trends for U.S. single-family homes with CACs

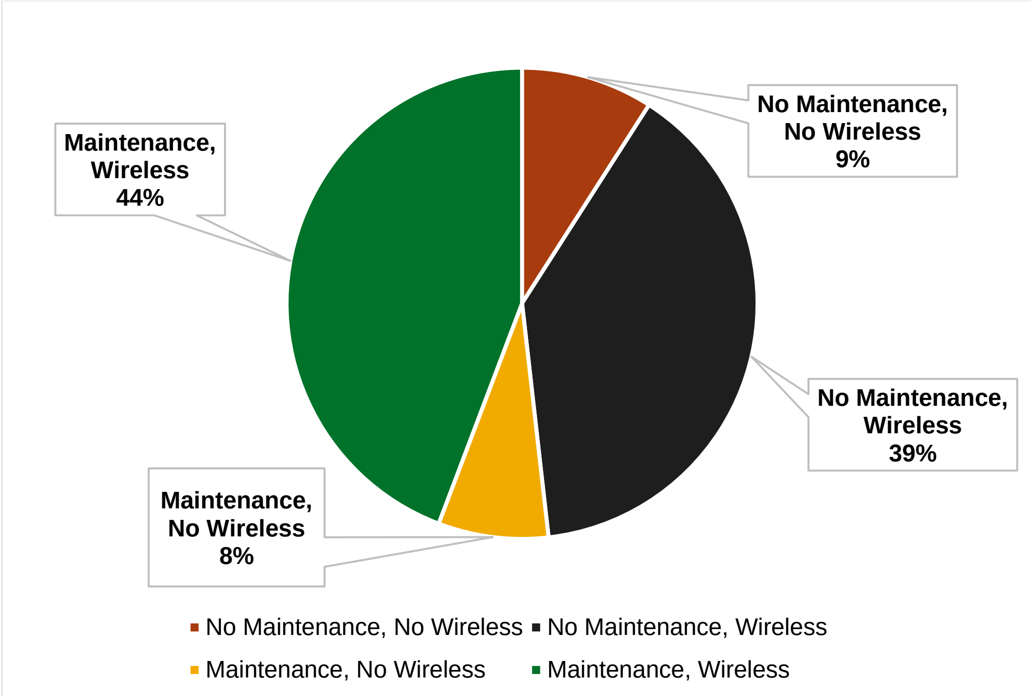

Figure 8. Maintenance and wireless internet trends for U.S. single-family homes with ASHPs

As CAC and ASHP equipment ages, it becomes more likely to experience performance degradation and failure, and when equipment fails in the later stages of its lifetime, it's typically more expensive to repair (DOE 2016). Using RECS 2015 data, Figure 9 provides the breakdown of single-family homes with CACs by equipment age bin. The average lifetime of split-system CACs, an equipment type that is viable for AFDD, varies between 18 years in the hot-humid climate region to 24 years in the North climate region (DOE 2016). Based on RECS 2015 data, an estimated 10% of CAC equipment in single-family homes is 20 years old or greater (approximately four million units), meaning this equipment is likely to fail soon and more likely to have energy efficiency degradation.

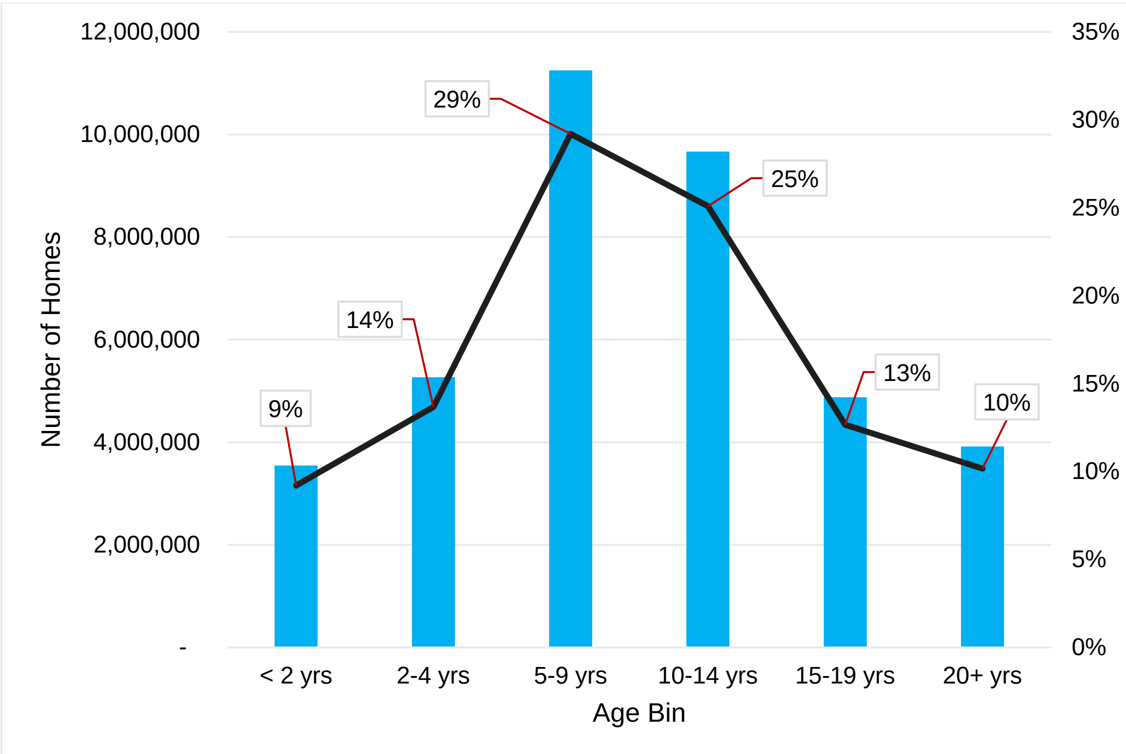

Figure 9. Equipment age for U.S. single-family homes with CACs

Figure 10 provides the breakdown of single-family homes with ASHPs by equipment age bin. The average lifetime of split-system ASHPs, which are the strongest candidates for AFDD due to greater annual run times, varies between 15 years in the hot-humid climate region to 16 years in the North climate region (DOE 2016). Based on RECS 2015 data, more than 19% of ASHP equipment in single-family homes is 15 years old or greater (approximately one million units), meaning this equipment is likely to fail soon and more likely to have energy efficiency degradation.

AFDD would provide an understanding of how equipment is performing to owners of 20+ year old CACs and 15+ year old ASHPs, which can offer insight as to whether equipment is in need of repair. Given this information, along with the frequency of repairs, equipment owners would have the advantage of planning for equipment replacement rather than facing an emergency replacement situation in which equipment choice is dependent upon model availability from wholesalers, retailers, or contractors.

Equipment near the end of their useful lifetime are strong candidates for replacement with AFDD-enabled equipment, or at a minimum, new equipment installed using smart diagnostic tools. Assuming all 20+ year old CACs and 15+ year old ASHPs were replaced with models with embedded AFDD or new equipment installed using smart diagnostic tools, there’s an opportunity for about five-million CAC and ASHP installations in this segment of the market.

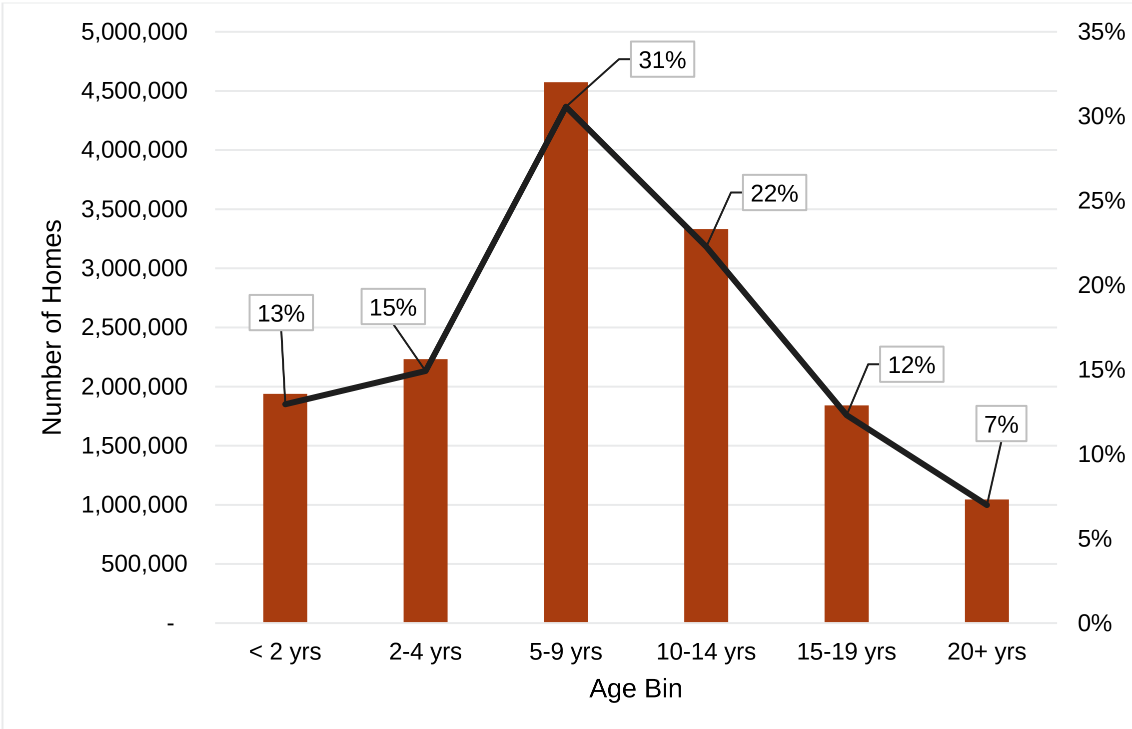

Figure 10. Equipment age for U.S. single-family homes with ASHPs

Approximately 85% of all residential HVAC equipment replacements are made due to equipment end-of-life reasons (Lawrence and Jenkins 2000). Once equipment has failed and repair is no longer considered cost effective from the owner's perspective, an "emergency" replacement process typically begins. HVAC contractors reportedly feel they are under greater pressure to perform timely service when a customer's equipment breaks down compared to planned replacements or the addition of new equipment. This sense of urgency is identified as a key barrier in the sale of more energy-efficient equipment and services (Lawrence and Jenkins 2000). By using smart diagnostic tools to facilitate quality installation, contractors reduce the potential for callbacks and improve the energy efficiency performance of equipment.[1]

Using RECS 2015 data, Figures 11 and 12 provide the distribution of single-family homes with failed CAC and ASHP equipment, respectively, by the number of days in which equipment was inoperable after a failure. The trend for equipment inoperability contrasts between single-family homes with CACs versus ASHPs, particularly as the number of days of inoperability increases. Only 10% of single-family homes with CACs have inoperable equipment for greater than one month, whereas twice as many single-family homes with ASHPs (i.e., 20%) have inoperable equipment for greater than a month. The reasons for this are unclear due to the limitations of the data, but this trend could be related to the seasonal run-time of the equipment, the supplemental heating source for ASHPs (i.e., back-up when the heat pump has failed), the likelihood of when failure occurs, and/or the cost of repairs.

[1] A callback is when an HVAC contractor returns to a location at which they've recently installed or repaired equipment to fix any issues stemming from improper installation or other issues with the equipment that were not identified during the initial visit.

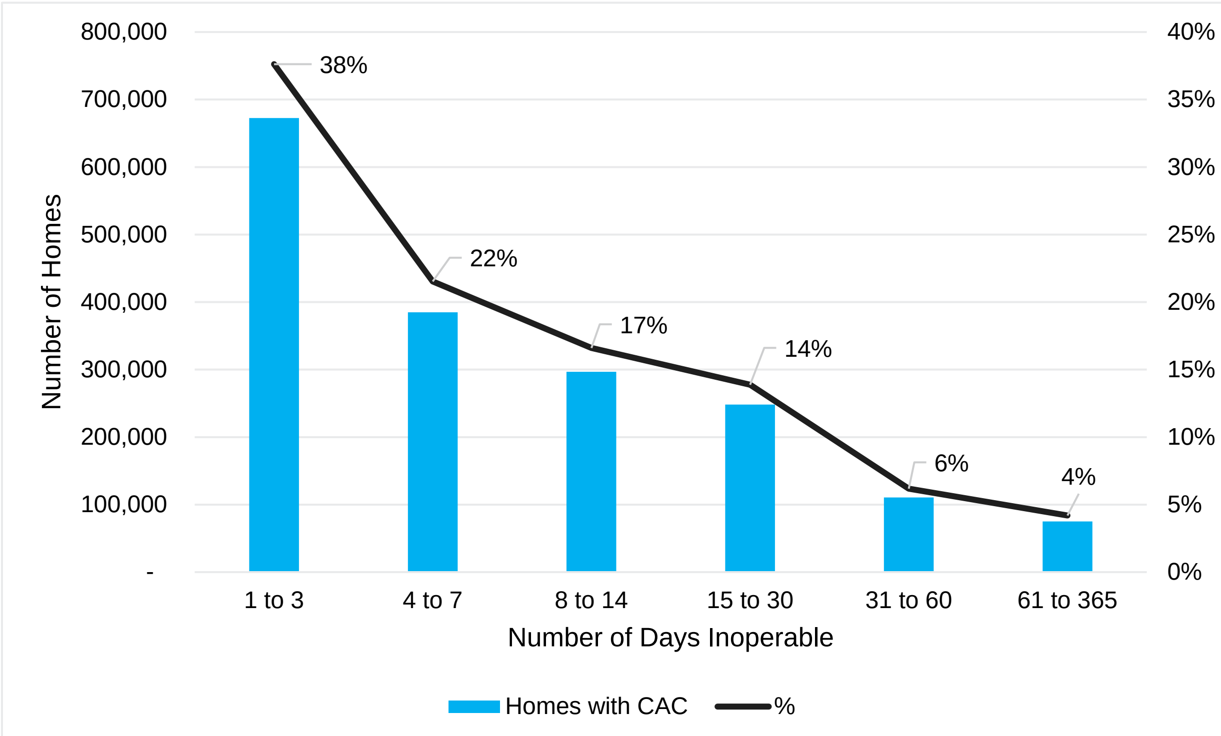

Figure 11. Duration of equipment failure for U.S. single-family homes with CACs

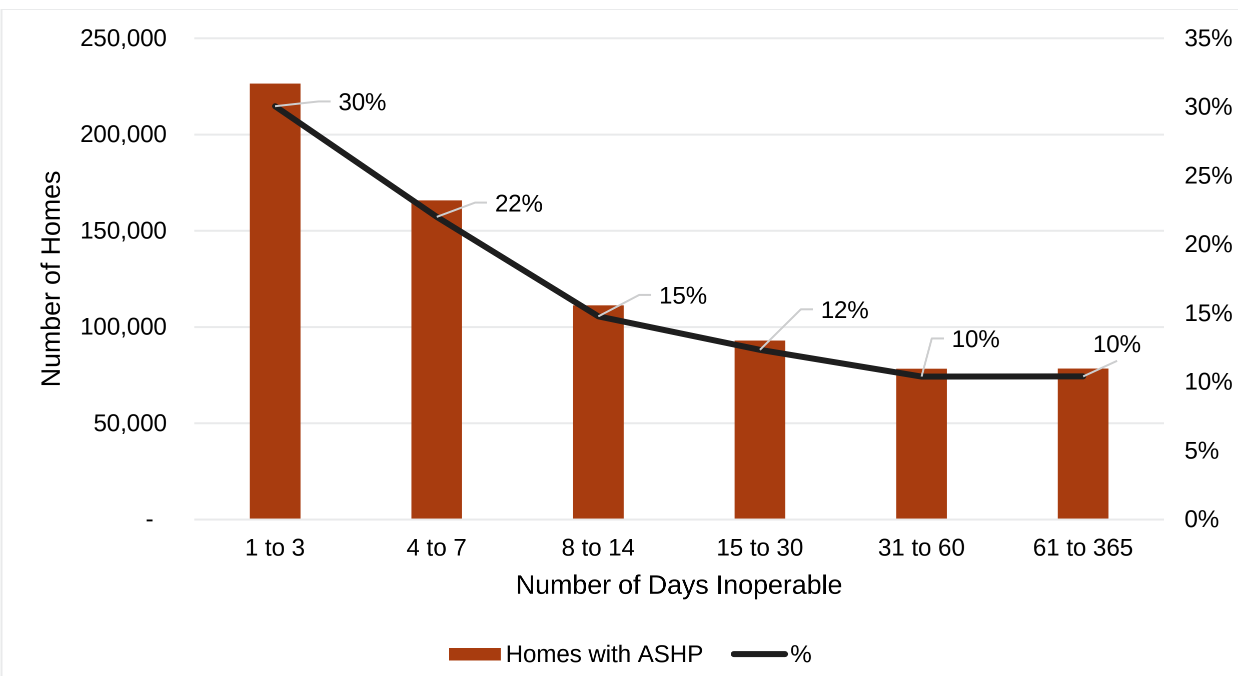

Figure 12. Duration of equipment failure for U.S. single-family homes with ASHPs

4.3.3 New Construction Trends

U.S. Census residential building permit data serves as a viable basis for characterizing new construction trends. Less than 2% of all new residential construction takes place in non-permit areas (Census 2020a). For single-family homes, approximately 94% of building permits result in completed new construction. For multifamily units, approximately 72% of building permits result in completed new construction (Census 2020b). Figure 13 provides the 20-year trend of total U.S. permit data for one, two, three to four, and five or greater unit residential buildings. Total residential building permits declined 73% from 2005 to 2009. From 2011 to 2015, growth in residential building permits was robust, with an annual rate of approximately 17%. Since then, growth has decreased to an annual rate of 4%.

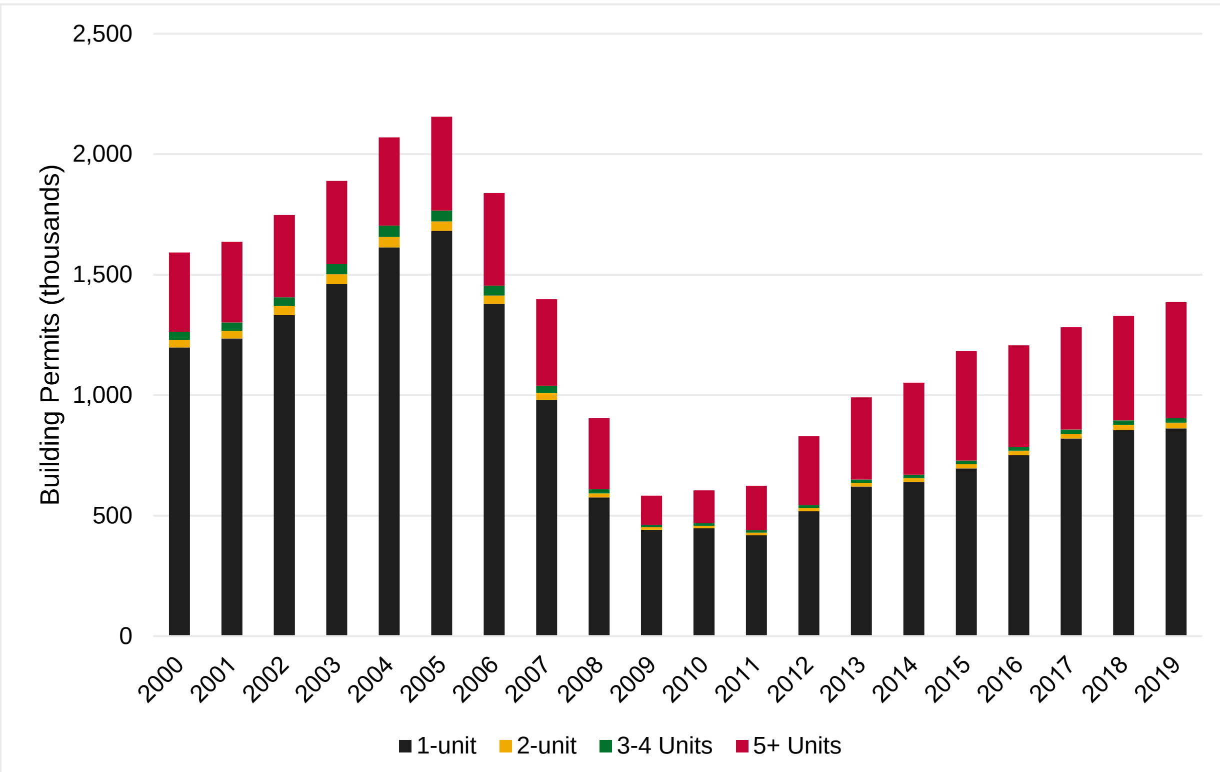

Figure 13. U.S. permits for 1, 2, 3–4, and 5+ unit residential buildings, 2000–2019

A heat map of 2019 residential building permits for new single-family homes in the U.S. is provided in Figure 14. The states with the most building permits for single-family homes were Texas, Florida, California, North Carolina, Georgia, Arizona, South Carolina, Tennessee, Colorado, and Washington (top 10, in order). States offering the greatest new construction market opportunity, both for CACs and ASHPs with embedded AFDD and quality CAC/ASHP installations using smart diagnostic tools, are represented by the colors green, yellow, and orange.

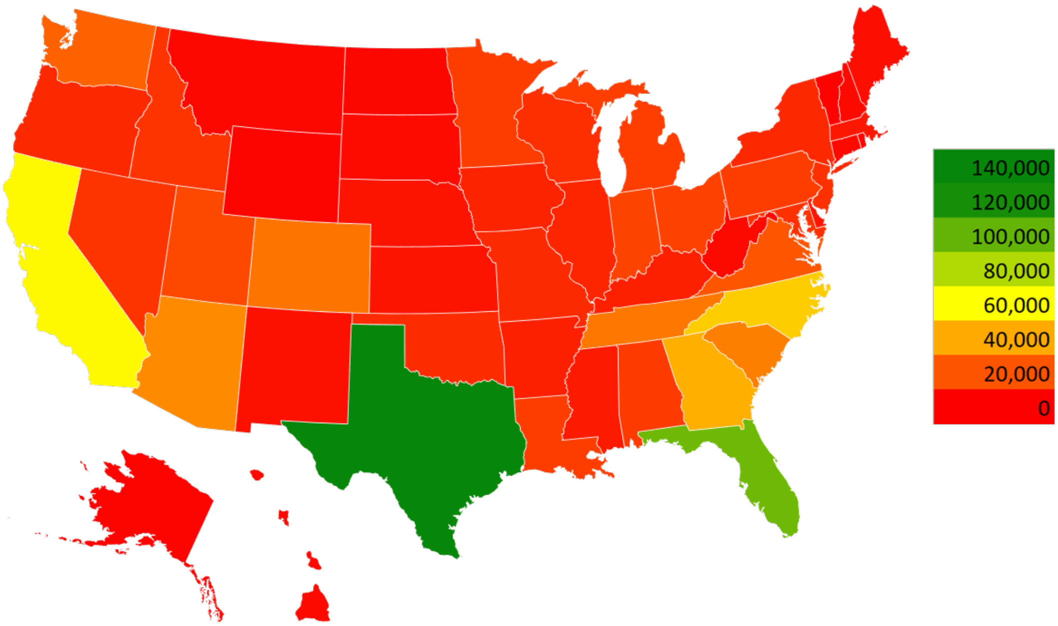

Figure 14. 2019 U.S. building permits for single-family homes

In conversations with new home builders about the viability of AFDD-enabled HVAC, one builder noted that the technology presents a significant opportunity for addressing a key issue: emergency responses to HVAC failures when temperatures become hot in the early part of the summer. This approach to AFDD integration highlights the potential value to all stakeholders for defining viable technological options for AFDD beyond the high-end market segment for equipment over the long-term.

4.4 Utility Provider Programs

This section provides insight on CAC and ASHP incentive programs as well as programs promoting smart diagnostic tools.

4.4.1 CAC and ASHP Incentive Programs

In 2019, CAC and ASHP incentive programs comprised 55% of the total number of existing ENERGY STAR certified HVAC/smart thermostat incentive programs, with the largest growth in ASHP incentives over the preceding year (EPA 2019). In terms of total programs, ASHP grew from 99 in 2018 to 219 in 2019. Conversely, programs for CAC decreased over this window, and those incentivizing smart thermostats increased from 126 to 207. Figure 15 compares the composition between the 549 programs operating in 2018 to the 715 available in 2019 nationally.

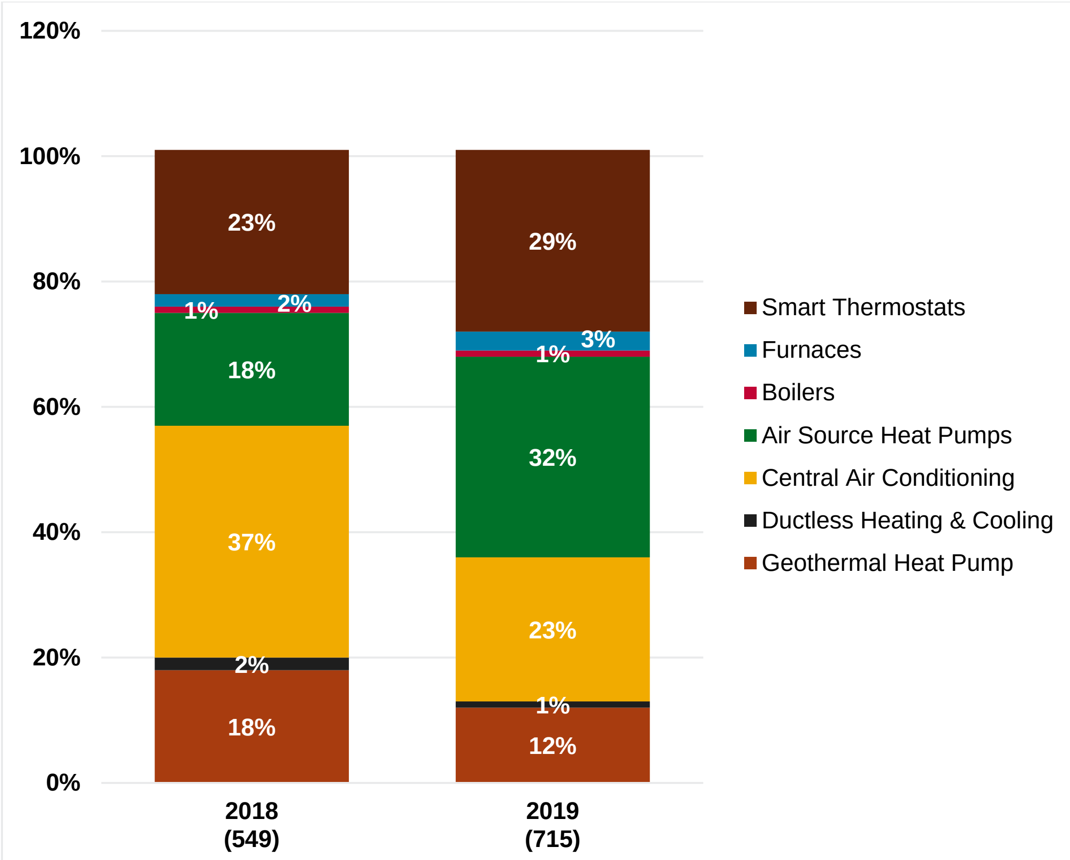

Figure 15. ENERGY STAR certified HVAC/smart thermostat incentive programs (EPA 2019)

Midwestern states have the largest number of total incentive programs, a factor that is influenced by large numbers of smaller cooperative and municipal utilities participating in ENERGY STAR. The majority of nationwide ASHP incentive programs are also in the Midwest, followed by the Southeast. Other regions have fewer programs, and a much larger proportion of smart thermostat incentives, comprising between 59% and 71% of available programs in other regions, as indicated in Figure 16.

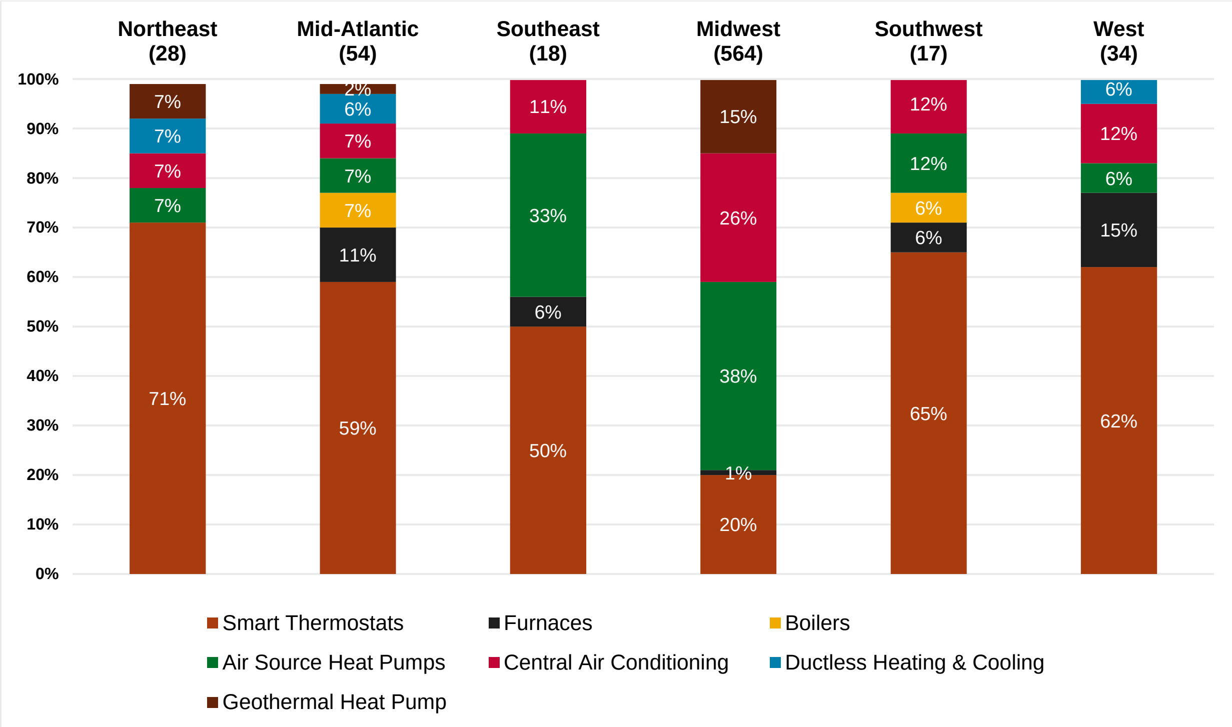

Figure 16. ENERGY STAR HVAC/smart thermostat incentive programs, by region, 2019 (EPA 2019)

Investments in HVAC/smart thermostat incentive programs nationwide are difficult to determine due to limited reporting of program budgets on a state-by-state basis. EPA's (2019) assessment of budgets for all relevant promotional programs indicates that of the state's reporting budgets for specific programs, most (in aggregate) add up to less than $5 million in 2019, as shown in Figure 17.

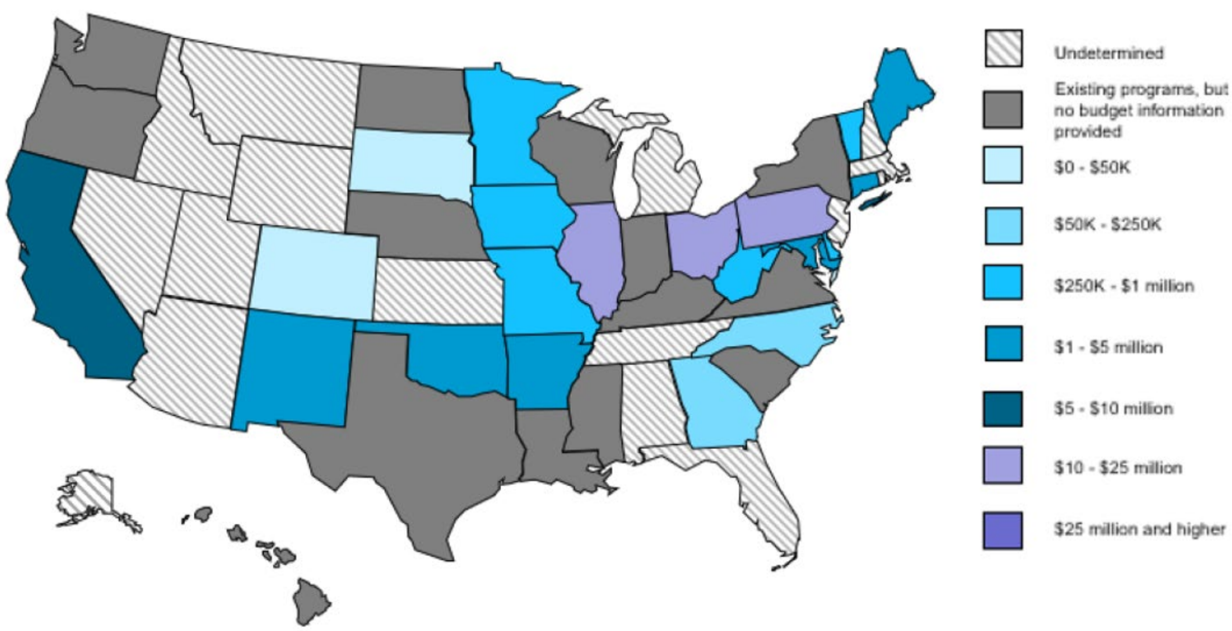

Figure 17. Incentive program budgets, by state (EPA 2019)

Four states—Pennsylvania, Ohio, Illinois, and California—had budgets greater than $5 million; breaking these states down by specific program investments and key actors, the largest investments are currently in the following areas:

- Updating heating and cooling equipment (e.g., ASHP, furnaces, boilers, ductless heating & cooling)
- Smart thermostat incentives.

Focusing on ASHP and smart thermostat incentives, the largest current investors in these programs are the following utilities (EPA 2019):

- PECO (formerly Philadelphia Electric Company, PA, 1,009,449 customers): ASHP ($10–20 million)
- Commonwealth Edison (ComEd) (IL, 2,454,905 customers): ASHP and smart thermostats ($10–20 million).

PECO incentives for ASHP are based on per ton of cooling capacity basis, ranging from $60 to $110/ton depending on Season Energy Efficiency Ratio (SEER), Energy Efficiency Ratio (EER), and Heating Season Performance Factor (HPSF) ratings (PECO 2020). ComEd offers rebates for smart thermostats and ASHP at $75 per thermostat and $350 to $450 for ASHPs, depending on SEER/HPSF rating (16/8.6 versus 18/8.8) (ComEd 2020).

Two other utilities, American Electric Power (AEP) Ohio and the Sacramento Municipal Utility District (SMUD), are noteworthy for their combined ASHP and smart thermostat incentive programs covering a total of 1.4 million customers between the two (EIA 2018). Like ComEd, AEP Ohio provides rebate incentives with a maximum $250 for ASHP installations and between $25 and $50 for smart thermostats, depending on a given home's heating source (gas or electric).

Deviating from the equipment-specific rebate structures of PECO, ComEd, and AEP Ohio, SMUD provides between $750 and $2,500 in rebates for converting existing electric or gas systems to high-efficiency ASHP-integrated HVAC systems based on the parameters outlined in Table 6 (SMUD 2020).

Table 6. SMUD HVAC upgrade requirements for rebate program (SMUD 2020)

	Split & mini-split system	Packaged system
A/C	• ≥ 16 SEER or better • ≥ 2-stage compressor	• ≥ 15 SEER or better • ≥ 2-stage compressor
Heat pump	• ≥ 8.2 HSPF • ≥ 2-stage compressor	• ≥ 8.0 HSPF • ≥ 2-stage compressor
All air handlers	• ECM blower motor as required by Title 24	• ECM blower motor as required by Title 24
Ductwork	• Must pass Title 24, via HERS CF3R and/or • If new ductwork is installed, it must be insulated to ≥ R8	• Must pass Title 24, via HERS CF3R and/or • If new ductwork is installed, it must be insulated to ≥ R8
Thermostat	• Wi-Fi-enabled • 7-day programmable	• Wi-Fi-enabled • 7-day programmable

Currently, SMUD does not require a full retrofit of all existing HVAC equipment to garner a rebate. Given that embedded AFDD equipment in the residential HVAC sector is most effective if all equipment is produced/designed by the same manufacturer, utility incentives may only be impactful if they are designed to reward homeowners who replace all of their existing HVAC equipment.

4.4.2 Programs for Smart Diagnostic Tools

Currently, there are few utility providers with promotional programs specifically targeting the use and deployment of smart diagnostic tools. Mass Save offers a measureQuick Contractor Training program in which contractors can receive a five-hour training on using the measureQuick mobile app to test air flow and refrigerant charge for CAC and ASHPs. The tests verify that equipment is installed and commissioned properly to ensure proper operation (MassSave 2020).

By participating in the Mass Save program, contractors are eligible to receive incentives for installation and verification, as well as reimbursements for training and diagnostic tool purchases. Once a trained contractor submits at least three passing measureQuick submissions to the program, they can apply to receive $150 for diagnostic tool reimbursement (per certified contractor). They can also become listed online as a certified Mass Save measureQuick contractor. This is advantageous because only certified contractors can offer customers a Mass Save zero-interest loan for equipment purchase. Certified contractors receive $130 for each submission of measureQuick data to verify proper installation, along with $250 for equipment downsizing and $2 per cubic foot per minute (CFM) of leakage reduced (max $600) for duct sealing. These incentives help contractors recoup the first cost of purchasing smart diagnostic tools. Once the first cost is recouped, the incentives serve as a viable revenue stream, particularly because Mass Save does not have a cap on the number of submissions per certified contractor.

As more contractors join the Mass Save program, a greater number of CAC and ASHPs are installed properly and verified by Mass Save through measureQuick data submissions. This helps Mass Save utilities achieve their energy efficiency goals and relieve peak load constraints. It also helps contractors by reducing callbacks, collecting incentives, and providing zero-interest loans to their customers.

Entergy Mississippi offers a residential CAC tune-up program that calls for the use of smart diagnostic tools. The tune-up is free to residential customers on a once-per-five-year basis. Residential customers can schedule tune-ups through a hotline or by using the participating contractor list (Entergy Mississippi 2020b).

Contractors participate in the program by receiving a free training on how to test equipment and submit a report using measureQuick. For this program, the measureQuick app was reconfigured to require the contractor to provide a serial number for each condenser, preventing duplication of reporting. To perform the tune-up, contractors operate the equipment at a steady state, and capture data to test the EER. After the initial test, contractors make a series of improvements such as correcting the refrigerant charge and cleaning the evaporator coil, outdoor condenser, and/or blower. Then, the equipment is operated in a steady state to test the EER after the maintenance. If the EER is improved, then the contractor receives an incentive of $150 per single-family home and $75 for multifamily buildings. Contractors have appreciated measureQuick for verifying their tune-ups and reducing the amount of paperwork for participating in a tune-up program.

Entergy Mississippi cross-promoted the free tune-up program along with other HVAC programs through the program overview brochure, trade ally reference guide, and email blasts. The tune-up program is also promoted through social media continuously (Entergy Mississippi 2020a).

4.5 Market Barriers

CACs and ASHPs with embedded AFDD have the potential to improve the quality of equipment installations, provide real-time feedback on equipment status, and reduce time between fault detection and the arrival of trained HVAC service contractors. All these factors in aggregate could improve the overall energy efficiency of homes and human comfort through minimizing equipment downtime. Achieving this level of transformation in the HVAC market, however, will require overcoming a number of extant barriers that, so far, contribute to embedded AFDD residential CAC and ASHPs only being available in higher end products. Table 7 summarizes the pertinent points outlined throughout this report and the tangible effects each may have on the promotion of AFDD HVAC technology in the existing residential market.

Table 7. Technical and market barriers to advancing AFDD in the marketplace

Barrier	Description
Lack of embedded AFDD for energy efficiency performance	Embedded AFDD for the purpose of measuring energy efficiency performance does not exist in current CAC and ASHP models.
Lack of AFDD standards and method of test	Manufacturers have different approaches and implementation strategies for AFDD in residential HVAC.
Product cost	Embedded AFDD for monitoring reliability is currently only available in high-end, variable-speed CAC/ASHPs. This would initially be the same for measuring energy efficiency.
Lack of standardized or industry-accepted communications protocol	In absence of standardized or industry-accepted communications protocols, the indoor unit, outdoor unit, and connected thermostat must be a matched set from the same manufacturer to enable AFDD, meaning third-party smart thermostats are incompatible.
Lack of standardized or industry-accepted fault codes	HVAC equipment fault codes are specific to each manufacturer, which means contractors have to learn a different set of fault codes to service each manufacturer's HVAC equipment.
Lack of knowledge	End-users note a lack of awareness about AFDD, and do not understand the potential benefits. Most are unaware of the possibility their HVAC equipment was improperly installed.
Lack of contractor training	Most HVAC contractors are unfamiliar with using AFDD and smart diagnostic tools to conduct installations or tune-ups. Training is needed so contractors understand how to administer testing and make use of the diagnostic data.

HVAC contractor business model	HVAC equipment manufacturers target HVAC dealers and contractors as their primary customers. Servicing HVAC equipment is not a primary revenue driver for most contractors, and thus is perceived negatively even though it can reduce callbacks.

5.0 Conclusions

This analysis characterizes the market opportunities for embedded AFDD in residential CAC and ASHPs as well as the use of smart diagnostic tools for quality CAC/ASHP installation. Decreasing improper CAC/ASHP installations can significantly improve the energy efficiency performance of CACs and ASHPs and lower HVAC service contractor costs due to callbacks. A recent meta-analysis by DOE found that poor HVAC installation results in at least one fault in 70–90% of homes in the U.S. Two faults, refrigerant charge and insufficient evaporator airflow rate, account for 9% of energy consumption of CACs and ASHPs, which is wasted energy.

Currently, embedded AFDD only exists in premium variable-speed CAC/ASHP models to ensure reliability rather than monitor energy efficiency performance. Using the sensors and controls equipped in premium variable-speed equipment, existing AFDD technology has the potential to monitor energy efficiency performance continuously and inform homeowners and HVAC service contractors through wireless or on-site communications technologies (e.g., smart thermostat). However, further R&D would need to be conducted to leverage the measurements and data from these sensors and controls. In certain product lines, such as the aftermarket product Emerson SensiPredict, wireless communications systems allow for the transfer of real-time data to a designated HVAC service contractor, reducing the potential for faults to go undetected and the time lost identifying specific faults once a contractor is on-site.

Single-family homes with wireless internet are the primary market opportunity for embedded AFDD technology in CAC and ASHP equipment. According to EIA and Census data, states with the highest potential include California, Texas, Florida, North Carolina, Virginia, Georgia, Illinois, Ohio, Pennsylvania, Tennessee, and Arizona. Based on the age distribution of installed equipment, approximately 10% of CACs and 20% of ASHPs in the U.S. will need replacement in the next five years. In the near term, these replacements are an opportunity for using smart diagnostic tools to facilitate quality installation of new equipment, thereby improving energy efficiency performance. Over the long term, the replacement of CAC and ASHP equipment is an opportunity to install new product models with embedded AFDD to ensure quality installation and continual performance monitoring, thus reducing energy waste over the entire lifespan of the equipment.

Until embedded AFDD technology is further developed, other alternatives for ensuring quality installation and the rapid detection of faults may prove more fruitful. Smart diagnostic tools can be used by HVAC contractors to check the status of equipment during the installation process. These tools are a relatively modest cost over their lifetime on a per-installation basis and allow contractors to monitor the status of equipment while on-site conducting tune-ups. Smart diagnostic tools perform targeted system measurements (e.g., suction pressure, high pressure, superheat, subcooling, airflow), which in combination with system specifications, can determine the real-time EER of equipment. Their applicability to all existing product lines and systems of CAC/ASHP equipment may provide the fault detection capabilities sought after with embedded AFDD technology during the installation phase with marginal to no cost increase to equipment purchasers/owners over conventional installation.

In addition, investments in expanding the capacity for smart diagnostic tool mobile applications to facilitate the logging, storage, and transmission of data collected on-site may allow for energy efficiency performance tracking and the comparison of similar CAC/ASHP equipment between homes. Consequently, the deployment of smart diagnostic tools in the near-term (i.e., next five years) can help establish contractor expertise as well as data collection and automation processes that utility provider programs can leverage once embedded AFDD for assessing energy efficiency is available. This is to say, smart diagnostic tools can set up programs to succeed once embedded AFDD for energy efficiency reaches the market.

Over the long term, embedded AFDD technology could serve a variety of uses, providing real-time information to homeowners, HVAC contractors, and, potentially, utility providers on equipment performance and corresponding maintenance needs. This is advantageous to utility providers interested in supporting quality installation incentive programs for contractors. These utilities can offer contractor training and certification programs to build a base of known contractors who seek to install equipment to the highest standards using diagnostic data. Instant rebates or buydowns, given directly to dealers and contractors, for AFDD-equipped ASHPs, CACs, and/or smart thermostats are one promising way in which this technology could quickly penetrate the market. In 2019, the highest percentage of incentives for ENERGY STAR certified CAC/ASHPs were offered in the Midwest, followed by the Southeast, and finally the Southwest. The highest percentage of incentives for ENERGY STAR certified smart thermostats were offered in the Northeast followed by the Southwest. To facilitate utility provider programs, ENERGY STAR specifications for CAC/ASHPs can incorporate embedded AFDD requirements, ensuring incentives and corresponding demand for this important technology in key regions.

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