U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Overview of Existing and Future Residential Use Cases for Connected Thermostats

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Preface

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List of Acronyms

AMI	Advanced Metering Infrastructure
API	Application Programming Interface
BEMS	Building Energy Management System
BTO	Building Technologies Office
CT	Connected Thermostat
DOE	U.S. Department of Energy
DSM	Demand-side Management
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
HEMs	Home Energy Management System
HVAC	Heating, Ventilation, and Air Conditioning
IDSM	Integrated Demand Side Management
IoT	Internet-of-Things
M&V	Measurement and Verification
PLM	Peak Load Management
R&D	Research and Development
RFID	Radio Frequency Identification

Executive Summary

This paper is intended to help inform future technology deployment opportunities for connected thermostats (CTs), based on investigation and review of the U.S. residential housing and CT markets, as well as existing, emerging, and future use cases for CT hardware and CT-generated data. The CT market has experienced tremendous growth over the last 5 years—both in terms of the number of units sold and the number of firms offering competing products—and can be characterized by its rapid pace of technological innovation. Despite many assuming CTs would become powerful tools for increasing comfort while saving energy, there remains a great deal of uncertainty about the actual energy and cost savings that are likely to be realized from deployment of CTs, particularly under different conditions.

There is substantial evidence to suggest that the CT industry will continue to innovate, providing consumers with access to an increasing number of features—possibly including those specific to advanced HVAC control and energy management, as well as those ensconced in a "smart home" context. This paper identifies a number of emerging and future CT use cases that could unlock new and additional residential energy savings from advanced home diagnostics, real-time measurement and verification of energy efficiency upgrades, advanced performance monitoring and fault detection, and the provision of integrated platforms for customer engagement, home energy management, and grid services. These opportunities present multiple benefits, including:

- Cheaper and widely available energy assessments;
- Improved reference models for building energy simulations;
- Quality maintenance benefits available to any connected system;
- Delivery of real-time, personalized behavioral energy efficiency interventions; and
- Improved grid reliability through demand response and other grid services

To enable these benefits, however, certain market gaps must be addressed. Without characterization of threshold conditions for accuracy, benchmarks and methods of comparisons across models and housing types for M&V of energy efficiency upgrades, and means of connecting disparate data streams and interoperable devices, these potential end uses will remain theoretical. Fortunately, opportunities exist for market actors to address and resolve certain of these barriers. Additional guidance on how future CT use cases may be supported is provided by the broad and growing experience of today's CT deployment efforts. For example, business models and other resources exist which can facilitate efforts to overcome certain market gaps, and in some cases strategic partnerships or pilot projects are already testing the waters on potential solutions that could eventually be brought to scale.

Finally, the market experience of this complex product reveals an important and clear lesson for driving continued interest and growth in CTs and their end use: clear communication about, and delivery of, customer value is key. Although insufficient in isolation, strong consideration of end-user needs and interests when designing and implementing demonstration projects may help to clarify key aspects of the "solutions" to existing market gaps. The crux of success of future CT use cases, both in their formulation and execution, may therefore come down to familiar territory for thermostats: customer comfort.

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1. Introduction

This report presents the findings of a study commissioned by the U.S. Department of Energy's (DOE) Building Technologies Office (BTO) to better understand additional end-use opportunities for Connected Thermostat (CT) technology in residential buildings in the United States.[1] For the purposes of this study, a Connected Thermostat is an internet-connected device that enables consumers to set and modify a setpoint schedule for HVAC control and incorporates remote communication to other devices in the home or via the web.[2] This functionality allows consumers to connect to the internet to remotely access thermostat controls or connect to other applications that enable the exchange of information via open or proprietary communication protocols.

Thermostat technology has evolved significantly in just the last five years, and CTs have become a fast growing segment in the HVAC market, promising both potential energy savings and the convenience of internet connectivity.[3] With increasing numbers of competing products and technological features and capabilities in the market, researchers and policymakers are demanding a common understanding of the energy savings-potential of these devices to confirm product performance and support purchase decisions. To this end, the U.S. Environmental Protection Agency's (EPA) ENERGY STAR program is currently working with stakeholders to finalize a standard CT specification (Connected Thermostats Specification V1.0) to help consumers identify products that deliver cost-effective energy savings.[4]

CTs present an opportunity for homeowners and renters to save energy by integrating communication technologies with commercially available HVAC products and home appliances. CTs can potentially achieve direct HVAC savings through deployment of advanced sensors and controls; in addition, connected devices like CTs can help consumers better understand their home's energy performance by providing home-specific data. This data could guide future home upgrades, track home energy performance, and verify energy and cost savings from efficiency improvements.

This paper explores the current and future landscape of the CT market, as well as existing, emerging, and future use cases for CTs that can contribute to the optimization of home energy use and identification of home performance improvements. To inform this paper, Energetics Inc. and the Vermont Energy Investment Corporation conducted secondary research and engaged key stakeholders from across the CT, efficiency, and home performance industry to 1) help identify existing CT activities in the residential market and 2) inform potential technology deployment activities and opportunities for collaborations with future or ongoing technology development in this sector.

[1] Connected Thermostats are also sometimes referred to as "communicating thermostats."

[2] ENERGY STAR Program Requirements for Connected Thermostats Version 1.0 Final Draft

https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Program%20Requirements%20for%20Connected%20Thermostats%20Version%201.0%20Final%20Draft.pdf

[3] Navigant Research, June 2014. *Smart Thermostats: Communicating Thermostats, Smart Thermostats, and Associated Software and Services: Global Market Analysis and Forecasts.*

[4] In addition to the features and capabilities used to define a CT for the purposes of this paper, the final draft ENERGY STAR specification for CTs (dated December 2, 2016) requires that devices also (1) provide consumer access to information regarding HVAC energy consumption, (2) provide feedback to occupants regarding the energy impact of their choices, and (3) be capable of basic demand response using open standards. Learn more at www.energystar.gov/products/spec/connected_thermostats_specification_v1_0_pd

2. Residential Buildings Market Landscape

Residential buildings, including single family and multi-family homes, across the United States consume more than 20 quads of primary energy annually, approximately 21% of total U.S. energy consumption.[5] The residential market is comprised of more than 114 million households and represents more than 223 billion square feet of floor space.[6] Of these households, about 80 million are single-family homes; 28 million are multi-family; and 6 million are manufactured homes.

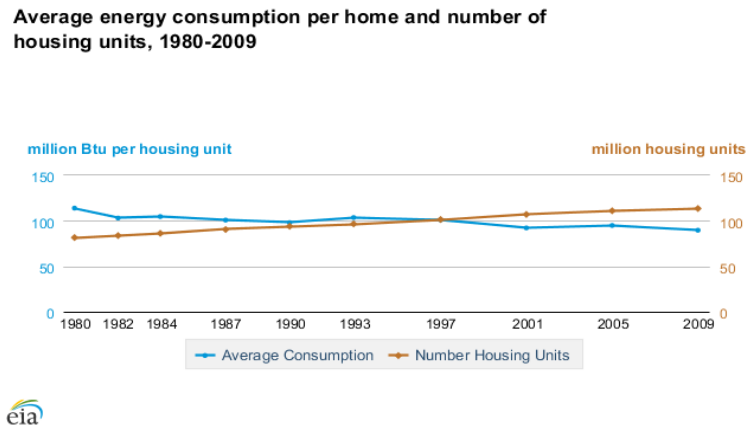

Figure 1: Residential Energy Consumption

Source: U.S. Energy Information Administration, Residential Consumption Survey.

Single-family homes represent over 80% of the residential building floor area and are projected to continue to remain the dominant type of residential building.[7] On average, the typical housing unit consumes more than 177 million Btu[8] and spends approximately $2,000 on energy per year. However, the percentage of expenditures for home energy varies across income levels. For households in the lowest 20% of income, energy bills amount to as much as 12% of total expenditures, while for those in the highest 20% of income, energy bills average only 2% of total expenditures.[9]

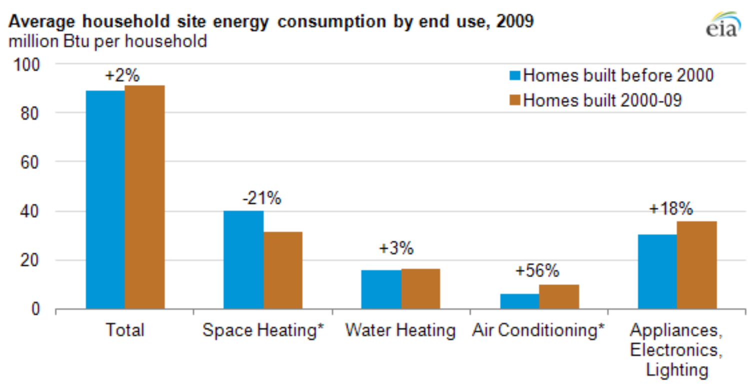

Figure 2: Energy Consumption by End Use

Source: U.S. Energy Information Administration, Residential Consumption Survey.

Energy use varies based on such factors as building structure type, age, and climate. To date, heating, cooling, and water heating account for more than half of all energy use in the sector, which represents a very large energy savings opportunity for

[5] U.S. Energy Information Administration, 2009 RECS Survey Data. U.S. DOE, 2012; CE1.1 Summary Totals and intensities, and CE3.1 End-use consumption Totals and averages, U.S. homes. http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption#summary

[6] Ibid.

[7] Ibid.

[8] U.S. Energy Information Administration, Annual Energy Outlook 2016 with projections to 2040. U.S. DOE 2016. https://www.eia.gov/forecasts/aeo/index.cfm

[9] Consumer Expenditure Survey, U.S. Bureau of Labor Statistics, August, 2016; Table 1101 Quintiles of income before taxes. http://www.bls.gov/cex/2015/combined/quintile.pdf

CTs.[10] Analysis from the U.S. Energy Information Administration (EIA) shows that on average homes built in 2000 and after are 30% larger than homes built before 2000, but consume only 2% more energy.[11] These new homes consumed 21% less energy for space heating than older homes due to increased efficiency in heating equipment and better building shells built to more stringent building energy codes. Geography played a role too, as new home construction shifted from cold climates to warm and humid climates; about 53% of newer homes are in the more temperate South, compared with only 35% of older homes.[12] However, an average new home uses approximately 18% more energy than an older home for appliances, electronics and lighting, due to increased plug loads such as televisions, miscellaneous electronics, clothes washers, and clothes dryers.[13]

As new homes are built with larger square footage, increasingly in regions that require large amounts of energy for cooling, energy efficiency gains from improved household appliances and systems are key to keeping residential energy consumption growth in check. Figure 3 below illustrates the sustained opportunity space for CTs in reducing household energy consumption from the number of new homes and their size, keeping all other residential energy consumption factors constant.[14]

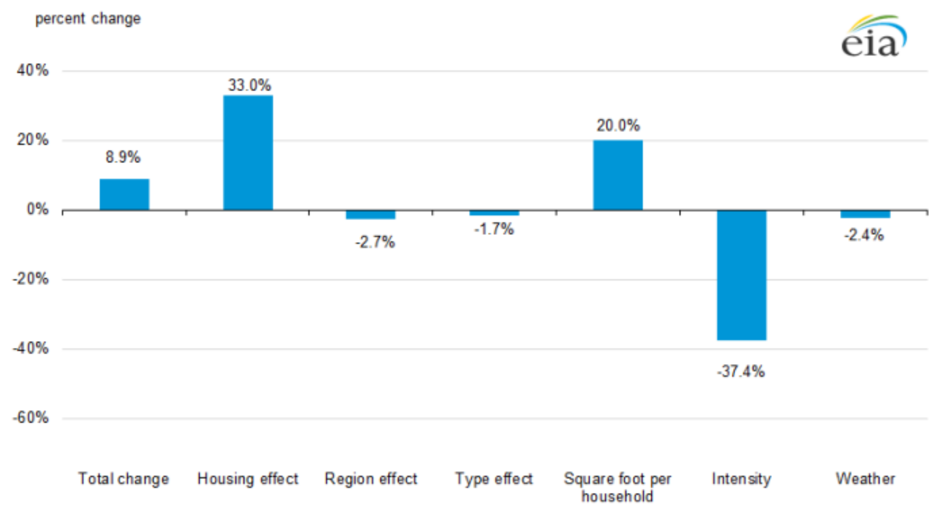

Figure 3: Decomposition of change in total residential energy consumption, 1980-2009.
Source: U.S. Energy Information Administration, Residential Consumption Survey.

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[10] U.S. Energy Information Administration, 2009 RECS Survey Data. U.S. DOE, 2012; CE3.1 End-use consumption Totals and averages, U.S. homes. Accessed:
http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption#summary

[11] Ibid

[12] U.S. Energy Information Administration, 2009 RECS Survey Data. U.S. DOE, 2012; CE3.1 End-use consumption Totals and averages, U.S. homes.
http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption#summary

[13] U.S. Energy Information Administration. "Newer U.S. homes are 30% larger but consume about as much energy as older homes." *Today in Energy*. Washington, DC: U.S. Department of Energy, 2013.
http://www.eia.gov/todayinenergy/detail.cfm?id=9951&src=%E2%80%B9%20Consumption%20%20%20%20%20%20Residential%20Energy%20Consumption%20Survey%20(RECS)-b3#

[14] EIA Residential Energy Consumption Surveys (1980 and 2009) and Monthly Energy Review 2013. U.S. DOE.
https://www.eia.gov/analysis/studies/buildings/households/pdf/drivers_hhec.pdf

Under EIA's Annual Energy Outlook 2016 scenario,[15] the energy intensity of residential buildings between 2014 and 2040 declines by 24% due to expected increased efficiencies in lighting, space heating, and water heating.[16] However, total energy use in the sector increases by 6.7% due to the increasing number of homes constructed during that period.[17] In 2014 alone, approximately 1 million new residential housing units were built.[18] EIA forecasts that new home construction will continue to increase at a rate of 1.3% per year, and by 2030 homes built after 2015 are expected to represent 20% of total residential housing units.[19]

A variety of existing and emerging energy-efficient technologies and installation techniques can reduce residential energy use while still providing important energy services and enhancing comfort for building occupants. DOE's Building Technologies Office estimates that if the energy performance of today's existing residential buildings was improved by 25%, it would save 5% of all energy consumed in the U.S. each year (or 5 quads), result in $63 billion in consumer cost savings, and reduce 284 million metric tons of carbon dioxide emissions.[20] Growing consumer interest in connected devices, including CTs, presents an opportunity to build on gains made in residential building energy efficiency to advance energy management in both new and existing homes across the country.

[15] EIA's Annual Energy Outlook only considers existing appliance energy standards and building energy codes in its models; future savings may result from stricter codes and standards, but are not included in this analysis.

[16] U.S. Energy Information Administration, Annual Energy Outlook 2016 with projections to 2040. U.S. DOE 2016. https://www.eia.gov/forecasts/aeo/index.cfm

[17] Ibid.

[18] Ibid.

[19] Ibid.

[20] U.S. Energy Information Administration, Annual Energy Outlook 2015 with projections to 2040. U.S. DOE 2015. http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf

3. Connected Thermostat Market Landscape

3.1 Evolution of the Thermostat from Programmable to Connected

Programmable thermostats were a very early addition to basic thermostat control of building heating and cooling systems. Programmable thermostat functionality enables users to set and modify a setpoint schedule, identifying different temperature setpoints for different times of day to provide both a convenience benefit (i.e. eliminating the need to manually change setpoints) and an energy-savings benefit (i.e. allowing occupants to maintain a comfortable temperature when someone is expected to be home while implementing temperature setbacks during periods of anticipated vacancy). The first programmable setback thermostats were introduced in 1906,[21] but additional features and functionality were introduced in each ensuing decade, including market introduction of the first digital programmable thermostats in the mid-1980s.

Through the 1990s and into the 2000s, programmable thermostats continued to evolve, offering consumers more sophisticated programming capabilities (e.g. seven-day scheduling), as well as additional control functionality for zoned spaces and ancillary heating and cooling services like humidification, dehumidification, and ventilation. Programmable thermostats were demonstrated to be capable of achieving up to 30% in HVAC energy savings through optimized thermostat setpoint schedules, and an ENERGY STAR certification program was established in 2003 to encourage households to purchase and use these tools to achieve ongoing energy and cost savings.[22,23]

Unfortunately, the expected levels of energy and costs savings from implementation of programmable thermostat controls were often not being realized by consumers, as savings were predicated on the correct and optimal use of scheduling functionality. In contrast, however, many consumers were frustrated by or apathetic about the process of programming a setpoint schedule – despite advancements made in ease-of-use and the thermostats' user interfaces – leading many consumers to misuse, override, or abandon the programmable functionality altogether.[24] CTs emerged in part as a market response to these usability problems, capitalizing on advancements in information and communications technologies to introduce new and improved interface options, as well as additional features to simplify and automate the schedule-setting process.

Today's CT market is less than 10 years old, marked by rapid growth and innovation, and is a key part of a much larger consumer-driven, Internet-of-Things (IoT) trend of growing connectivity and automation in

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[21] Meir, Alan K. and Walker, Iain S. March 2008. "Residential Thermostats: Comfort Controls in California Homes." Lawrence Berkeley National Laboratory. LBNL-938E. Honeywell's 1906 model used a clock to turn the temperature down at night and up in the morning.

[22] U.S. Environmental Protection Agency. "Programmable Thermostat Specification." Accessed June 30, 2016 at: https://www.energystar.gov/index.cfm?c=archives.thermostats_spec

[23] The U.S. EPA suspended its ENERGY STAR labelling program for qualifying programmable thermostat models in 2009, as a result of uncertainty about consumer behavior – specifically, that many consumers were either not using or misusing the programmable functionality – and the resulting failure by many consumers to achieve expected levels of energy savings.

[24] U.S. Environmental Protection Agency. May 4, 2009. "ENERGY STAR Programmable Thermostat Spec Suspension Memo". https://www.energystar.gov/ia/partners/prod_development/revisions/downloads/thermostats/Spec_Suspension_Memo_May2009.pdf

homes and buildings. Automated smart home systems include CTs, home energy management systems, and other connected devices. The interaction of these connected devices and the associated consumer benefits extend beyond home energy management – including security, convenience, and comfort – and are important contributing factors for driving and accelerating market adoption of CTs.

The technological innovation in this product area has generated new capabilities for customers and stakeholders in energy efficiency and demand response programs. As the market has evolved from programmable thermostats to increasingly connected and cognitive (i.e. algorithms for learning or "smart" operation) thermostats with web-enabled software platforms, a multitude of rapidly expanding feature sets for CTs have emerged, which include:

- **Temperature Control:** Although the most traditional of the thermostat features, CTs offer an enhanced ability to minimize inefficient operation of the heating and cooling system to strike a balance between efficiency and comfort. Utilizing additional sensor inputs (see below), monitoring equipment and home thermal performance, and accessing forecasted weather data allow the CT to make fine-tuned adjustments to the temperature control. Some CTs also have the capability to manage the residential cooling system output by dehumidifying the home, as well as the capacity to control fan modes (on, auto, and circulate) when compatible equipment is available.
- **Energy Management Services:** The connected functionality of the thermostat allows for performance tracking of the home over time – building a data-rich opportunity for energy management services or service providers to improve the energy performance of the home. While conventional demand response services may provide remote curtailment of HVAC equipment, the added value of detailed data flows allows for an array of performance enhancements that may also manage prioritized savings opportunities based on homeowner preferences, predicted usage of the building during the day/year, and other external relevant signals in addition to those from gas or electric utilities.
- **Mobile and Home Automation Platform:** Remote accessibility is often cited as the most important consumer feature for selecting or valuing CTs. Accessibility to CTs and any associated home automation platform allows for deeper temperature setbacks when occupants are sleeping or away, as well as greater integration of connected devices for improved performance and service.
- **Input from Local Sensors and Web-enabled Data:** Sensors associated with HVAC equipment, occupancy, and weather and humidity provide additional functionality to extend the capabilities of CTs. Occupancy-driven operation of the HVAC system is achieved through geo-fencing, using radio frequency identification (RFID) to define a geographic boundary, and other technology solutions relatively new to the CT market. Data provided through additional sensors in the home, as well as integration into broader smart home systems, have enabled additional functionality of the CTs to support security and automation within the home or business. Connected functionality for accessing weather forecasts expands the CT's ability to predict the optimum operation of the heating and cooling system to balance comfort and efficiency.
- **Simplified Installation and Learning:** The capability of CTs to receive local equipment and home usage information, as well as access the massive and increasingly useful pool of web-accessible datasets, enables CTs to "learn," self-configure, and run diagnostic tests to identify performance problems – though in some cases a contractor may still be required to support these functions, depending on individual home requirements. Additionally, connected devices allow for remote programming updates to improve or increase functionality without requiring the onsite removal, replacement, or updating of hardware located in the home.

3.2 Market Growth

The growing CT market is supported by manufacturers, as well as service providers offering independent third-party, web-enabled software platforms that work with both new and existing CT technologies (See Figure 4). Although Nest, Honeywell and, more recently, Ecobee are leading the CT market, other leading HVAC manufacturers and new market entrants are vying for larger shares of the residential and commercial market. Other third party software platforms – notably Weatherbug and EnergyHub – support new and existing CTs in the market by providing a supplementary service to individual customers to improve the heating and cooling energy performance, while also acting as an aggregator for utilities for efficiency and demand response programs.

The sale and distribution of CTs is supported through multiple channels including: key cross-market partnerships, direct to consumer, online and traditional retailers, HVAC contractors and supply channels, and utility demand-side management (DSM) programs (gas & electric). A new study found that of the 40 million thermostats sold in 2015, 40% were “smart.” These CTs were sold and distributed predominantly by retail channels (45%), HVAC channels (25%), utilities (15%), and security channels (15%).[25]

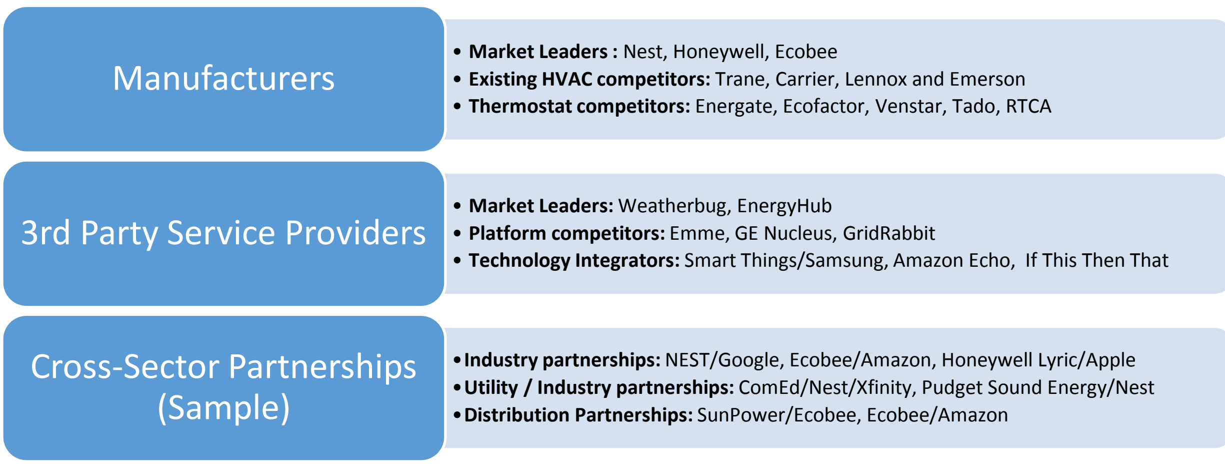

Figure 4: Connected Thermostat Market Overview

In 2009, 60% of U.S. homes had central thermostats to control heating and cooling systems and about half of those thermostats were programmable.[26] Nest’s introduction of the Learning Thermostat in 2011 jumpstarted the evolution of simple, programmable thermostats into CTs, and catalyzed market growth over 100% per annum. Since then CT sales have achieved rapid penetration in residential homes, and the potential for continued market growth expands with possible adoption of multiple CTs in a single home.[27] A recent market analysis estimated that in 2014 the installed base of CT in North American homes was

[25] Parks Associates. July 15, 2015. “Over 40% of thermostats sold in 2015 will be smart thermostats.” http://www.parksassociates.com/blog/article/pr0715-smart-thermostats. Sales percentages for HVAC, utilities and security channels were approximated by the figure in the research report.

[26] U.S. Energy Information Administration. January 28. 2014. “Most homes have central thermostats on heating and cooling equipment.” *Today in Energy*. Washington, DC. https://www.eia.gov/todayinenergy/detail.cfm?id=14771

[27] Navigant Research, June 2014. *Smart Thermostats: Communicating Thermostats, Smart Thermostats, and Associated Software and Services: Global Market Analysis and Forecasts.*

2.5 million from the current suite of Wi-Fi and modern mobile-connected products.[28] This same study forecasts the installed base to grow to 24.6 million by 2019. By this same year, the global CT market is forecasted to exceed $1 billion.[29] This CT market represents an important share (6%) of the much larger smart home market, forecasted to exceed $15 billion by 2019.[30]

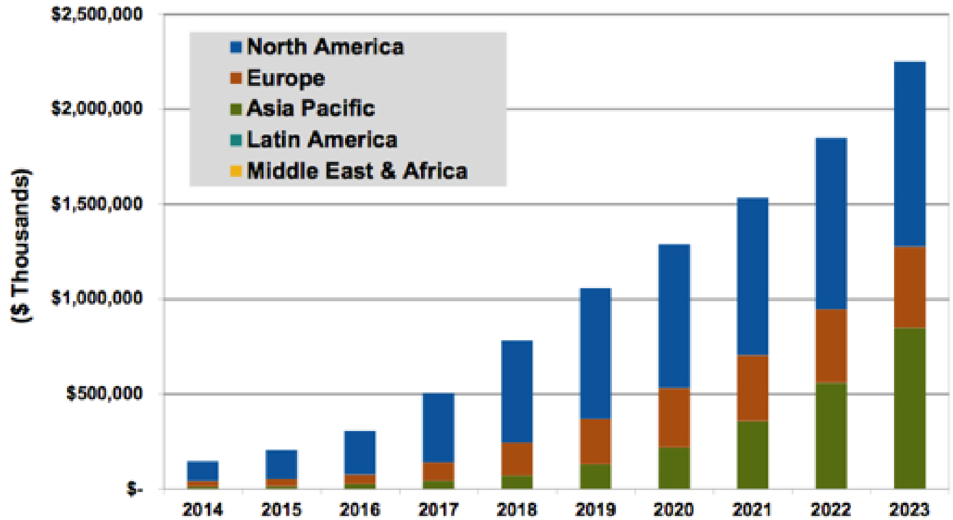

Figure 5: Residential Market growth forecast for North American CTs

Source: Navigant Research, Global Market Analysis and Forecasts. 2014

The growth of CTs in residential homes does not directly equate to a corresponding increase in energy savings. A literature review of 35 reports, studies, and evaluations from 2007 to 2016 (see Appendix B) demonstrates the attention given to the energy-related aspects of this product area. Overall, the real-world performance of tens of thousands of devices were examined by third parties, mapping a wide-ranging spectrum of results, with reported energy savings falling somewhere between 1% and 15%.[31] The bulk of these studies (80%) focused on energy savings due to automatic HVAC controls, with two-thirds (67%) also including customer behavioral savings. The vast majority of studies (89%) focused on electricity savings, with slightly more than half this amount (46%) also looking at heating savings for natural gas.

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[28] ACHR News. January 19, 2015. “The Number of Homes with Smart Thermostats Doubled in 2014.” Accessed November 15, 2015: http://www.achrnews.com/articles/128554-jan-19-2015-the-number-of-homes-with-smart-thermostats-doubled-in-2014

[29] U.S. Energy Information Administration. January 28. 2014. “Most homes have central thermostats on heating and cooling equipment.” *Today in Energy.* Accessed April 20, 2016: https://www.eia.gov/todayinenergy/detail.cfm?id=14771

[29] ACHR News. January 19, 2015. “The Number of Homes with Smart Thermostats Doubled in 2014.” Accessed November 15, 2015: http://www.achrnews.com/articles/128554-jan-19-2015-the-number-of-homes-with-smart-thermostats-doubled-in-2014

[30] Grand View Research. June 2014. Smart Home Market Analysis By Applications (Security, Lighting, Entertainment, Energy Management, And HVAC) And Segment Forecasts To 2020. Accessed June 30, 2016: https://www.grandviewresearch.com/press-release/global-smart-homes-market

[31] In some instances, energy consumption appears to have increased following deployment of CTs.

More than two-thirds (69%) assessed the energy efficiency impact of CTs, while slightly more than 63% looked at energy demand savings. According to these studies, the factors affecting savings included not only local weather conditions, but also a diverse collection of hardware, software, building, and occupant characteristics; collectively, these factors make it difficult to develop simplified claims about CT-related energy savings for the general population of homes and products.[32]

3.3 Home Energy Management Systems

One evolving market opportunity for CTs is integration with connected devices in a "smart home" platform, under the aegis of a home energy management system (HEMS) (see Figure 7 for data flow examples). For decades, commercial buildings have found efficiencies in the operation of complex systems (e.g. HVAC, lighting, and security) by grouping the control of those systems under a single architecture that automates their usage based on a building's need. These systems, called building energy management systems (BEMS), are often expensive and require dedicated personnel to manage, making it cost prohibitive for smaller commercial or residential usage. CT integration into an energy management platform has the potential to optimize a home's HVAC system as well as increase occupant comfort and convenience.

In the last decade, with advances in wireless communication and increasingly affordable and available IoT capabilities in residential appliances, many actors have started to investigate the potential for broader adoption of home energy management systems (HEMS).[33] While the exact definition of what is included in a HEMS differs vastly across stakeholders, generally it is agreed that such a system would encompass any product or service that monitors, controls, or analyzes energy in a home. A HEMS acts as a central controller, managing devices across a large variety of residential use cases, including lighting; heating and cooling; security systems; and other miscellaneous plug loads such as appliances, televisions, and game systems. These systems and devices are connected via the home's wireless network and can be controlled by a dedicated remote or through mobile applications.

CT manufacturers have recently established partnerships with key market actors in telecommunications, home automation/security, and household appliance, lighting, and HVAC sectors to enable and participate within the broader smart home market. "Works with Nest," a program launched by Nest in 2014, is a label for products certified to easily connect with Nest Thermostats through Google's development platform;[34] current market partners include lighting manufacturers Philips, Insteon, Hue, and Lutron; IP telephone manufacturer Ooma; and appliance manufacturers LG and Whirlpool.[35] Similarly, Apple's HomeKit platform allows for users to connect products via their iPhone and control them from within a single application or using voice control (via Siri).[36] Amazon's Echo device also allows for voice command through its Alexa virtual assistant, integrating a number of connected products including smart

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[32] See Appendix B: Summary of CT Energy Savings Literature.

[33] Other terms for HEMs include Home Automation Systems, Home Automation Hubs, and Home Comfort Automation

[34] Nest. "Works with Nest". Accessed June 28, 2016: https://nest.com/works-with-nest/

[35] Brown, Michael. January 5, 2015. "'Works with Nest' Program Gains Traction with 15 New Smart Device Integrations." *Tech Hive*. Accessed June 29, 2016: http://www.techhive.com/article/2864067/connected-home/works-with-nest-program-explodes-with-15-new-smart-device-integrations.html

[36] Apple. "HomeKit". Accessed June 28, 2016: http://www.apple.com/ios/homekit/

home platforms from Samsung and Insteon.[37] Another business model is vertical integration of smart home technology. For example, Alarm.com's "Smart Thermostat" is integrated into their security system, which allows consumers to control the temperature, lighting system, Wi-Fi-enabled locks, and garage door with their smartphone application.[38]

Integration of home performance data generated by multiple systems—including metering, heating and cooling, lighting, water heating, or security—has the potential to enable advanced functionality or new services that can identify opportunities to increase, or improve, overall home energy performance. However, outside of vertically developed partnerships between manufacturers of connected devices and web-enabled software platforms, an absence of standardized communications and interoperability of devices and systems across manufacturers remains as an ongoing challenge for facilitating a broader market adoption of smart home systems and smart residential appliances. This is compounded by the fact that with many new market entrants and technologies, reliance on connected functionality increases the potential for new products to lose a portion or all of their functionality if the service provider or manufacturer goes out of business.

[37] Wroclawski, Daniel. May 18, 2016. "Everything that works with Amazon Echo and Alexa." *Reviewed.com*. Accessed June 30, 2016: http://smarthome.reviewed.com/features/everything-that-works-with-amazon-echo-alexa

[38] Alarm.com. November 28, 2015. "Meet the Alarm.com Smart Thermostat!" Accessed June 28, 2016: http://www.alarm.com/blog/meet-our-smart-thermostat

4. Current Market Growth Activities

Connected thermostats are sustaining a rapid pace of innovation to increase functionality to better serve the customer. In addition to hardware improvements to attract new customers, CTs have the ability to push new functionalities and improvements in older CT models' control algorithms via the cloud to existing customers. However, each update has the potential to change the performance of the home's heating and cooling system. As the CT market grows, so too does the need to develop common performance criteria to help establish product requirements and evaluation of energy savings and demand response opportunities in residential homes.

Energy efficiency programs and utilities are currently investigating energy savings opportunities and demand response capabilities from CTs across the country. These groups are partnering with manufacturers and third-party service providers to test and evaluate CT capabilities and impact as they are deployed within specific U.S. regions.

4.1 Performance Standardization

The growth of the CT market has accelerated the need for typical support mechanisms in the DSM market, including performance criteria – e.g. ENERGY STAR® – and rigorous evaluations that provide measurable and repeatable evidence of energy savings to support funding from gas and electric energy efficiency programs. However, the rapid rate of software-driven change in performance, which can occur multiple times per year even for already-installed devices, requires a new approach to both product rating and program evaluation methods. Fortunately, the rich data streams from CTs offer a potential solution to this challenge.

Some data standards and specifications have been developed to support contracts for individual utility programs and pilots, but these developments have occurred without concomitant levels of market sales. As a result, industry uptake has been slow to coalesce around a common standard. More recently, increased collaboration between industry and utilities has resulted in establishing a framework "to develop specifications and requirements for collection, reporting and analysis of data collected by connected devices for utility DSM programs and other needs." [39]

The summary table below highlights ongoing utility and government activities in the market that support the development of a minimum set of common performance criteria and data reporting for tracking individual-product installed performance in homes.

[39] Electric Power Research Institute. April 2016. "Thermostat Data Specification (Draft Version 2)."

<table>
<tr><td rowspan="6">Specifications, Performance Criteria and Data Standardization</td><td>EPA ENERGY STAR</td></tr>
<tr><td>Performance Criteria: In recognition of the quickly evolving functionality of CTs and supporting software platforms, EPA shifted strategies in 2014 and initiated the development of a set of minimum product requirements, as well as a method for demonstrating in-field energy savings.[40] EPA is proposing both a prescriptive method for developing in-field energy savings and also custom, tailored approaches for individual ENERGY STAR partner technology solutions. Unlike most ENERGY STAR criteria, EPA recognizes the split path of “hardware-centric” and “service-centric” CT solutions – focusing on the service provider as the actual ENERGY STAR partner. This approach is similar to that taken for television set top boxes, in which the partner is the service provider who ultimately deploys and controls the technology. EPA anticipates finalizing the specification at the end of 2016.

Data: In December 2015, EPA solicited in-field data from the CT industry in an effort to inform the development of a standard metric for the performance criteria and in-field savings.[41] Additionally EPA is proposing to require a bi-annual submission of in-field performance data for the installed base of CTs by individual ENERGY STAR partners. As EPA recognizes the potential confidentiality concerns around shared data, currently the data would only be accessible to external parties in aggregate form – a barrier for efficiency programs for evaluating savings.</td></tr>
<tr><td>Consortium for Energy Efficiency</td></tr>
<tr><td>Performance Criteria: Consortium for Energy Efficiency (CEE) helps efficiency program members develop program strategies to support energy savings through the deployment of CTs. As part of its role, CEE is developing advanced criteria to differentiate between CT functionality and capability to support peak load management (PLM) / demand response. These criteria are designed to complement and layer on top of the existing requirements set forth by ENERGY STAR.

Data: Developing standardized testing protocols and data reporting and sharing requirements are necessary for supporting climate and utility territory specific energy savings estimates. CEE also serves as a forum to aggregate the myriad of pilots and evaluations conducted by individual utility and efficiency program members.</td></tr>
<tr><td>Electric Power Research Institute</td></tr>
<tr><td>Data: Electric Power Research Institute (EPRI) is developing specification requirements for data collected by connected devices to support data collection, reporting and analysis for utility integrated demand side management (IDSM) programs and/or other needs. These standardized requirements can help lower the cost of existing approaches to data acquisition. Standardized data from connected devices can be used to achieve many objectives including: establishing best practices for data collection, developing new methods to validate analysis and measure the effectiveness of replacing existing industry monitoring and verification methods, identifying industry barriers to evaluate and develop new approaches, and aligning utility customer records with device records to measure program participation.</td></tr>
</table>

Table 1: CT Data Specifications Activities

[40] U.S. Environmental Protection Agency. November 2015. “ENERGY STAR® Connected Thermostat Products: Method for Demonstrating Field Savings Rev. November 2015.”Accessed: https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Test%20Method%20for%20Connected%20Thermostat%20Field%20Savings.pdf

[41] U.S. Environmental Protection Agency. December 2015. “ENERGY STAR Connected Thermostat Data Request.” Accessed May 5, 2016: https://www.energystar.gov/sites/default/files/Energy%20Star%20CT%20Data%20Request.pdf

4.2 Current Market Deployment Efforts for Energy Efficiency and DSM Programs

CT manufacturers are focused on developing products that provide readily accessible customer value. This value may not always be focused on energy savings, but instead on convenience and reliability. However, utilities and other third-parties often seek to better control residential energy demand, and CTs offer the opportunity to dynamically respond to periods of high or low electricity demand within a particular jurisdiction's grid to implement load shedding or load shifting. As CTs proliferate in the market, utilities can increase enrollment in energy efficiency and demand response programs through partnerships with manufacturers and third-party service providers.

Using data from occupancy sensors (or related methods like geo-fencing), indoor and outdoor temperature, and setpoints, there are several common mechanisms for achieving savings[42]:

- Schedule optimization: occupancy patterns can be used to optimize setback timing.
- Temperature optimization: nudging users to accept a more conservative comfort temperature.
- Weather-adaptive controls: minimizing time at comfort temperature by returning from setback later on mild days.
- Reducing use of auxiliary heat for heat pumps.
- Correcting for faulty temperature readings due to poor thermostat location too close to a vent or window.
- Multi-zone control with multiple sensors and a single point of control.

With the emergence of many recent CT evaluations and deployment initiatives, utility efficiency and demand response programs have benefitted from forums for sharing performance results, best practices, and lessons learned.

[42] Some manufacturers of residential CTs do offer the capability to manage the cooling system output to improve dehumidification, but this ability is chiefly aimed at improving occupant comfort and not for achieving energy savings.

Utility and Efficiency Program Initiatives, Pilots and Evaluations	**Electric Power Research Institute (EPRI) Connected Devices Working Council:** A consortium of utilities, CT service providers, and other stakeholder organizations have been organized by EPRI to act as a forum for sharing findings and insights from multiple, multi-year CT pilot deployments. The EPRI working council is evaluating the industry needs and opportunities for efficiency and demand response – through response to price signals and capability to shed load, or with the connected home providing quickly-deployable thermal energy storage.
	Consortium for Energy Efficiency (CEE): The scale and diversity of pilots and evaluations conducted by North American efficiency programs and utilities is documented as a compendium of data by CEE, segmented by heating and cooling applications, participants, and gas and electric energy savings. CEE has focused on the performance of CTs in the Residential Heating and Cooling Systems Initiative, as well as part of a separate working group in the Emerging Technology Collaborative. Additionally, CEE's Connected Committee has worked in collaboration with other key stakeholders (e.g. EPRI, ENERGY STAR) on the data.
	Divergent Strategies for Deployment: Although many utilities have scaled down their programs for supporting the deployment of CTs while they conduct rigorous evaluations of energy savings, others have accelerated plans for CT adoption. The most notable recent example is an ongoing initiative by Northern Illinois utilities to deploy 1 million "smart thermostats" by 2020[43]. Utilities have developed individual partnerships with CT service providers to access customer CT data. Standardization and accessibility of the data remains as one of the core issues for utility promotions of CTs.

Table 2: Utility and Efficiency Program initiative, Pilots, and Evaluations

Existing energy use cases for CTs have emerged as a result of low-hanging customer and utility frustrations with conventional programmable thermostats. The ability to communicate with other devices allows for many possible solutions to common barriers to saving energy from thermostats, such as invisibility of energy usage, ease-of-use, and common misconceptions for how thermostats and heating and cooling systems work.[44] Existing use cases have been identified through market and stakeholder research. These existing use cases are outlined below as primary use cases that are commonly employed in the residential market.

Primary Use Cases for CTs in the Residential Market

1. Grid and HVAC Energy Management: Provide a channel for configuring and controlling customer time-of-day energy usage through passive or active changes to schedules and setpoints to save energy and system peak costs. Examples in the field:
    - Many utilities have scale-deployments of CT-facilitated programs to support customer participation in reductions of energy usage during high cost periods.
    - NVEnergy's PowerShift program freely provides a CT, internet gateway, and software to eligible customers that enables personalized, automatic weather and grid-system adjustments.

[43] Savineje, D. October 9, 2015. "ComEd targets 1M smart thermostats by 2020" *Utility Dive*. Accessed June 30, 2016: http://www.utilitydive.com/news/comed-targets-1m-smart-thermostats-by-2020/407083/

[44] Common misconceptions include generally erroneous beliefs that setbacks use more energy, and that the rate of heating or cooling is affected by how high or low the temperature setting is relative to the current temperature (e.g. "To make it more comfortable in here more quickly, I'll set my air conditioning to a much lower setting.")

Conveniences afforded though the CTs include ongoing remote monitoring and controls and event-specific participation configuration.[45]

2. Basic Feedback: Provide customers with intelligible feedback based on temperature setpoints, HVAC system runtimes, and usage and performance models. Examples in the field:

- The Nest learning thermostat conspicuously displays a green leaf on the thermostat (and application screen) to convey when a temperature is "energy saving" based upon initial set ranges that then are adjusted to suit the customer characteristics--differing for different zones within the same house.[46]
- Monthly e-mails include an "energy report" that provides summary runtime statistics, context for changes such as occupancy, weather, and schedule, and customer percentile benchmarking ("you're in the top 20%").

3. Optimizing Demand Response Program Performance: Evaluate peak load curtailment alongside demand response programs to identify savings potential. Examples in the field:

    - Existing thermostat demand response programs are analyzed based on HVAC runtime and schedule data from CT in the context of utility consumption data—either monthly billing or 15 minute or hourly data if available—to calculate actual system costs and benefits across the program and at the customer level.[47]
    - These datasets are also used to screen for eligibility in programs based upon compatible systems and schedules. In addition to program screening and recruitment, analytics on CT usage may be overlaid with event schedule models to customize the estimates of impact on customer charges and comfort.

Emerging use cases identified below are different from existing use cases in that they are relatively novel and not commonly used. However, unlike future use cases, all emerging use cases described below are already in use or are being actively piloted in the market.

Emerging Use Cases for CTs in the Residential Market

1. Advanced Feedback: Provide customers with information on whole-home energy performance and diagnostics. Examples in the field:

    - Earth Networks WeatherBug Home is a service that models customer energy usage incorporating thermostat, utility, and weather data to actively manage home temperatures and system runtime to maintain occupant comfort.[48]
    - These energy models and analytics are also used to communicate equipment and envelope performance statistics that suggest savings opportunities. Observed changes in these values

[45] NVEnergy. "Smart Thermostat Powershift Program." Accessed June 6, 2016: https://www.nvenergy.com/home/saveenergy/rebates/smart-thermostat/learn-more.cfm

[46] Nest. "How Does the Nest Green Leaf Work?" Accessed June 6, 2016: https://nest.com/support/article/How-does-the-Nest-Leaf-work

[47] Electric Power Research Institute. October 19, 2015. "Smart Thermostats: Learning about Connected Customers." *Behavioral Energy and Climate Change Conference.* Accessed June 6, 2016 at: http://beccconference.org/wp-content/uploads/2015/10/presentation_narayanamurthy.pdf

[48] WeatherBug Home. "Home Page." Accessed May 30, 2016: https://weatherbughome.com

over time can relate to weather patterns, equipment tune-ups & upgrades, or envelope measures, and can provide engagement pathways for customer visibility into their comfort, cost, and energy.

2. Basic Fault Detection: Alert customers to maintenance and operational issues (air-filter replacement, HVAC tune-ups, disabled fan, etc.). Examples in the field:

   - EcoFactor provides an add-on service to an existing DR program that assesses the CT data to look for HVAC performance issues. In one example 6% of homes were flagged for follow-ups that confirmed 95% accuracy through onsite technician visits.
   - The most common issues were related to coolant or coil problems, compressor short-cycling, wiring and deferred or neglected maintenance.[49]

3. Continuous HVAC Optimization: Continuous optimization of occupant schedules and setpoints to balance comfort and energy savings. Examples in the field:

   - Nest's seasonal savings program is once a season, and is an add-on service that tunes setpoint schedules to optimize performance based on historical weather patterns and forecasts.[50]
   - Weatherbug and Ecofactor offer continuous and active weather and grid-related "optimizations".

4. Standard CT Performance Metrics: Support development of market-defined, data-driven performance metrics for meaningful comparison of CTs in the field. Examples in the field:

   - ENERGY STAR's Connected Thermostat Specification is using CT data from leading manufacturer's to support a standardized approach to comparing the real-world energy performance of CTs across the country.[51]
   - The real metrics derived from the CT datasets provides a feasible pathway to understanding the diverse complexity of building construction, HVAC systems, occupant behavior, and weather conditions that drive varied energy savings through thermostat controls.

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[49] EcoFactor. "Making the Connected Thermostat Smart." Accessed at: http://www.ecofactor.com/wp-content/uploads/2014/02/EcoFactor-Services-Overview.pdf; EcoFactor. 2015. "EcoFactor Identifies HVAC Issues with 95% Accuracy Using Just Thermostat Data. "Accessed at: http://www.ecofactor.com/wp-content/uploads/2015/09/HVAC-Performance-Monitoring-Case-Study-May-2015.pdf

[50] Nest. "Seasonal Savings: results from Summer 2013" published May 2014, Accessed at: https://nest.com/downloads/press/documents/seasonal-savings-white-paper.pdf

[51] U.S. Environmental Protection Agency. "Connected Thermostat Specification V1.0." Accessed: https://www.energystar.gov/products/spec/connected_thermostats_specification_v1_0_pd

5. Future Market Opportunities for Connected Thermostats

As the CTs and HEMS industries evolve, a number of other new CT use cases are emerging, stemming from CTs' connectivity. The potential to integrate CT-generated data with other home performance information collected and compiled by HEMS within a broader smart home ecosystem offers potentially significant new value propositions. Based on published literature, media reports, and discussions with key stakeholders across the CT market, the following sections present an overview of these future use cases and market opportunities. They identify and evaluate market gaps that could prevent potential use cases from emerging and highlight opportunities for market actors to address and resolve select barriers.

5.1 Opportunities and Market Gaps for Future Connected Thermostat Use Cases

During numerous interviews, researchers identified the integration of CT data with data from other sources (e.g. advanced metering infrastructure (AMI), local weather stations, building asset databases like DOE's Standard Energy Efficiency Data (SEED) Platform or Zillow, and energy audits) as a means to improve predictions of home energy use. Numerous end uses were identified that could benefit from this data integration, as were associated market gaps impeding emergence of these use cases (see Figure 6 below for a high-level discussion of use cases, or Appendix A for greater detail).

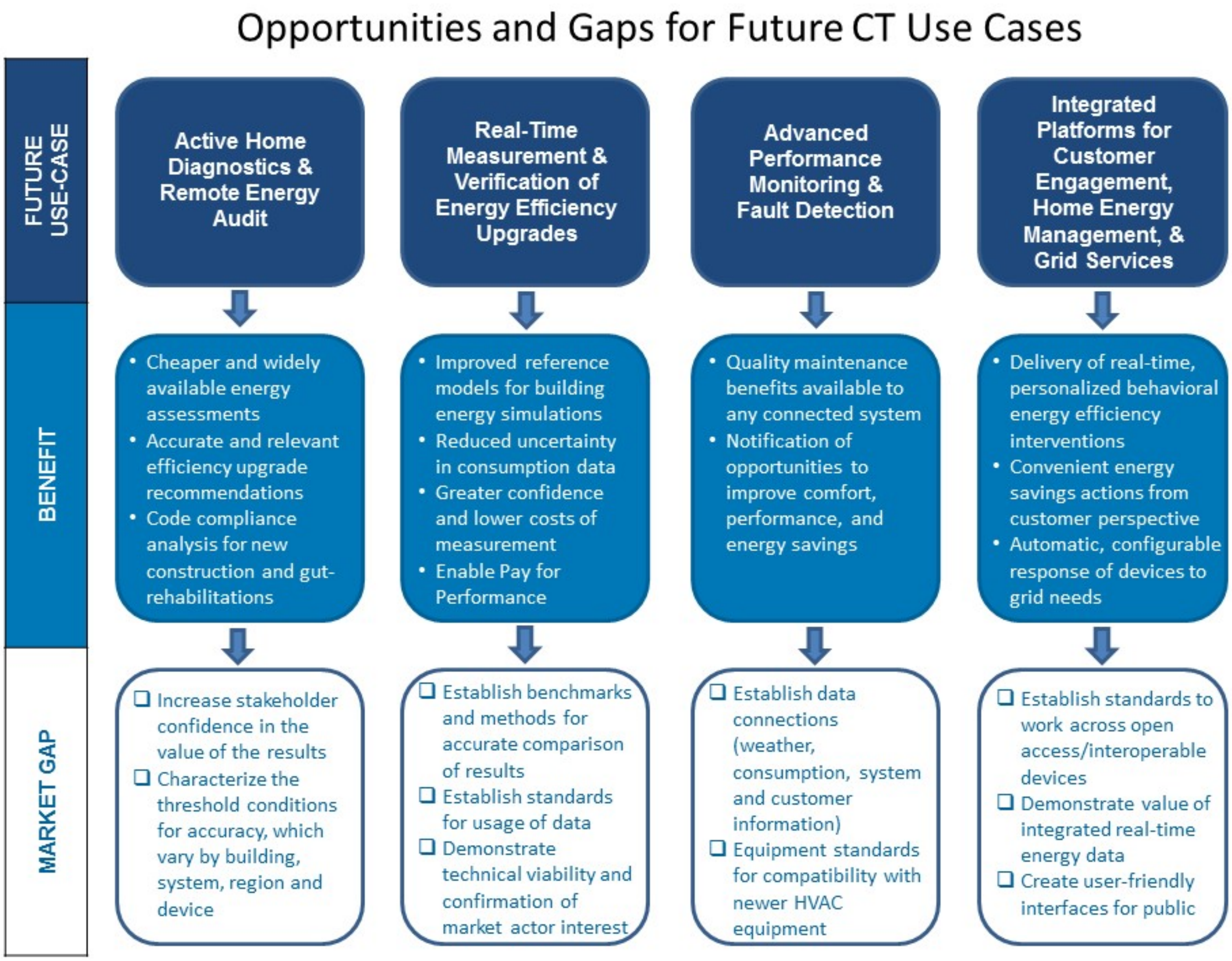

Figure 6: Opportunities and Gaps for CT Future Use Cases

Figure 6 represents the culmination of stakeholder interviews and literature review investigating future CT market opportunities. The four highlighted use cases represent opportunities with the most significant deployment potential, based on expected benefits and current stakeholder interest. The bottom row represents opportunities for stakeholder action around market gaps to overcome identified barriers to deployment.

Overall, stakeholders believed that CTs could enable a paradigm shift in active home diagnostics and remote energy audits, allowing faster, more available, and relevant energy assessments that offered targeted efficiency upgrade recommendations. Similarly, CTs could act as a powerful quality assurance tool that verify efficiency upgrades are performing as planned, enabling better residential energy consumption data and reducing the cost of its collection. With advances in control algorithms and feedback mechanisms, stakeholders posited that CTs could enable residential equipment monitoring and fault detection to notify homeowners of sub-optimal performance in advance of failure – and helping ensure predicted equipment energy savings are realized. Finally, stakeholders envisioned a future where CTs play a key role in an integrated platform that enables home owner engagement, home energy management, and interaction with the grid, helping to give actionable, understandable energy data to consumers and managing demand for utilities.

In interviews, utility stakeholders focused on the potential applications of CT data to enhance CTs' existing system optimization and demand response functions. For example, utility stakeholders are interested in how CT data could help measure the contributions of CT-related energy savings to utility-funded programs for DSM and demand response. This group is also interested in whether the data could clarify how consumers actually use CTs (e.g. whether devices were operating in energy savings mode, and if so, how frequently), as well as whether CT data could be combined with AMI data to enable additional, utility-specific M&V use cases (e.g. enabling a Pay-for-Performance program model).[52]

Manufacturers, services providers, researchers, and utility stakeholders all expressed interest in how CT data could provide insights into the benefits that consumers see from CTs (e.g. convenience, cost savings, comfort, and reliability)—as this issue is ultimately key to the successful uptake and use of CTs in the residential market—as well as if the data can be used to meet or inform regulator-mandated distributed energy resource requirements or contribute to future grid services. These are key questions at the intersection of customer benefit and alternative use cases for CTs:

- What role will CTs play in improving the connection between customers and the grid-value of their home energy end-use operation?
- How will the market react to tradeoffs between CTs' relative strengths (real-time multi-party communication and end-use flexibility) and CTs' potential weaknesses (reliability compared to conventional approaches)?
- Where might service platforms incorporate insights from the CT customer experience to better optimize the realization of ancillary service opportunities?

The answers will be informed through the experience of demonstration projects, and the follow-on development of future offerings. These concrete examples will be required to broaden awareness and enrich understanding of the relationship between future use cases, customer benefits, and the particular forms and functions of their shared foundation: data.

5.2 Connected Thermostat Data Needs in Future Use Cases

As demonstrated by the existing and future uses cases identified by relevant stakeholders and literature review, the data from CTs— particularly when combined with information from other sources—hold significant and critical value for the current and future CT market, the home performance industry, and ongoing efforts to increase grid resiliency and reliability. There is no clear consensus, however, on which data are required by whom, nor in what structure and granularity, in order for the different use cases to be realized and delivered to customers.

Figure 7 below illustrates both existing and potential future pathways through which data from CTs and other connected devices can flow to support or enable existing, emerging, and future CT use cases.

[52] Utilities already have access to AMI data.

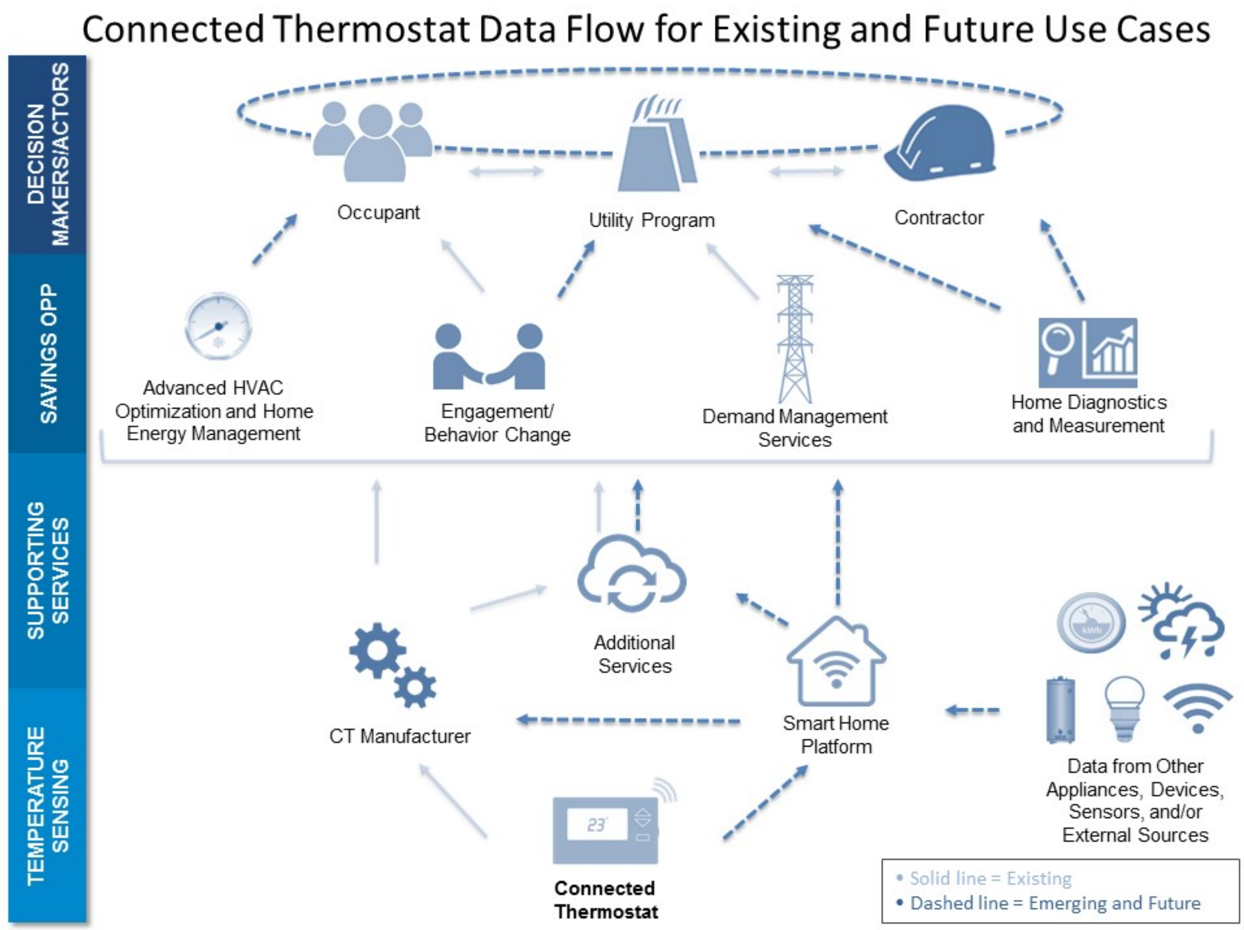

Figure 7: CT Data Flow

Currently, temperature and occupancy data from a home is collected by a CT and connected sensors. This data is then interpreted by algorithms from either the CT manufacturer or a third-party service to determine if the HVAC system needs to take action in response to changing conditions.[53] Within the current market, demand management services or occupant preferences set the parameters for when and how the CT adjusts HVAC operation.

Emerging and future capabilities demonstrate the potential for CT data to be interpreted by a smart home platform (as an alternative to the existing pathway that routes data through a CT's manufacturer), which then integrates CT data with additional data from other connected devices and external sources to optimize energy savings opportunities. Emergence of new, cost-effective sensors in the residential sector (e.g. measuring pressure, air flow, or daylight) can further contribute to this data collection and aggregation within a "smart" home. Integrating data from new, emerging, and existing devices and sensor will help hone energy savings opportunities specific to each home, taking into account weather, construction of home, thermal profile of the home, appliances and devices in the home, and behavior. As a result, energy savings could be realized through a variety of pathways, including advanced HVAC

[53] In this model, CT manufacturers and the third-party service providers with whom they have partnered are the primary custodians of customer device data, and they provide the support services for HVAC optimization and energy management opportunities for customers, utilities, and other key stakeholders in the home performance industry.

optimization and home energy management; home diagnostics and measurement, demand management services, and by influencing occupant behavior. These emerging and future channels may enable more home-specific energy savings opportunities, as more data will be available that is specific to each home.

5.3 Market Barriers for Future Connected Thermostat Use Cases

In addition to identifying emerging and future use cases for CTs and CT data, Figures 6 and 7 also highlight and demonstrate the barriers preventing future data flow channels from being implemented today. In order to enable future CT end uses and potentially unlock energy savings from advanced HVAC optimization as well as home energy management, diagnostics, and continuous M&V, the following barriers must be overcome:

- User-friendly interfaces for the public;
- Equipment standards for compatibility with newer HVAC equipment;
- Standard or characterization of the threshold conditions for accuracy, which vary by building, system region, and device;
- Benchmarks and methods for accurate comparison of results;
- Standards for usage of the data;
- Proven value of utilizing integrated, real-time, energy data; and
- Standards to work across open access/interoperable devices.

5.3.1 Data Access & Availability

Many of the data-enabled emerging and future use cases illustrated in Section 4.2 and Figure 6 above are predicated on the access to highly granular CT data. However, CT manufacturers and their third-party partners are the primary custodians of customer device data. Open access to this data is often limited by these actors' need to balance strategic business interests with preservation of customer trust, as well as native data structures and systems on the part of manufacturers and service providers. Similar to utilities, manufactures and service providers prioritize customer satisfaction with their products, as well as upholding privacy and security rights, to sustain customer confidence in CTs and promote continued market growth.

Leading CT service providers and manufacturers interviewed have divergent views and approaches to data management, with some explicitly building in functionality allowing secure and protected customer-data access to partners and services providers, and others limiting wide-spread access to the data generated by their devices. All providers have a substantial volume of quality data already available to them via proprietary systems, but have different stances on the value of sharing their data with larger research studies or collaborative activities, or providing for other third party access. These providers are already exploring a diverse set of potential use cases enabled through the application of CT data, many of which could be introduced through proprietary solutions in the marketplace.

This disagreement on the value of open data access mirrors an earlier disagreement in CT manufacturers' support for, and adoption of, open application programming interfaces (API) for CTs. APIs are a defined set of functions, definitions, and procedures that allow third-party programs to "talk" to or interact with a proprietary software platform. An open API invites software and hardware developers to connect with a manufacturer's products; in contrast, a closed API allows a manufacturer to retain control over who or what can interact with their devices. In the case of CTs, an API is the pathway by which a HEMS or other device can connect to a CT's temperature sensors or setpoint controls. Both open- and closed-API CTs were introduced on the market in the early days of the CT era, circa 2011 through 2013.

Towards the end of 2013, however, even those CTs with APIs that were initially closed began transitioning to an open-API model; this shift was driven in part by clear signals of market demand for open APIs that could facilitate a CT's integration with a variety of HEMS platforms and other smart devices in an open "Smart Home" ecosystem.[54] Today, while the degree of API "openness" differs across manufacturers and products, CTs with completely-closed APIs have largely become a thing of the past.[55] Given the different approaches being taken by leading CT manufacturers' around data availability, data access may be another fault line where market demand will identify clear consumer preferences, which in turn could have implications for the future behavior of CT manufacturers.

Today's concerns about the limited open market for sharing CT data, as well as corresponding access to data on building characteristics, occupancy, and gas and electric utility billing, continues to be an area of focus for new partnerships between the various stakeholders. Existing pathways to access CT data include utility program requirements, collection through a smart home platform, and paid access through data aggregation services. Researchers can also continue to collect comparable data by installing data loggers in individual homes, though this is costly and would likely limit research around new CT use cases by curtailing sample size and complicating data integration efforts.

Barriers and solutions addressing data access from deployed AMIs remains a potential example for a path forward for wide-spread CT data access. The Green Button Alliance offers one model for customer-driven data sharing, whereby consumers are empowered to simply and easily contribute their energy-use data to support meaningful third-party services.[56]

5.3.2 Data Standardization

As highlighted in Section 4.1, a standardized format for CT data would reduce barriers associated with obtaining, exchanging, and/or processing disparate data types, which can limit or prevent the broad application of CT data for new use cases.

Some researchers specifically cited the need for initial data specifications that (1) were simple and limited in scope, (2) identified and built on other available data streams to enable specific use cases, and (3) could draw upon existing or emerging activity around data standards in the building science space. The Building Performance Institute's Standard for Home Performance-Related Data Transfer and Project Haystack were both highlighted by industry stakeholders as examples of existing efforts around building-related data standards. Additionally, BTO's existing portfolio of data standardization projects (e.g. SEED and BEDES) could also be looked to for inspiration.

[54] Burns, Matt. September 25, 2013. "Nest Labs to Opens Up Its Learning Thermostat to Developers." *TechCrunch*. Accessed August 5, 2016: https://techcrunch.com/2013/09/25/nest-labs-to-open-up-its-learning-thermostat-to-developers/

[55] Meagher, Kevin. July 21, 2016. "Utilities and the Smart Home." *Electric Light & Power*. Accessed August 5, 2016: http://www.elp.com/articles/powergrid_international/print/volume-21/issue-7/features/utilities-and-the-smart-home.html

[56] Green Button Alliance. "History". Accessed June 15, 2016 at: http://www.greenbuttonalliance.org/history

Stakeholders consistently called-out automated M&V and fault detection as use cases that would most benefit from a near-term effort to develop industry-wide minimum standards for data reporting and data sharing. Furthermore, they observed that the market was already moving toward these use cases, highlighting the emergence of nascent market solutions as a reason to prioritize the development of standardized data formats.[57]

Data standardization and collection could be complimented by additional temperature, building system, and performance information gathered via a standardized field evaluation protocol for residential homes.[58] Industry and researchers recognize the need to test hypotheses with high-quality home performance data, but often lack access to standardized, compiled CT datasets.[59] Manufacturers may be limited in the data they have available to segment CT performance based on external characteristics (e.g. demographics, housing type or other customer-specific information) – discouraging them from developing additional use cases due to lack of data they can use for validating new algorithms or models. The broadest array of use cases from connected thermostat data will likely be enabled through high-quality, independently collected and verified datasets that incorporate building, occupant, environmental, and historical CT data.

As highlighted in Section 4.2 and Figure 6, CT manufacturers and service providers are working collaboratively with utilities in the development and roll-out of new use cases for CT data either on proprietary or open-source platforms.

5.3.3 Interoperability

Interoperability was another market gap identified by stakeholders and in the literature, one which could prevent or limit development and deployment of additional use cases for CTs and CT-generated data, and which is also closely related to the question of data standardization. Interoperability can be defined as the ability of devices or systems to securely exchange commonly-defined and -structured information on their status and operations.[60] It remains an open matter as to which levels of data definition and data availability are required to sufficiently enable the successful deployment and adoption of emerging use cases, but some stakeholders are attempting to formally investigate these questions and develop IoT interoperability standards.[61]

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[57] Key elements identified for data set standardization include data structure, defined collection of specific data and sensor placement, sensing and data collection durations, sensing accuracy and interaction of thermostat data with other datasets/dictionaries (e.g. contextual information about the home needed to fully utilize CT data).

[58] National Renewable Energy Laboratory. February 2014. "The Building America Indoor Temperature and Humidity Measurement Protocol." NREL/TP-5500-61040. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/indoor_temp_humidity_protocol.pdf

[59] Recently a leading CT manufacturer offered customers the opportunity to share their data for research purposes and may expand this initiative in the future to encourage emerging use case development.

[60] Building Technologies Office, U.S. Department of Energy. February 2016. "The National Opportunity for Interoperability and its Benefits for a Reliable, Robust, and Future Grid Realized Through Buildings." http://energy.gov/sites/prod/files/2016/03/f30/Interoperability%20and%20National%20Benefits%20Through%20Buildings-031616.pdf

[61] Open Connectivity Consortium. January, 2016. "Introduction of OIC standard." Accessed June 28, 2016: https://openconnectivity.org/wp-content/uploads/2016/01/OIC_Specification_Overview_201501131.pdf

Stakeholders' interest in seeing CTs becoming broadly interoperable is spurred by two factors: (1) a belief that broader residential control systems—notably home energy management systems (HEMS) – provide opportunities to bundle together the energy savings and other end-use benefits of multiple smart technologies[62], and (2) the observation that home automation systems are frequently purchased by consumers for non-energy benefits (e.g. integration of home security systems, home theaters, ambiance-related lighting controls, sprinklers, and other wireless appliance and sensor controls). By ensuring that CTs are broadly interoperable with centralized residential control systems and their various system components, energy-efficiency interests can piggy-back on the purchase of HEMS and other automation tools to increase the deployment of CTs in the market as part of a smart home ecosystem.

In addition, ensuring interoperability between CTs, HEMS, connected appliances, and other devices will be essential to enabling a smart home platform that serves as an alternate vector through which CT and other data can be integrated to enable new use cases.

5.3.4 Data Security and Privacy Issues

Alongside the need for standardized data formats and device interoperability, interviewees offered pointed comments on the paramount importance of ensuring that data standards and transfer protocols are protected by high-quality encryption or other cybersecurity measures.[63] Stakeholders affirmed that ensuring the security of CT and other smart device data is essential to the successful deployment of CTs and other smart home components. For example, consumers might eschew CTs for more conventional programmatic thermostat models if they feel that their personal, financial, or other identifiable information could be compromised by external forces. Given the October 2016 cyberattack on Dyn, which impacted web service providers such as Twitter, Amazon, and Spotify, this fear is not unwarranted.[64]

Consumer privacy concerns were another factor that interviewees said could complicate efforts to expand access to CT data, particularly the data needed to enable research and development into the new use cases described above. In addition to information about consumer preferences for thermostat setpoints, some CTs collect information about when consumers leave and return to the home for their optimization algorithms. Unlike conventional thermostats, CT manufacturers could use this data for secondary purposes, similar to companies like Facebook, Google, and Twitter. Currently, CT manufacturers' existing privacy policies stipulate when and how individual data are shared with third parties, and often require receipt of individual permissions. Without modification to these privacy policies, CT manufacturers could not share data with third-party companies or research organization without explicit consumer authorization. Even if explicit consumer authorization were obtained, however, CT manufacturers may still not want to provide industry stakeholders with details about the data collected by their products, for fear of losing a competitive advantage.

[62] Under the Building America Technology Roadmap, smart home technologies were flagged as a potential focus area for BTO research, development, and deployment (RD&D) activities for the period 2020-2030.

[63] Given the rising prevalence of wireless communication in home energy management and automation, one stakeholder highlighted the specific need for higher quality *wireless* encryption protocols for securing customer's data transmitted over a home's wireless network.

[64] Perlroth, Nicole. October 21, 2016. "Hackers Used New Weapons to Disrupt Major Websites Across U.S." *The New York Times.* http://www.nytimes.com/2016/10/22/business/internet-problems-attack.html

6. Conclusion

This paper is intended to help inform future technology deployment opportunities for CTs, based on investigation and review of the U.S. residential housing and CT markets, as well as existing, emerging, and future use cases for CT hardware and CT-generated data. Key informant interviews were conducted to verify and supplement the findings of desk research, including with utility actors, efficiency program administrators and advocates, research organizations, industry stakeholders, and others across the CT market.

The CT market has experienced tremendous growth over the last 5 years—both in terms of the number of units sold and the number of firms offering competing products (see Section 3.2)—and can be characterized by its rapid pace of technological innovation. However, despite many assuming CTs would become powerful tools for increasing comfort while saving energy, there remains a great deal of uncertainty about the actual energy and cost savings that are likely to be realized from deployment of CTs, particularly under different conditions (see Section 3.2). In addition, prognostications of the future CT market remain murky, given the presence of both optimistic market forecasts on one hand, and recent reports on the other suggesting that the home automation industry as a whole is experiencing a period of "overreach and retrenchment."[65]

There is substantial evidence to suggest that the CT industry will continue to innovate, providing consumers with access to an increasing number of features—possibly including those specific to advanced HVAC control and energy management, as well as those ensconced in a "smart home" context. Literature review and discussion with key stakeholders have identified a number of emerging and future CT use cases that could unlock new and additional residential energy savings from advanced home diagnostics, real-time measurement and verification of energy efficiency upgrades, advanced performance monitoring and fault detection, and the provision of integrated platforms for customer engagement, home energy management, and grid services (Section 5.1). These opportunities present multiple benefits, including:

- Cheaper and widely available energy assessments;
- Improved reference models for building energy simulations;
- Quality maintenance benefits available to any connected system;
- Delivery of real-time, personalized behavioral energy efficiency interventions; and
- Improved grid reliability through demand response and other grid services

To enable these benefits, however, certain market gaps must be addressed. Without characterization of threshold conditions for accuracy, benchmarks and methods of comparisons across models and housing types for M&V of energy efficiency upgrades, and means of connecting disparate data streams and interoperable devices, these potential end uses will remain theoretical. Fortunately, opportunities exist for market actors to address and resolve certain of these barriers (Section 5.3). Furthermore, additional guidance on how future CT use cases may be supported is provided by the broad and growing experience of today's CT deployment efforts. For example, as described in Section 4.2 and Appendix A, business models and other resources exist which can facilitate efforts to overcome certain market gaps, and in

[65] St. John, Jeff. June 10, 2016. "How Nest's Shakeup Could Alter Its Approach to Energy Management." *GreenTech Media.* Accessed June 10, 2016 at: http://www.greentechmedia.com/articles/read/how-nests-shakeup-could-alter-its-approach-to-energy-management

some cases strategic partnerships or pilot projects are already testing the waters on potential solutions that could eventually be brought to scale.

Finally, the market experience of this complex product reveals an important and clear lesson for driving continued interest and growth in CTs and their end use: clear communication about, and delivery of, customer value is key (see Section 5.1). When end-use services and customer value are well aligned, it has driven rapid rates of adoption, product and service improvements, and wider market acceptance. When absent, there have been serious setbacks. Although insufficient in isolation, strong consideration of end-user needs and interests when designing and implementing demonstration projects may help to clarify key aspects of the "solutions" to existing market gaps. The crux of success of future CT use cases, both in their formulation and execution, may therefore come down to familiar territory for thermostats: customer comfort.

Appendix A: Opportunities and Gaps for Future CT Use Cases – Full Table

FUTURE USE CASES	BENEFITS	MARKET GAPS	REFERENCE EXAMPLES	SELECTED ACTIVE PILOTS
Active Home Diagnostics (Calibration Test Routines) & Remote Energy Audit	1) Cheaper, more widely available, and user-friendly energy performance assessments 2) More accurate and relevant efficiency upgrade recommendations 3) Code compliance analysis for new construction and gut-rehabilitations 4) Improved accuracy of energy models needed for controls optimization, and thermal performance metrics	1.) Increased stakeholder (customer, contractor, manufacturer/service provider, utility and regulator) confidence in the value of results 2.) Characterization of threshold conditions for accuracy, which vary by building and system, region, and device capabilities 3.) Improved understanding of the costs and benefits to departure from conventional product boundaries and truly informed customer consent and perception of use case	Efficiency Vermont conducted a field research study in 2014 to test the hypothesis that meaningful differences in household thermal performance could be discerned by data available from a programmable communicating thermostat paired with supplemental location, weather, and other broadly available information sources.	A Building America project will fund a partnership between Eversource and Fraunhofer CSE to develop a software tool that automatically and remotely analyzes “smart” (i.e. connected) thermostat and interval meter data to identify household-specific retrofit opportunities that reduce heating energy consumption, potentially improving program effectiveness by 50 percent or more.
Real-Time Measurement & Verification of Energy Efficiency Upgrades	1.) Improved reference models for building energy simulations and operation for different types of building stock and equipment 2.) Reduced uncertainty and unexplained variations in electrical and thermal energy consumption data analysis	1.) Establish benchmarks, methods and protocols for meaningful and accurate comparison of CT-based results with conventional approaches and real world conditions 2.) Establish standards and systems for appropriate usage of CT data--or derivative metrics--in	ENERGY STAR's Connected Thermostats initiative is working to establish a metric based on aggregated field performance data analysis. Bonneville Power Authority has developed a comprehensive data set for 100 homes that	Although not in the current scope of any active projects identified in the research for this report, many of the stakeholders associated with active pilots for other future use-case categories--including the Building America and SMUD projects--have explicitly stated that real-

	3.) Greater confidence and lower costs of measuring energy impacts (e.g. Enabling Pay-for-Performance for home retrofit programs, contractors, and customers) 4.) Visibility to and feedback for customers and contractors for actions taken	performance evaluations in determining energy efficiency baselines and assessing post-treatment effects 3.) Demonstrate technical viability and confirmation of market actor interest needed to support investments in developing and deploying new models	represent what CTs can provide to establish baseline for savings analysis.	time M&V of upgrades are anticipated as immediate follow-on activities to their current work.
FUTURE USE CASES	**BENEFITS**	**MARKET GAPS**	**REFERENCE EXAMPLES**	**SELECTED ACTIVE PILOTS**
Advanced Performance Monitoring & Fault Detection	1.) Quality installation and maintenance benefits available to any system connected to a communicating thermostat 2.) Automatic notification of performance that falls outside of norms to target interventions to high-value customer engagement around comfort and savings opportunities 3.) Providing indicators of analytics-driven performance based on benchmarked norms for the whole home as a system (equipment, distribution, controls, envelope) diagnostics	1.) Develop equipment standards for compatibility with newer HVAC equipment 2.) Establish and improve data connections (weather, consumption, system and customer information)	Multiple vendors are developing proprietary solutions to be offered either direct to customer or in partnership with trade allies to reduce conversion costs and spur early detection and increase savings.	SMUD is piloting a multi-prong partnership to explore available market solutions to use indoor and/or outdoor temperature data to quantify the performance of homes envelope and HVAC system.

Integrated Platforms for Customer Engagement, Home Energy Management, & Grid Services	1.) Delivery of real-time, personalized, behavioral energy efficiency interventions 2.) Convenient energy savings actions from customer perspective 3.) Automatic & configurable response of customer devices to avoid costs of power generation, distribution, and other grid needs	1.) Establish standards to work across open access/interoperable devices 2.) Demonstrate value of integrated real-time energy data 3.) Create user-friendly interfaces & participation models for public understanding and participation	WeatherBug Home is a service that combines customer thermostats with AMI and weather data analysis for a consumer-facing scorecard, mobile app, opportunities to connect to other equipment.	Consolidated Edison's Connected Homes Platform, ConED, is a partnership with Opower, Enervee, and Nest to enable a single, customer-focused platform to inform and enable behavioral and direct efficiency actions. It is currently being deployed.

Appendix B: Summary of Reviewed CT Energy Savings Literature

DATE	SPONSOR/ AUTHOR	DOCUMENT TITLE
2007	ACEEE	Communicating Thermostats for Residential Time-of-Use Rates: They Do Make a Difference *http://aceee.org/files/proceedings/2008/data/papers/7_554.pdf*
2009	Florida Power & Light	FPL Residential Thermostat Load Control Pilot Project Evaluation *http://aceee.org/files/proceedings/2010/data/papers/1953.pdf*
2012	Washington State University	"Smart" Residential Thermostats: Capabilities, Operability and Potential Energy Savings *http://e3tnw.org/Documents/Smart%20Thermostats_FINAL.pdf*
2012	Pacific Gas & Electric	EcoFactor Thermostat System Laboratory Testing *http://www.etcc-ca.com/reports/ecofactor-thermostat-system-laboratory-testing*
2012	San Diego Gas & Electric	Home Area Networks Pilots Process Evaluation-Residential Automated Controls Technology Pilot (RACT) *http://www.calmac.org/publications/SDGE_HAN_Pilot_PE_ID_SDG0259_051512.pdf*
2012	Oklahoma Gas & Electric	OG&E Consumer Behavior Study Evaluation Report *https://www.smartgrid.gov/files/Chapter_1_Overview.pdf*
2012	The Electric and Gas Program Administrators of Massachusetts	Wi-Fi Programmable Controllable Thermostat Pilot Evaluation *http://ma-eeac.org/wordpress/wp-content/uploads/Wi-Fi-Programmable-Controllable-Thermostat-Pilot-Program-Evaluation_Part-of-the-Massachusetts-2011-Residential-Retrofit-Low-Income-Program-Area-Study.pdf*
2013	Wisconsin Public Service	iCanConserve Final Report *https://www.focusonenergy.com/sites/default/files/WPS_%20Territory%20Wide%20CY2012%20Evaluation%20Report_%2010-14-13.pdf (Appendix G)*
2013	Nest	Rush Hour Rewards: Results from Summer 2013 *https://nest.com/downloads/press/documents/rush-hour-rewards-white-paper.pdf*
2013	Nest	Seasonal Savings: Heating and Cooling Results *http://downloads.nest.com/seasonal_savings_white_paper.pdf*
2013	Sacramento Municipal Utility District	Communicating Thermostat Usability Study *http://www.herterenergy.com/pdfs/Publications/2014_Herter_CommunicatingThermostatUsability.pdf*
2013	Earth Networks	White Paper: WeatherBug Home Optimization Program Pilot Energy Efficient Achievement and Calculated Savings Available via: *http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B86EB2003-61B3-4DDD-800E-3B834BC885EF%7D*
2013	Liberty Utilities	Wifi Programmable Thermostat Pilot Program Evaluation *https://www.puc.nh.gov/Regulatory/Docketbk/2012/12-262/LETTERS-MEMOS-TARIFFS/12-262%202013-08-22%20ENGI%20DBA%20LIBERTY%20FILING%20ITS%20PROGRAM%20EVALUATION%20STUDY.PDF*

2014	Southern California Edison	2013 Load Impact Evaluation of Southern California Edison's Peak Time *https://library.cee1.org/content/2013-load-impact-evaluation-southern-california-edison%E2%80%99s-peak-time-rebate-program*
2014	Efficiency Vermont	Are Thermostats the New Energy Audits? *https://www.efficiencyvermont.com/Media/Default/docs/white-papers/efficiency-vermont-are-thermostats-new-energy-audits-white-paper.pdf*
2014	DTE Energy	SmartCurrents: Dynamic Peak Pricing Pilot (Final Evaluation Report) *https://www.smartgrid.gov/files/DTE-SmartCurrents_FINAL_Report_08152014.pdf c Peak Pricing Pilot (Final Evaluation Report)*
2014	Energy Trust of Oregon	Nest Thermostat Heat Pump Control Pilot Evaluation *http://energytrust.org/library/reports/Nest_Pilot_Study_Evaluation_wSR.pdf*
2014	Pacific Gas & Electric	Findings from the Opower/Honeywell Smart Thermostat Field Assessment (ET Project Number ET11PGE3074) *http://www.etcc-ca.com/sites/default/files/reports/et11pge3074_opower_honeywell_final_report.pdf*
2015	Nicor Gas; ComEd	Emerging Technology Program 1022: Home Energy Management System Utilizing a Smart Thermostat Final Public Project Report *https://www.nicorgasrebates.com/-/media/Files/NGR/PDFs/ETP/1022_Smart_Thermostat-HEMS_FINAL_APPROVED_Public_Project_Report_to_Nicor_Gas_05-04-2015.pdf*
2015	Nest	Energy Savings from Connected Thermostats: Issues, Challenges, and Results *http://www.iepec.org/wp-content/uploads/2015/papers/148.pdf*
2015	Western Electricity Coordinating Council	Engaging with a Thermostat: Using Seasonal and Connectivity Based Differences in Residential Thermostat Use to Maximize Savings *http://www.weccusa.org/sites/www.weccusa.org/files/pdfs/white%20papers/becc-whitepaper-october-2015-v2.pdf*
2015	The Cadmus Group	Evaluation of 2013–2014 Smart Thermostat Pilots: Home Energy Monitoring, Automatic Temperature Control, Demand Response *http://www.ceeforum.org/system/files/private/12464/Natgrid_Weaterbug_Report_FINAL_2015.pdf*
2015	The Cadmus Group	Evaluation of the 2013–2014 Programmable and Smart Thermostat Program *http://www.cadmusgroup.com/papers-reports/evaluation-2013-2014-programmable-smart-thermostat-program/*
2015	CPS Energy	Evaluation, Measurement & Verification Of Cps Energy's Fy2015 Dsm Programs-Smart Thermostats *https://www.sanantonio.gov/Portals/0/Files/Sustainability/STEP/CPS-FY2015.pdf*
2015	Electric Power Research Institute	FirstEnergy Consumer Behavior Study: Phase 2 Impact Analysis *http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?productId=000000003002006715*
2015	FirstEnergy	FirstEnergy's Smart Grid Investment Grant - Consumer Behavior Study *https://www.smartgrid.gov/document/FirstEnergy-Smart-Grid-Consumer-Behavior-Study.html*

2015	Puget Sound Energy	Impact Evaluation of the PSE Web-Enabled Thermostat Pilot Program *https://conduitnw.org/Pages/File.aspx?rid=2965*
2015	DNV GL; Austin Energy	Innovative Austin Energy WiFi Thermostat Program Evaluation *http://www.iepec.org/wp-content/uploads/2015/papers/161.pdf*
2015	ACEEE	New Horizons for Energy Efficiency: Major Opportunities to Reach Higher Electricity Savings by 2030 *http://aceee.org/research-report/u1507*
2015	Vermont Energy Investment Corporation	Smart Thermostats Aren't Just for DR Anymore: Summary of Programs and Research Efforts *http://aesplibrary.conferencespot.org/58584-aesp-2015-1.1865312/t-016-1.1865552/f-016-1.1865553/a-043-1.1865554/ap-081-1.1865557?qr=1*
2016	Tsinghua University	A Systematic Study for Smart Residential Thermostats: User Needs for the Input, Output, and Intelligence Level *http://www.mdpi.com/2075-5309/6/2/19/pdf*
2016	University of California Davis	Do occupancy-responsive learning thermostats save energy? A field study in university residence halls *http://www.sciencedirect.com/science/article/pii/S0378778816303851*
2016	Journal of Policy Analysis & Management	Empowering Consumers Through Data and Smart Technology: Experimental Evidence on the Consequences of Time-of-Use Electricity Pricing Policies *http://onlinelibrary.wiley.com/doi/10.1002/pam.21928/full*
2016	Energy Trust of Oregon	Energy Trust of Oregon Smart Thermostat Pilot Evaluation *http://assets.energytrust.org/api/assets/reports/Smart_Thermostat_Pilot_Evaluation-Final_wSR.pdf*
2016	Energy and Buildings Journal	Integrated HVAC Management and Optimal Scheduling of Smart Appliances for Community Peak Load Reduction *http://www.sciencedirect.com/science/article/pii/S0378778816302353*
2016	Fraunhofer USA Center for Sustainable Energy Systems	Energy Savings from Five Home Automation Technologies: A Scope Study of Technical Potential *https://www.cta.tech/CTA/media/policyImages/Energy-Savings-from-Five-Home-Automation-Technologies.pdf*
2016	IoT Platform Research Center, Korea Electronics Technology Institute	TTEO (Things Talk to Each Other): Programming Smart Spaces Based on IoT Systems *http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4850981/*

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